

Supplementary Information for:
Mapping Global Avian Influenza Risk Patterns Through Waterbird Activity Entropy

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Supplementary References

Supplementary Text 1: Data sources and processing of socio-environmental and climatic covariates

Population density:

The population density data was download from Center for International Earth Science Information Network (Gridded Population of the World, Version 4, GPWv4) for the year 2015 at ~1 km spatial resolution ¹. The population data was collected census observations in 2015 and then distributed to cells using proportional allocation of population from census and administrative units. The population density at each grid was calculated as the number of persons per square kilometer, consistent with national censuses and population registers.

Cattle and Poultry density:

We download cattle and poultry density data from Gridded Livestock of the World, Version 4 (GLW 4), which collected detailed livestock census statistics from agricultural yearbooks or through direct contacts with ministries or statistical bureau at ~10 km spatial resolution ². The data predicted spatial pattern of cattle, buffaloes, horses, sheep, goats, pigs, chickens and ducks in 2015 based on the random forest models. In this study, we only focus the spillover of avian influenza to chicken, duck and cattle. The duck and chicken density gridded maps were summed as poultry density.

Gross primary productivity and net primary productivity:

The gross primary productivity (GPP) was obtained from Zhang (2017) ³, which provided 8-days temporal resolution and ~500 m spatial resolution from 2000 to 2016. The data is based on an improved light use efficiency theory and is driven by satellite data from MODIS and climate data from NCEP Reanalysis II. It has shown satisfactory performance when validated against in situ GPP estimates. We averaged the annual monthly GPP from the 8-day grids and calculated the GPP coefficient of variation. The Net Primary Productivity (NPP) data is derived annually from the MODIS Net Primary Production product (MOD17A3) at a 1-kilometer pixel resolution. This product aims to provide an accurate and regular measure of terrestrial vegetation growth.

Uncertainty analyses of this study

The dataset used to simulate the monthly abundance of waterbirds is sourced from citizen science data (GBIF data), and the use and limitations of this data have been discussed in relevant literature ⁴. Despite our efforts in data cleaning to improve the quality of the data, factors such as the expertise level of the observers and the geographic distribution bias of the observation points still lead to incompleteness and systematic bias in the observation data ⁵.

Remote sensing index:

We used Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI) and Leaf Area Index (LAI) to reflect the impact of vegetation and habitat preference on waterbirds. The NDVI was used from MOD13A2 V6.1, derived from National Oceanic and Atmospheric Administration-Advanced Very High-Resolution Radiometer (NOAA-AVHRR). This dataset features cloud-free, low view angle, and noise reduction. The formula for NDVI is as follows:

$$NDVI = \frac{\rho_2 - \rho_1}{\rho_2 + \rho_1} \quad (1)$$

where ρ_1 and ρ_2 represent bands of MODIS 1 (620-670 nm, Nadir_Reflectance_Band1) and MODIS 2 (841-876 nm, Nadir_Reflectance_Band2), respectively.

The NDWI was calculated by MOD09A1 V6.1, which provided 8-day estimates of the surface spectral reflectance of Terra MODIS bands 1-7 at 500m resolution. The formula for NDWI is as follows:

$$NDWI = \frac{\rho_5 - \rho_2}{\rho_5 + \rho_2} \quad (2)$$

where ρ_5 and ρ_2 represent bands of MODIS 5 (1230-1250 nm, Nadir_Reflectance_Band5) and MODIS 2 (841-876 nm, Nadir_Reflectance_Band2), respectively.

The LAI was downloaded from National Oceanic and Atmospheric Administration Climate Data Record (NOAA-CDR). This dataset is derived from the NOAA-AVHRR Surface Reflectance product and has a spatial resolution of 0.05° daily. All remote sensing data were averaged to an annual scale and filtered for the year 2010.

The nighttime lights density data was downloaded from Earth Observation Group, which detects visible and near-infrared (VNIR) emission sources at night with a spatial resolution of approximately 1 km and a temporal resolution of one month ⁶. The spatial resolution of the remote sensing data was resampled at 0.5° to be consistent with Species Distribution Models (SDMs).

Road density:

The road density data was downloaded from the Food and Agriculture Organization of the United Nations (FAO). This data is provided by the Global Roads Inventory Project (GRIP) dataset ⁷, which offers global raster datasets of road density at ~8 km resolution. The nightlight density data, which measures the intensity of artificial light in an area, was sourced from the Earth Observation Group. This dataset provides valuable insights into human activity patterns and urbanization levels.

Improvement of the SDMs by considering more environmental factors

In this study, we also introduced water proportion as an input variable to improve the SDMs (SDM-w, see Methods). Since open surface water body is important habitats

for waterbirds, which are natural hosts of avian influenza, surface water proportion can be a critical predictor for predicting waterbird distribution⁸⁻¹⁰. Comparing the two SDM construction methods among 753 species (with and without water proportion data inputs), we found a significantly improved model performance (Supplementary Fig. 15). Incorporating water information into the SDMs outperformed the original method, which typically uses simple and rough filters to determine host presence, subsequently influencing the AIV exposure risk assessment.

Supplementary Text 2: Statistical analysis

Peak month definition:

Based on the results of SDMs for each 753 waterbirds, we firstly calculated spatial pattern of species richness per pixels (Fig. 1). Furthermore, monthly temporal variation also been calculated using monthly SDMs (Fig. 2). To figure out the seasonal variation of waterbirds, we used Augmented Dickey-Fuller Test (ADF-test) to test the stationary of monthly species richness per pixels. The ADF-test incorporates three types of trend models. Considering the birds migration and random observation error, we used 'type2' which included drift but no linear trend. For non-stationary pixels, we determined the most significant turning point of month to classify the pixels into 'peak' or 'pit'. We utilize urban boundary data to extract the fluctuations in monthly species richness across Calgary, Moscow, Houston, Guangzhou, Kampala, Adelaide, Paris, and Makassar. These cities serve as typical urban representatives, each illustrating the classification of monthly changes in species richness.

Multi-criteria filtering process for restricting poultry-to-poultry transmission cases:

To minimize the interference caused by secondary AIV infections within poultry flocks, we applied a systematic multi-step filtering process to exclude likely poultry-to-poultry transmission cases from the global surveillance dataset compiled by FAO (Supplementary Fig. 7). The initial dataset included 56300 cases, of which 39374 involved poultry. Each step of the framework was designed to progressively eliminate recorded poultry cases that were probably transmitted within poultry flocks, or not directly infected from wild waterbird exposure.

In Step 1, we excluded infection subtypes that primarily spread within poultry. Specifically, subtypes with $\geq 80\%$ of cases reported in poultry were removed (1519 cases removed). This filter resulted in minimal change in the predictive performance of WAE (AUC = 0.859). In Step 2, we filtered poultry-to-poultry transmission cases using a spatio-temporal criterion. Based on the EU's High Pathogenicity Avian Influenza (HPAI) Surveillance Zone¹¹, we assumed a 10 km radius as the spatial range for local transmission within poultry populations. Accordingly, we segmented the global AIV surveillance dataset into 10×10 km grids during epidemic seasons, defined as November to March for wintering and May to September for breeding.

Within each grid cell, only the earliest poultry case was retained; any subsequent poultry cases reported during the same season were considered intra-poultry transmissions and excluded. This filtering step removed 23284 poultry cases and substantially improved the predictive power of WAE (AUC = 0.868).

In Step 3, based on the encounter probability between recorded poultry cases and adjacent wild waterbird host, we applied a spatial filtering criterion reflecting the local activity range of wild waterbird hosts (~50 km)¹². Poultry cases were considered valid only if they were potentially infected with AIV through direct encounters or contacts with wild waterbirds, requiring at least one confirmed wild bird AIV detection within a 50 km radius of the poultry case. While this strict three-step filtering method is effective in countries/regions with comprehensive surveillance systems (e.g., the United Kingdom, Germany, and other Western European countries), its application in less-developed regions is challenged by limited wild bird surveillance, which may lead to inaccurate filtering due to data constraints. In Step 4, we aimed to eliminate cases of possible lateral spread by removing poultry-adapted subtypes, here assumed to be subtypes where poultry cases accounted for $\geq 90\%$ of total cases (i.e., initial poultry cases / [initial poultry + wild bird cases] ≥ 0.9). The excluded subtypes included H7N6, H7N8, H7N9, H5N2, H9N2, H5N9, among others. Accordingly, due to the imbalance in wild bird surveillance records, omitting the long-distance and potential lateral transmission filtering steps for poultry cases (Step 3 and Step 4) in the global assessment helps prevent the erroneous exclusion of poultry spillover cases in developing and underdeveloped countries with insufficient wild bird monitoring. While it is recognized that many poultry outbreaks, particularly the initial case of a poultry outbreak, commonly originate from such spillover events¹³, even if followed by secondary transmission within poultry populations. Accordingly, results based on both unfiltered and complete filtered (after the 4-step process) poultry-to-poultry transmission cases are presented in the Supplementary Fig. 17, enabling assessment of WAE's predictive performance under different assumptions.

Consequently, considering the widespread data limitations across these regions, we ultimately adopted the first two step filtering process focused on removing local poultry-to-poultry transmission cases occurring after initial spillover events. The cases retained after applying the two-step filtering procedure were subsequently used to determine the high-WAE and low-WAE thresholds in the main results.

Driver analysis:

To explore the potential driving factors of waterbird activity entropy (WAE), we classified the factors into three groups: geographic and climate factors, vegetation factors, and human activity factors. The geographic and climate factors included longitude (°), latitude (°), precipitation (mm), temperature (°C), and the number of days below 0 °C (frost days). The vegetation factors included gross primary productivity (GPP, g C m⁻² day⁻¹), gross primary productivity coefficient of

variation (GPP CV), net primary productivity (NPP, $\text{g C m}^{-2} \text{ day}^{-1}$), normalized difference vegetation index (NDVI), normalized difference water index (NDWI) and leaf area index (LAI). The human activity factors included nighttime lights (light density), road density (m per km^2), human density (log-transformed, number per km^2), and poultry density (log-transformed, number per km^2). All waterbirds were classified into five functional groups based on their habitat and life cycle: seabirds, shorebirds, waterfowl, large wading birds, and others. For each group of drive factors, we performed a Mantel test to examine the correlation between driving factors and the composition of different functional groups using the vegan R package¹⁴. We further analyzed the correlations between three types of driving factors and WAE across different regions using Pearson correlation in key exposure countries/regions.

Supplementary Text 3: Drivers of WAE in High Exposure Risk Regions

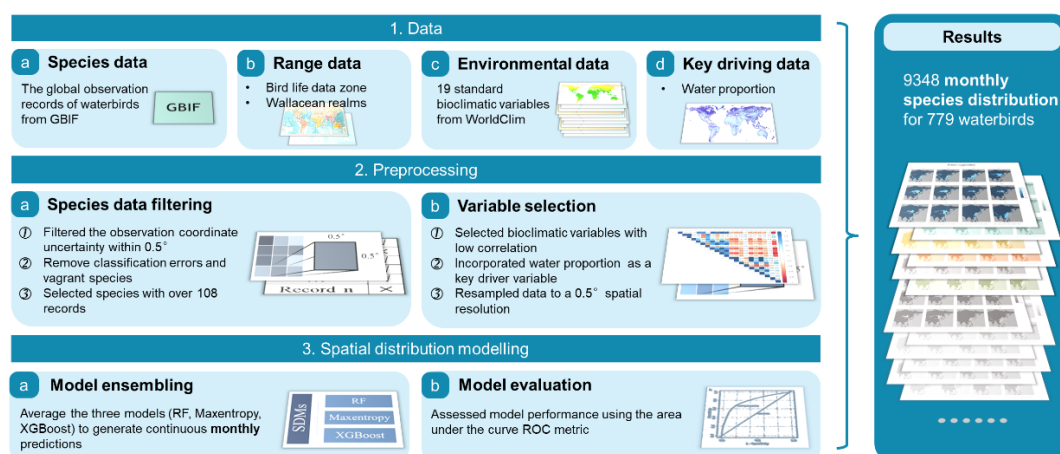
In the key exposure countries/regions—USA, EU, China, and India, which have the largest hotspot areas—we analyzed the correlations between WAE and various biotic and abiotic environmental factors (Supplementary Fig. 16a). Within the geographic and climate factors group, precipitation exhibit a robust positive correlation with WAE, whereas frost days demonstrates a strong negative correlation. In the vegetation indicator group, productivity-related factors such as GPP, NPP, and NDVI show potent positive correlation with WAE, suggesting a likely impact on waterbird distribution and migration patterns. Human activity factors revealed a significant positive correlation between WAE and human, cattle and poultry density. These relationships are more influential. By strategically arranging the distribution of human populations and cattle and poultry farming away from the waterbird habitats, there is an opportunity to better manage and mitigate the avian influenza spillover risk from waterbirds.

Subsequently, we applied linear regression models to WAE against human, cattle, and poultry density (Supplementary Fig. 16b). The results indicate a significant positive correlation between human density and WAE, particularly in the USA, China, and India, where the explanatory power (R^2) exceed 0.4 ($P < 0.001$). Cattle density is significantly correlated to WAE in the USA, India ($P < 0.001$), with R^2 exceeding 0.3. For poultry density, China exhibits the steepest linear trend ($k = 1.97$), with an R^2 surpassing reaching 0.56. This may imply a greater urgency and difficulty in managing the high exposure risk in China.

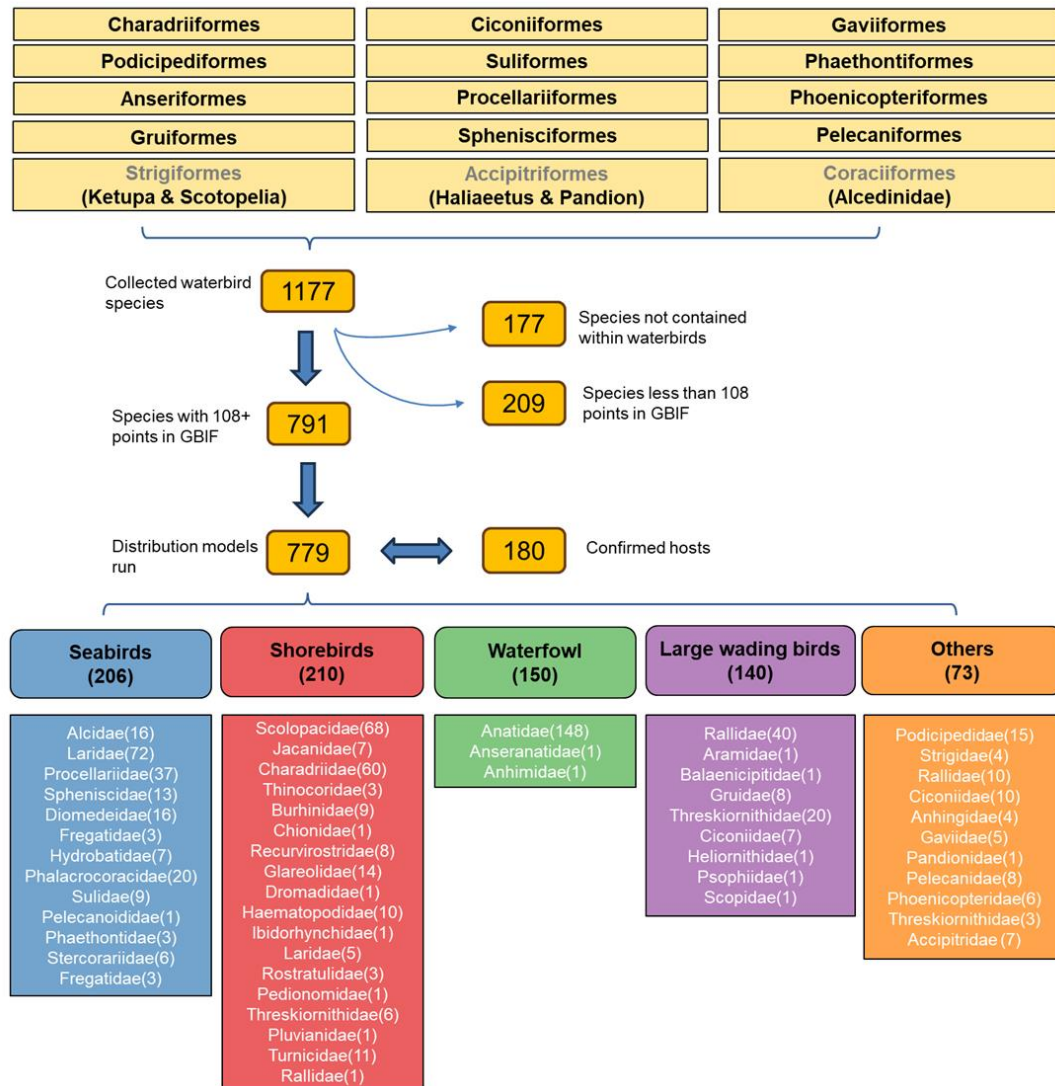
Based on these findings, we further categorized waterbirds into five functional group types: seabirds, shorebirds, waterfowl, large wading birds, and others. The Mantel test results for USA (Supplementary Fig. 16c) revealed a strong correlation (Mantel's $r > 0.4$) between geographic and climate factors and the WAE and similarly a strong correlation between vegetation indicators and the WAE of seabirds. Out of all the functional groups considered, only seabirds showed a strong correlation with human density. The functional groups in the other three regions exhibit diverse

characteristics (Supplementary Fig. 16d). In the EU, only waterfowl are strongly correlated with both human and cattle density (Mantel's $r > 0.5$). In China, poultry density is more strongly correlated with waterfowl. Our findings highlight the variability in exposure levels of human, cattle, and poultry to the dominant waterbird functional groups across different key exposure countries/regions.

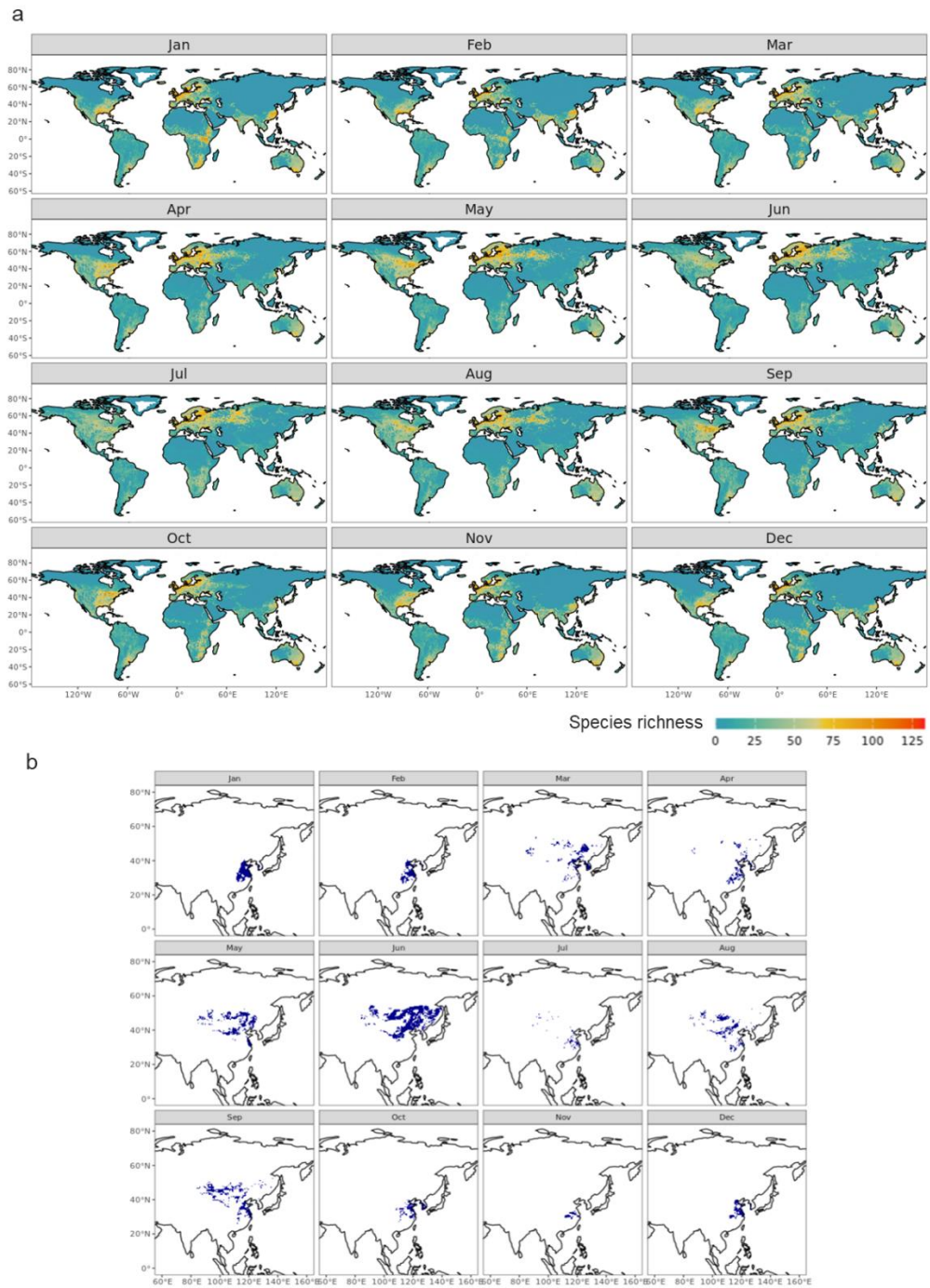
Supplementary Figures



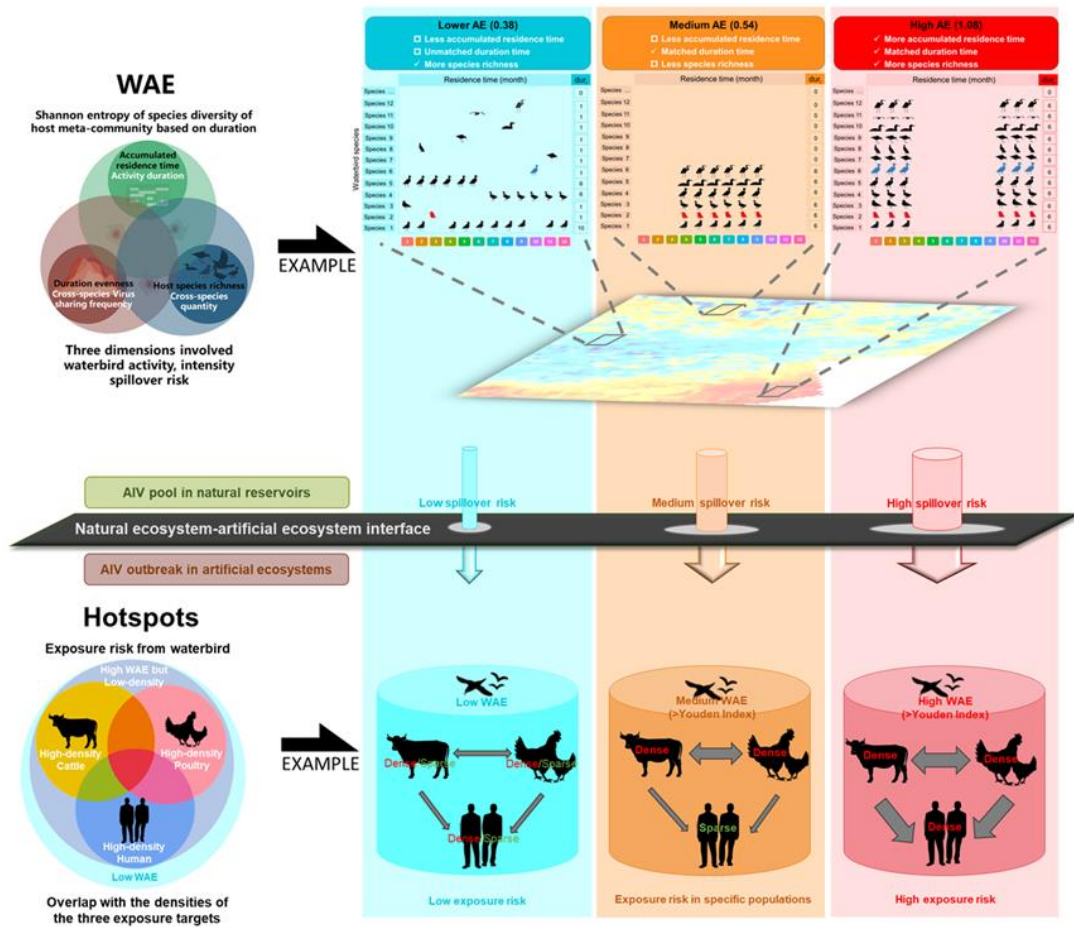
Supplementary Fig. 1 Flowchart for the simulation of monthly species distribution. The methodology for this study is divided into three main parts. First, occurrences data were sourced from the Global Biodiversity Information Facility (GBIF), and environmental data were derived from global climate and weather data (WorldClim), as well as data layers representing the water proportion and elevation. Range data for each species were utilized to eliminate outliers. Second, we thinned the species data, followed by careful filtering, cleaning, and selection. The environmental variables were subjected to rigorous selection to avoid collinearity and resampling to a common spatial resolution. Third, simulations were conducted on a monthly basis to capture temporal variation in species distributions. We employed an ensemble approach, averaging the outcomes of three models—random forests, maximum entropy, and extreme gradient boosting—to derive predictions. The receiver operating characteristic (ROC) curve was subsequently used to assess the performance of the simulations. Ultimately, this approach allowed the successful modeling of 779 waterbird species, resulting in 9036 monthly distribution maps.



Supplementary Fig. 2 Process of selecting waterbird species. Initially, we collected data on 1177 species across 15 orders. We excluded species not classified as waterbirds or those with fewer than 9 unique records each month in the Global Biodiversity Information Facility (GBIF). We successfully modeled 779 waterbird species, among which 180 were confirmed hosts. Furthermore, we categorized the 779 species into five functional groups: seabirds, shorebirds, waterfowl, large wading birds, and others. The numerals in the figure correspond to the species count.

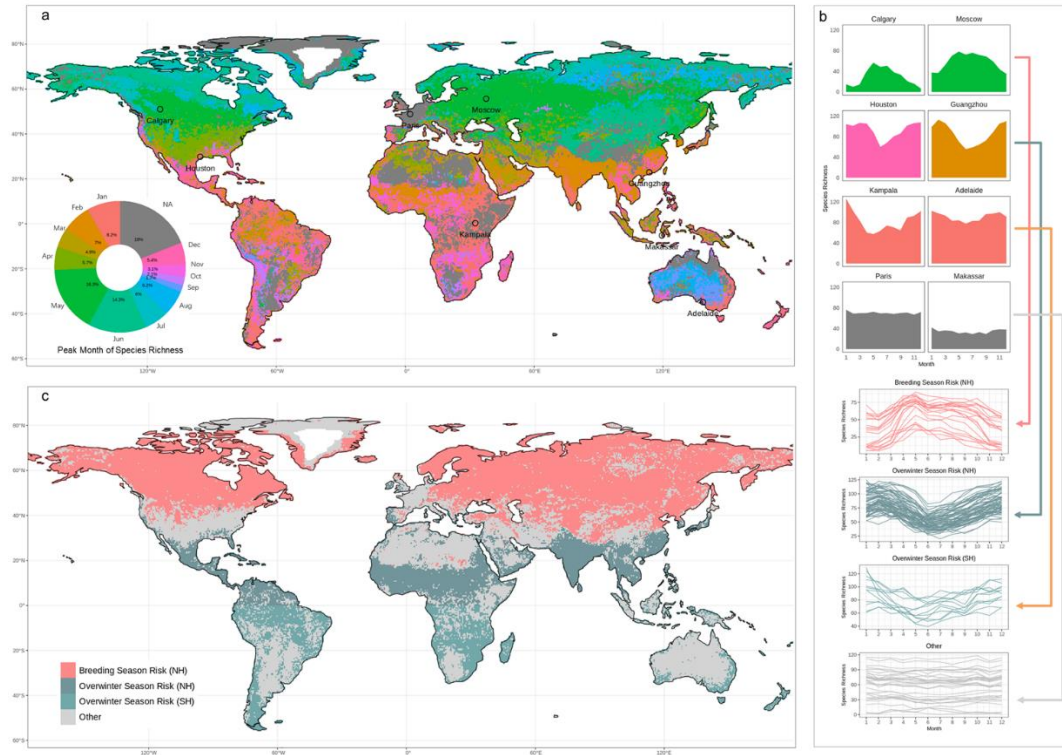


Supplementary Fig. 3 Monthly waterbird species richness and simulation of monthly distribution results. (a) Monthly waterbird species richness patterns. **(b)** Simulated monthly distribution results for the swan goose (*Anser cygnoides*). The titles in the figure correspond to the respective months, providing a clear temporal representation of species distribution patterns throughout the year.

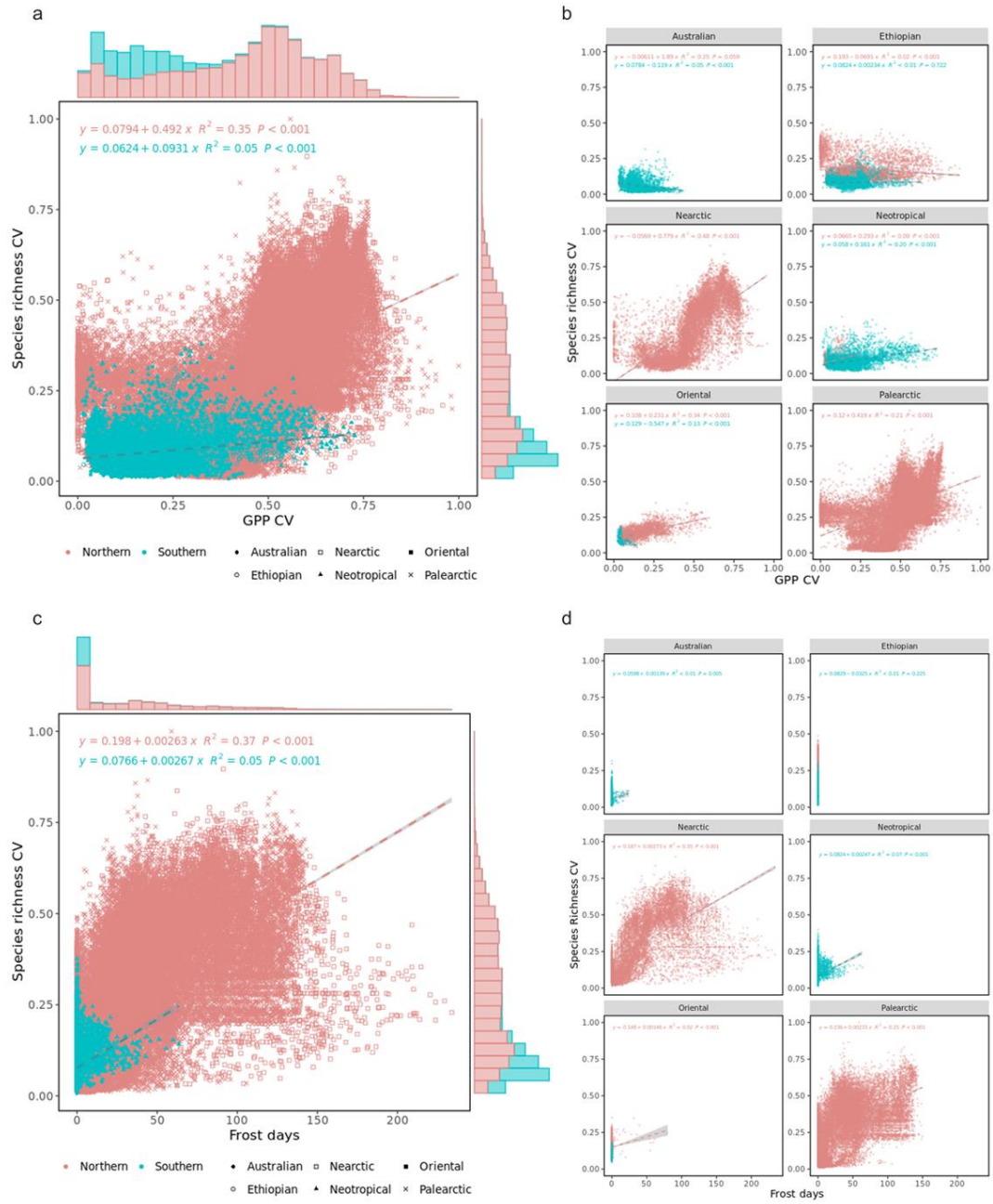


Supplementary Fig. 4 Scheme for defining waterbird activity entropy (WAE) and identifying exposure risk hotspots. The top section of the diagram illustrates the concept of WAE, highlighting three risk dimensions: accumulated residence time, duration match (alignment of species' residency periods), and host species richness. Three scenarios are outlined: (1) Low WAE: high species richness but less-overlapping residence times, resulting in low AIV cross-species transmission risk. (2) Medium WAE: low species richness and residence time, with brief species encounters, leading to moderate AIV transmission risk. (3) High WAE: high species richness and residence time increase AIV transmission risk due to frequent species interactions. The middle section depicts the AIV spillover risk from natural to artificial ecosystems, where WAE levels are correlated with spillover magnitude, potentially causing outbreaks in artificial systems. The lower section identifies exposure risk hotspots by overlaying WAE with cattle, poultry, and human populations. Using the Youden index, high-risk areas were identified, with high-density populations based on the top 15th percentile of grid cells. Three exposure risk scenarios are shown: (1) Low exposure risk: low WAE areas, regardless of population density. (2) Specific population exposure risk: medium WAE with high cattle/poultry density but low human density, increasing exposure risk for livestock. (3) High exposure risk: high WAE with dense human, cattle, and poultry populations, representing the highest AIV transmission risk. Credit: all

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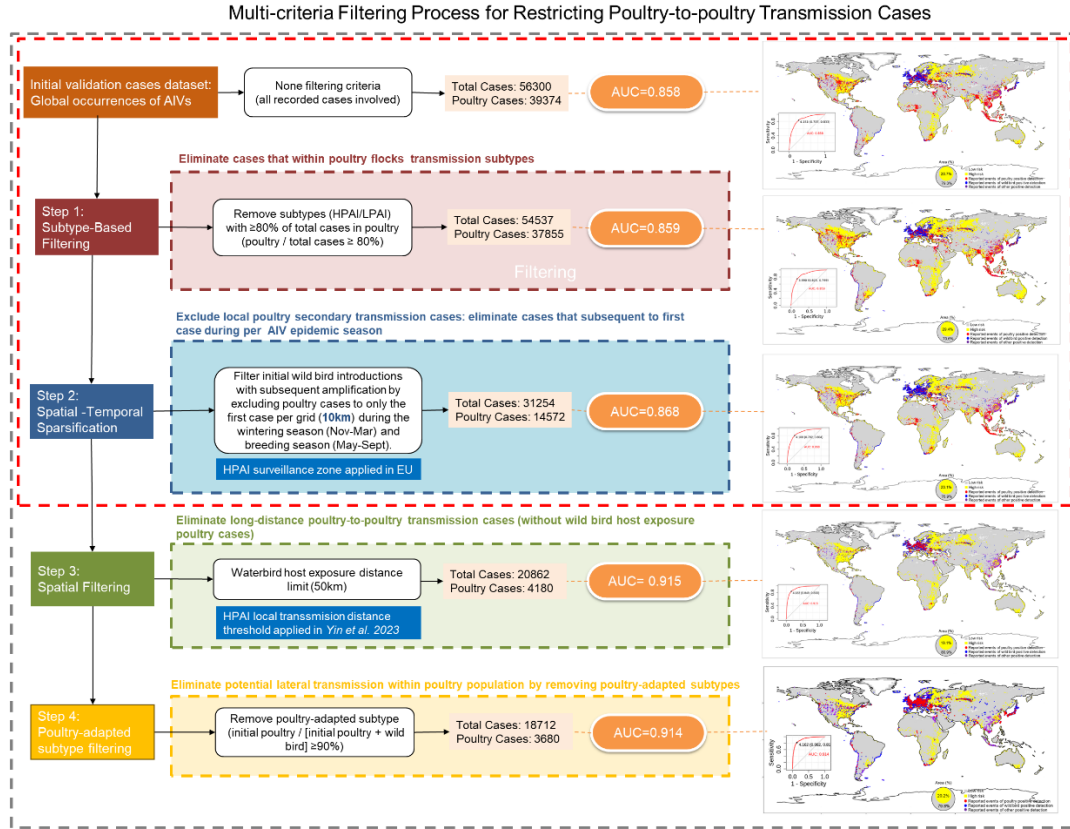


Supplementary Fig. 5 Seasonal analysis of global waterbird species richness based on monthly species distribution models. (a) Global waterbird pattern of peak months with the highest seasonal variation in one year on the basis of monthly species distribution models. The pie chart illustrates the percentage of each peak month. The locations of the eight typical cities on the drawing are shown on the map. **(b)** Monthly variation in the seasonal migration of waterbirds and city examples with different migration seasons. Changes in the species richness of eight typical cities are shown and classified into four types via an augmented Dickey–Fuller test. **(c)** Spatial distribution of the classification of the monthly changes in species richness. “Breeding season risk” refers to areas where the peak month occurs in the summer, whereas “overwinter season risk” refers to areas where the peak month occurs in the winter. ‘NH’ denotes the Northern Hemisphere, and ‘SH’ denotes the Southern Hemisphere. “Other” indicates relatively smooth changes in monthly species richness.

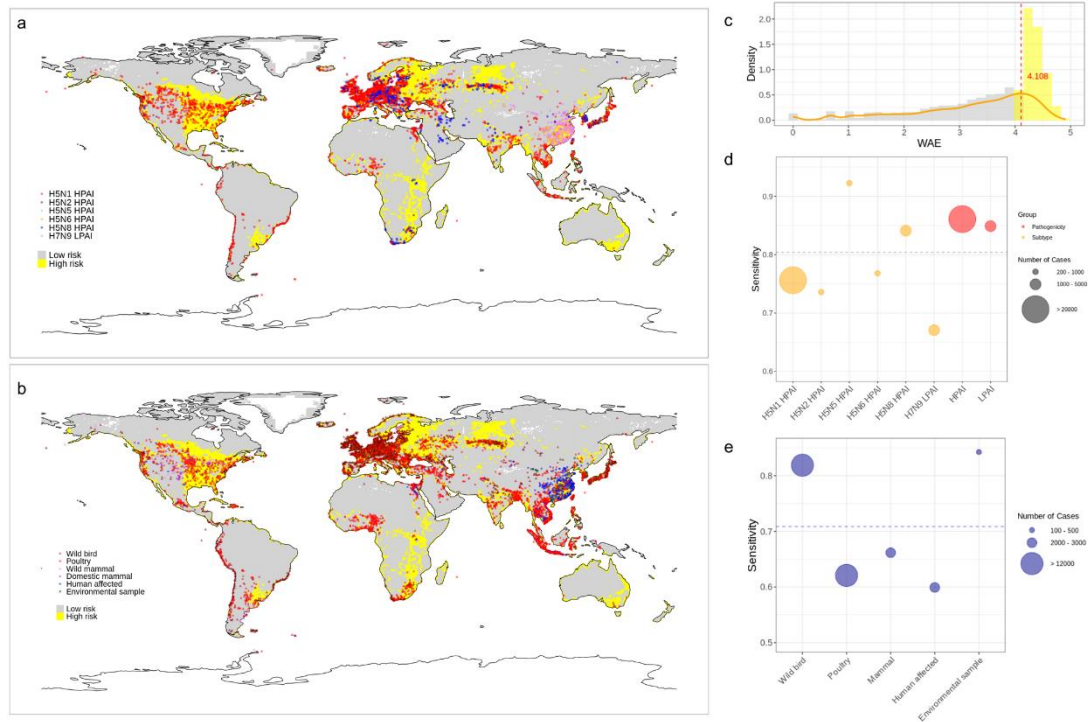


Supplementary Fig. 6 Relationships between the species richness coefficient of variation (CV) and gross primary productivity (GPP) coefficient of variation (CV) and between species richness (CV) and frost days. (a) Linear relationship between species richness CV and GPP CV across different Wallace's realms. Red points and bars represent pixels derived from the Northern Hemisphere, whereas blue points and bars represent pixels derived from the Southern Hemisphere. Different shapes of points correspond to the six Wallace's realms. **(b)** A detailed demonstration of the linear relationship between species richness CV and GPP CV within different Wallace's realms. **(c)** The linear relationship between species richness CV and frost days across different Wallace's realms. Red points and bars represent pixels derived from the Northern Hemisphere, whereas blue points and

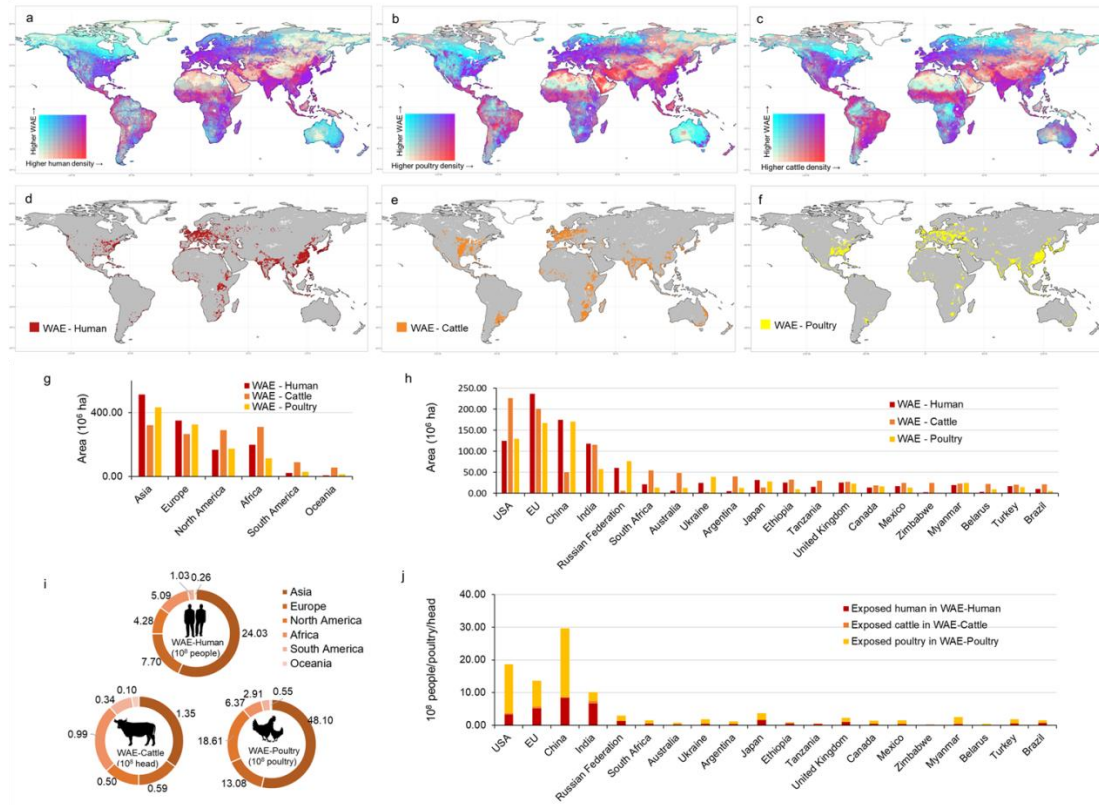
bars represent pixels derived from the Southern Hemisphere. Different shapes of points correspond to the six Wallace's realms. **(d)** A detailed demonstration of the linear relationship between species richness CV and frost days within different Wallace's realms.



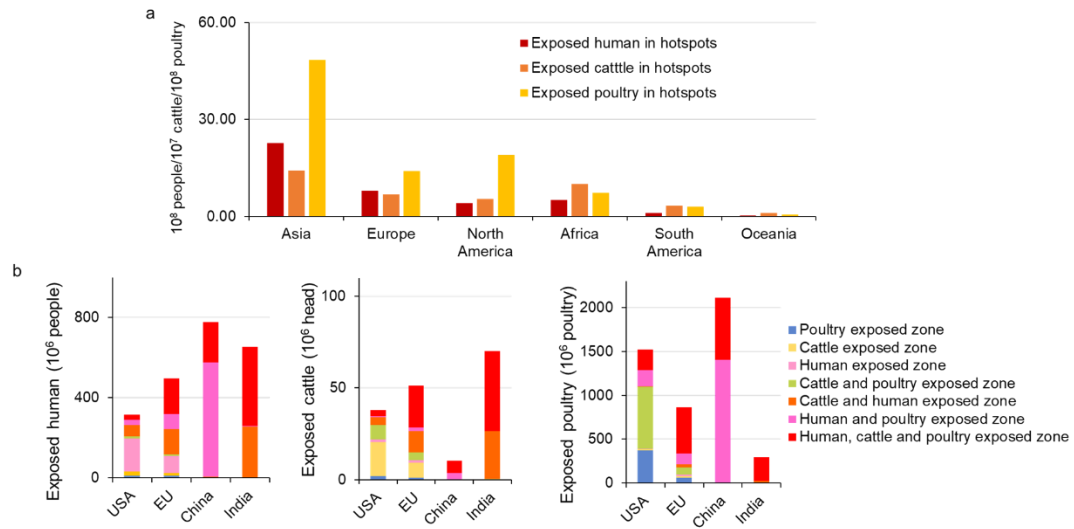
Supplementary Fig. 7 Multi-criteria Filtering Process for Restricting Poultry-to-Poultry Transmission Cases. Each panel displays the final output of one filtering step, highlighting the spatial distribution of reported avian influenza (AIV) detections. Red dots represent reported events of poultry positive detection, blue dots indicate wild bird positive detection, and purple dots mark other positive detections. Yellow-shaded areas denote high-risk area, derived using the optimal WAE threshold identified via the Youden index at each corresponding step. Due to widespread limitations in wild bird surveillance, only the first two filtering steps were applied in the main analysis to target local poultry-to-poultry transmission following initial spillover events.



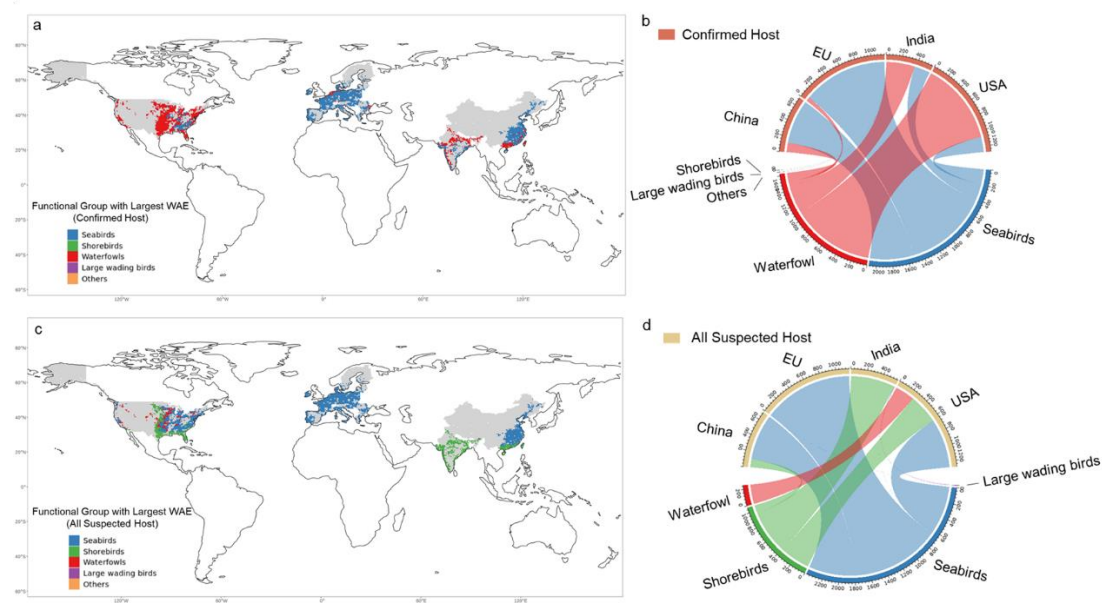
Supplementary Fig. 8 Validation of waterbird activity entropy (WAE) for predicting avian influenza after restricting poultry-to-poultry transmission. (a) Spatial distribution of high and low binary exposure risk areas and locations of reported different subtype cases. The high- and low-exposure risk areas were divided by the optimal threshold of WAE (4.11), which was determined from the receiver operating characteristic (ROC) curve via the Youden index. The red points represent the reported cases of H5N1 HPAI; the violet points denote H5N5 HPAI cases; the blue triangles indicate occurrences of H9N2 LPPI; and the dark green points signify H7N3 HPAI reports. Cases of H5N2 HPAI are shown as dark red points, and H5N6 HPAI is represented by orange points. The purple points reflect H5N8 HPAI instances, and light green triangles mark reported cases of H7N9 LPPI. **(b)** Spatial distribution of high- and low-binary exposure risk areas and locations of different infected animals, humans and environmental samples. Red points represent cases in poultry, whereas dark red triangles indicate cases in wild birds. Domestic mammals are shown with purple points, and human-affected cases are marked with blue points. The environmental samples are represented by dark green squares, and the wild mammal samples are shown with violet triangles. **(c)** The probability density of WAE. The histogram is gray for values ≤ 4.11 and yellow for values > 4.11 . **(d)** Predictive sensitivity of different subtypes and various pathogenicities. The size of the circles indicates the number of reported cases. The dotted line represents overall sensitivity. **(e)** Predictive sensitivity across different infected animals, humans and environmental samples. The size of the circles indicates the number of reported cases. The dotted line represents the overall sensitivity.



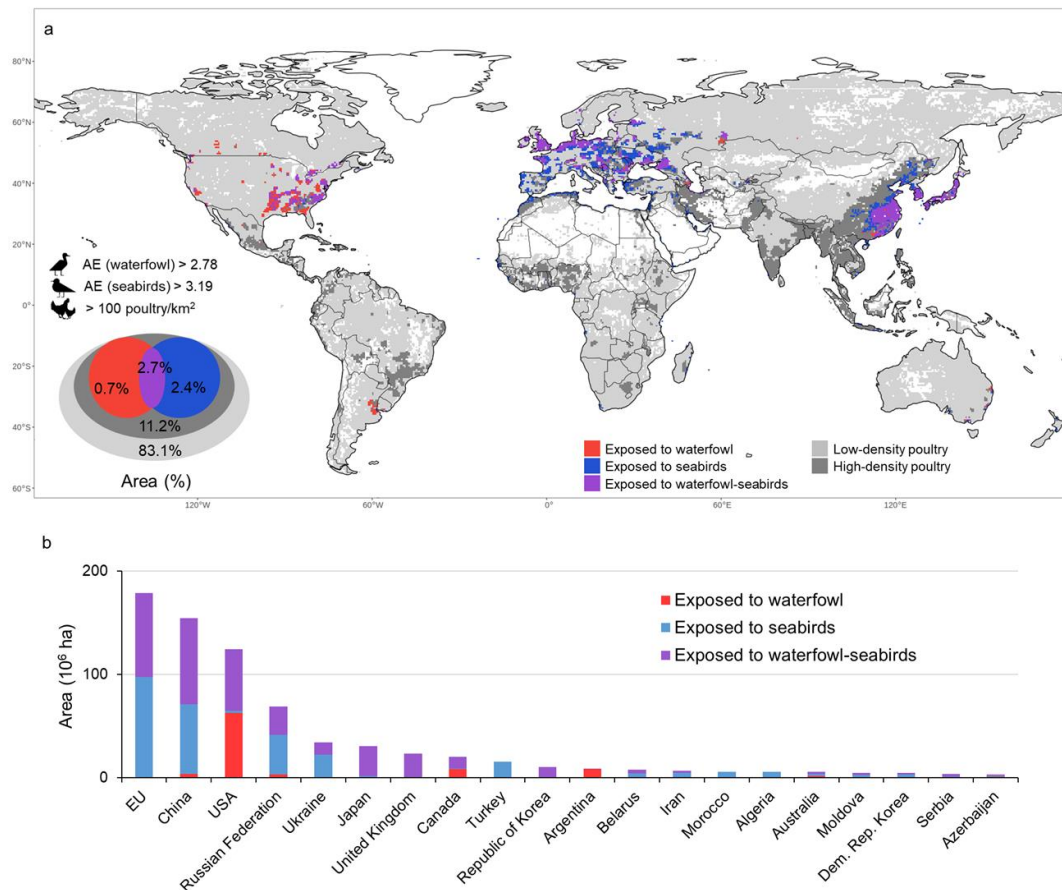
Supplementary Fig. 9 Global overlap patterns between waterbird activity entropy (WAE) and human density, cattle density, and poultry density. The bivariate color maps illustrate the relationships between WAE and human density (a), cattle density (b), and poultry density (c). Regions in purple indicate areas with high activity entropy concurrent with high human, cattle, or poultry density. All variables are separated by the tenth percentile. The exposure risk areas for human density (WAE-Human) (d), cattle density (WAE-Cattle) (e), and poultry density (WAE-Poultry) (f) are identified. Statistics are provided for the areas of WAE-Human, WAE-Cattle, and WAE-Poultry among different continents (g) and countries (h). Additionally, statistics on the numbers of exposed populations within the WAE-Human, WAE-Cattle, and WAE-Poultry regions across different continents (i) and countries/regions (j) are shown. Credit: all silhouettes in i, PhyloPic under a Creative Commons CC0 license.



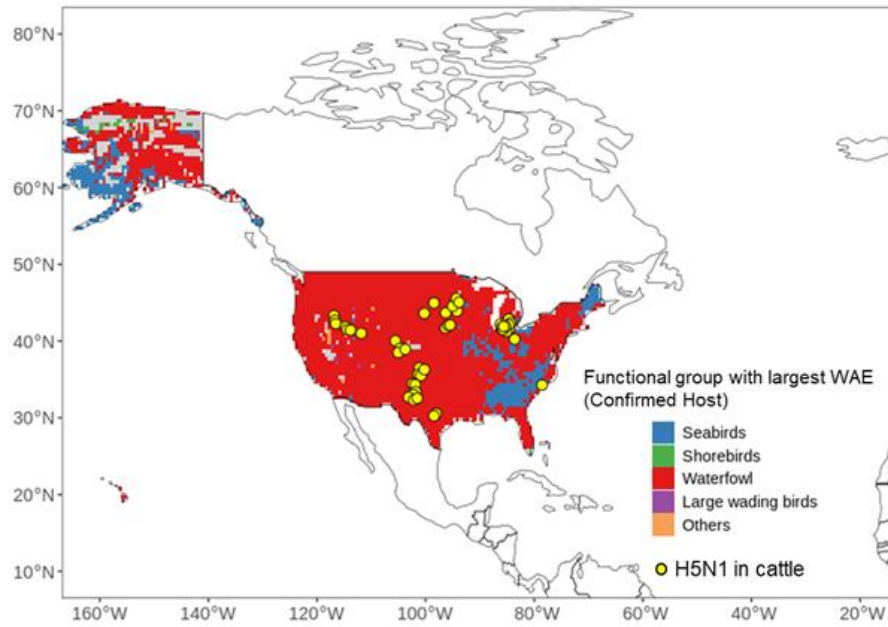
Supplementary Fig. 10 Statistics of the area and exposed population in exposure hotspots. (a) Statistics on the number of exposed humans, cattle, and poultry within hotspots among different continents. Hotspots are categorized into poultry-exposed zones, cattle-exposed zones, human-exposed zones, cattle- and poultry-exposed zones, cattle- and human-exposed zones, human- and poultry-exposed zones, and human-cattle- and poultry-exposed zones. **(b)** Statistics on the number of exposed human, cattle, and poultry populations within hotspots among the key exposure countries/regions.



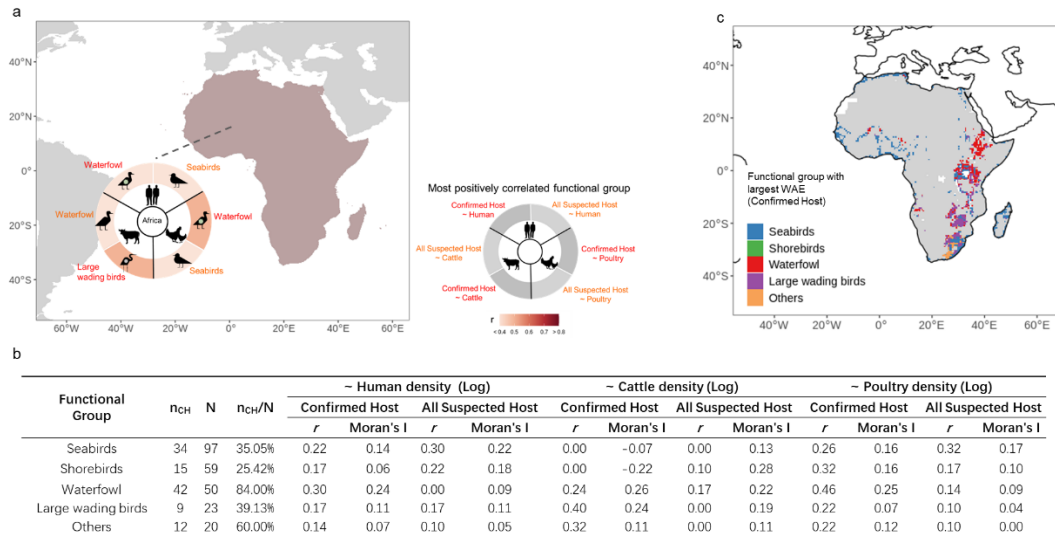
Supplementary Fig. 11 Waterbird functional groups with the highest water activity entropy (WAE) in hotspots among key exposure countries/regions (USA, EU, China and India). Each pixel is identified as one of the following functional groups with the highest WAE: seabirds, shorebirds, waterbirds, large wading birds, and others. This identification is based on confirmed avian influenza virus-carrying hosts **(a)** or all suspected hosts **(c)**. The numbers represent the number of pixels among the waterbird functional groups of confirmed hosts **(b)** or all suspected hosts **(d)** with the highest WAE across hotspots in the different key exposure countries/regions. The chord diagrams highlight the dominant waterbird groups with highest WAE in each region, revealing distinct regional patterns of host group and potential exposure risk.



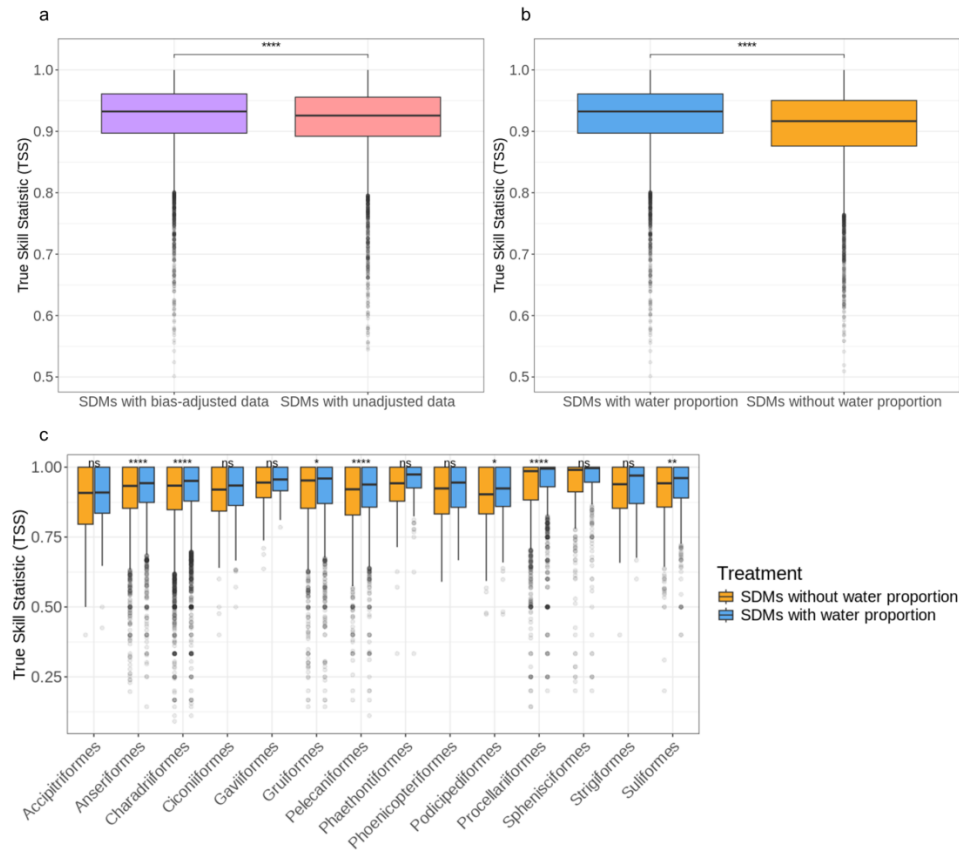
Supplementary Fig. 12 Global hotspots of high-density poultry exposed to activity entropy (AE) of waterfowl and seabirds. (a) Overlay map illustrating the spatial convergence of high-density poultry, waterfowl AE, and seabird AE. Thresholds for each variable were defined as the top 15% quantile of their respective distributions. **(b)** Statistics on the risk areas stratified by exposure to waterfowl AE, seabird AE, or both, across the top twenty countries/regions. Credit: all silhouettes in a, PhyloPic under a Creative Commons CC0 license.



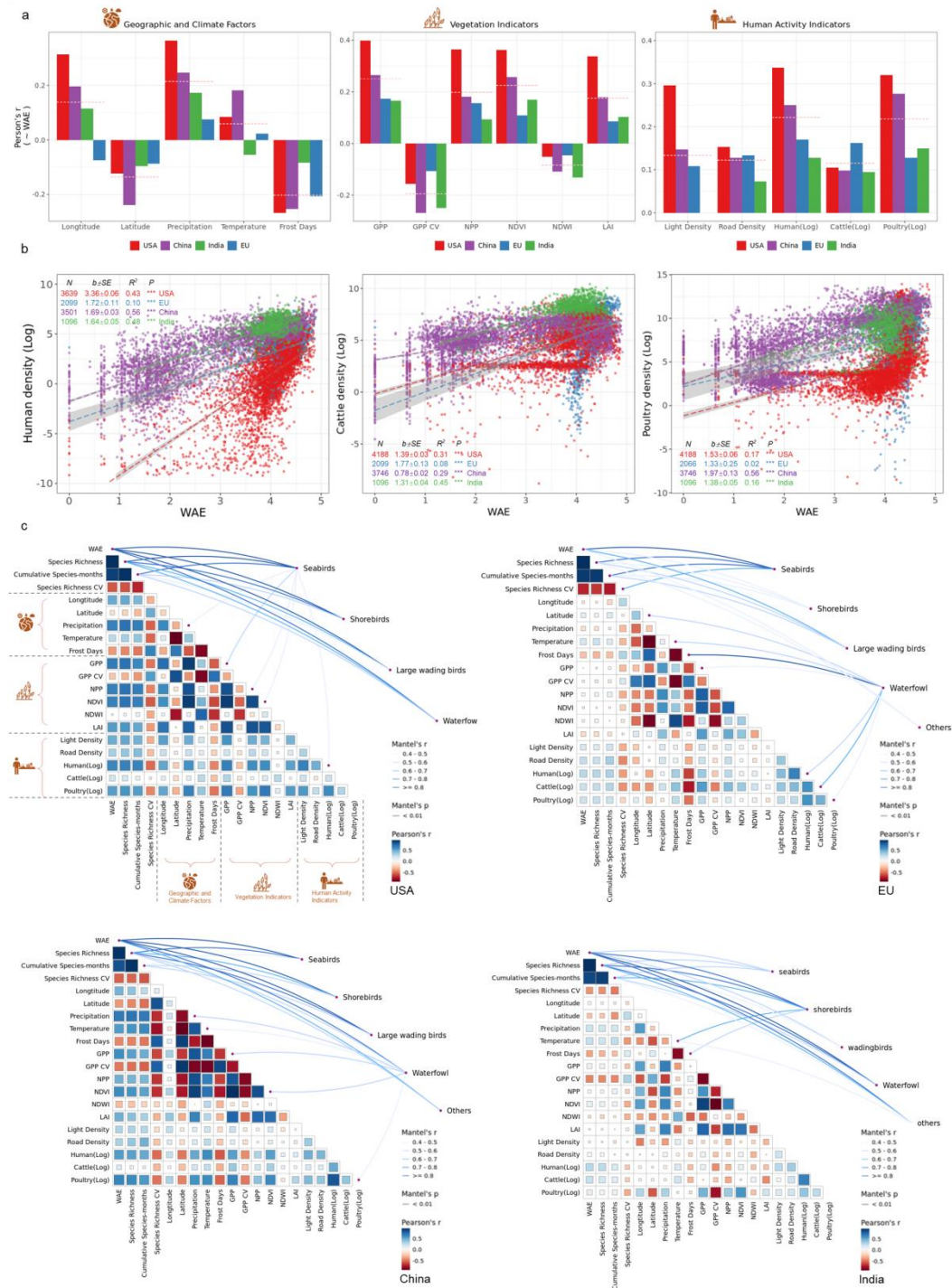
Supplementary Fig. 13 Spatial distribution of dominant waterbird functional groups (confirmed host) in relation to H5N1 outbreaks in U.S. cattle. Yellow circles indicate H5N1 cases in cattle.



Supplementary Fig. 14 Analysis of waterbird functional groups in Africa. (a) The waterbird functional groups most positively correlated with human density, cattle density, and poultry density in Africa. **(b)** Relationships between waterbird activity entropy (WAE) and human or poultry density among different waterbird functional groups in Africa. 'n_{CH}' represents the number of confirmed hosts, and 'N' represents the number of all suspected waterbirds. ' r ' represents the Pearson correlation coefficient, and ' $Moran's I$ ' represents the global Bivariate Moran's I statistic. **(c)** Waterbird functional groups with the highest water activity entropy (WAE) in Africa. The identification is based on confirmed avian influenza virus-carrying hosts. Each pixel is identified as one of the following functional groups with the highest WAE: seabirds, shorebirds, waterbirds, large wading birds, and others. Credit: all silhouettes in **a**, PhyloPic under a Creative Commons CC0 license.

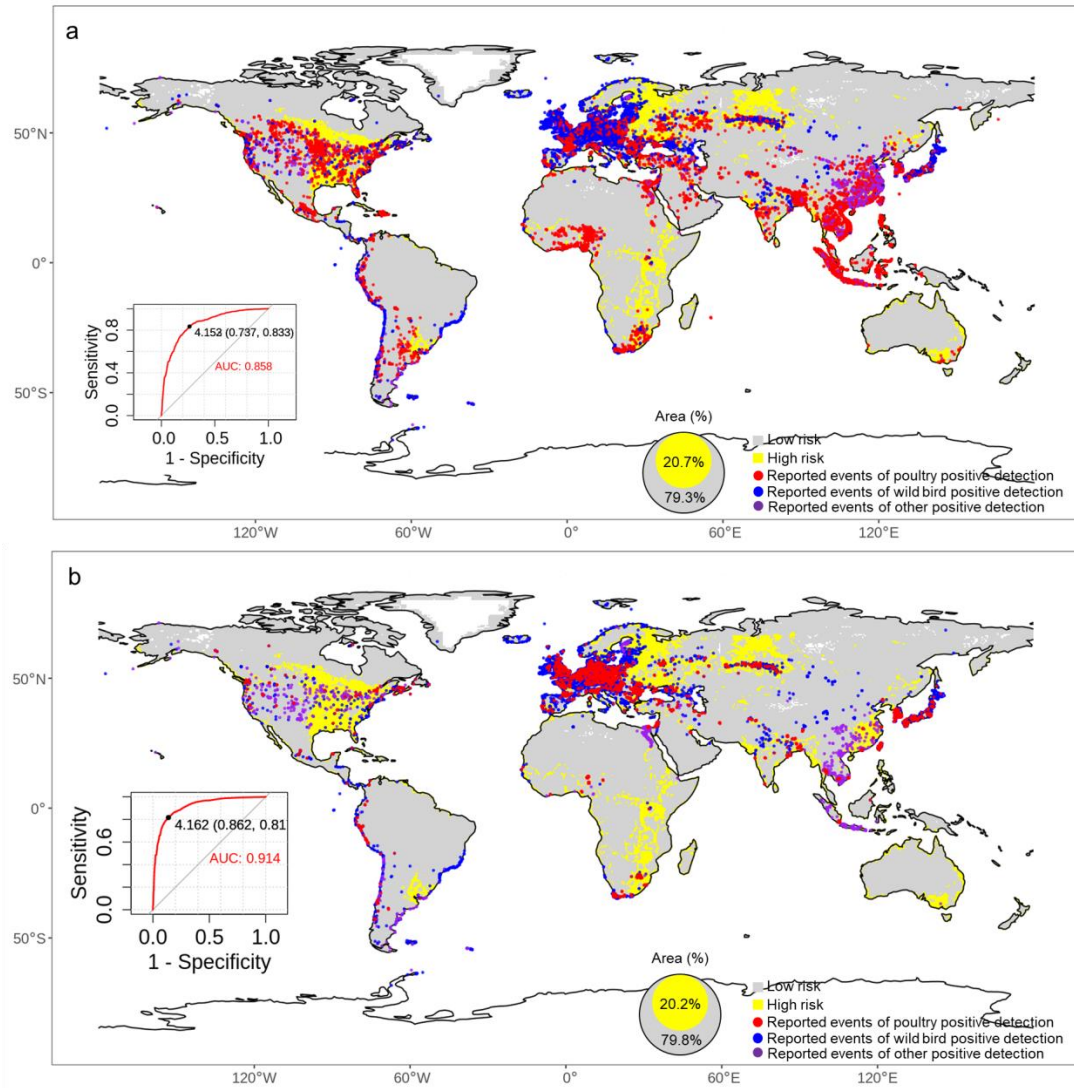


Supplementary Fig. 15 Comparison of the True Skill Statistic (TSS) before and after adjusting for observational biases. (a) Comparison of the TSS of conducting SDMs based on bias-adjusted observation data and unadjusted observation data. Purple boxplots represent SDMs without bias-adjusted observation data, whereas red boxplots represent SDMs with unadjusted observation data. **(b)** Comparison of the TSS of conducting SDMs with and without water proportion. Blue boxplots represent SDMs with water proportion, whereas orange boxplot represent SDMs without water proportion. **(c)** Comparison of the TSS of conducting SDMs with and without water proportion across different orders. We combined the outcomes of various modeling approaches to simulate the distribution patterns of waterbird species, enabling a comprehensive evaluation of model performance and predictive accuracy.

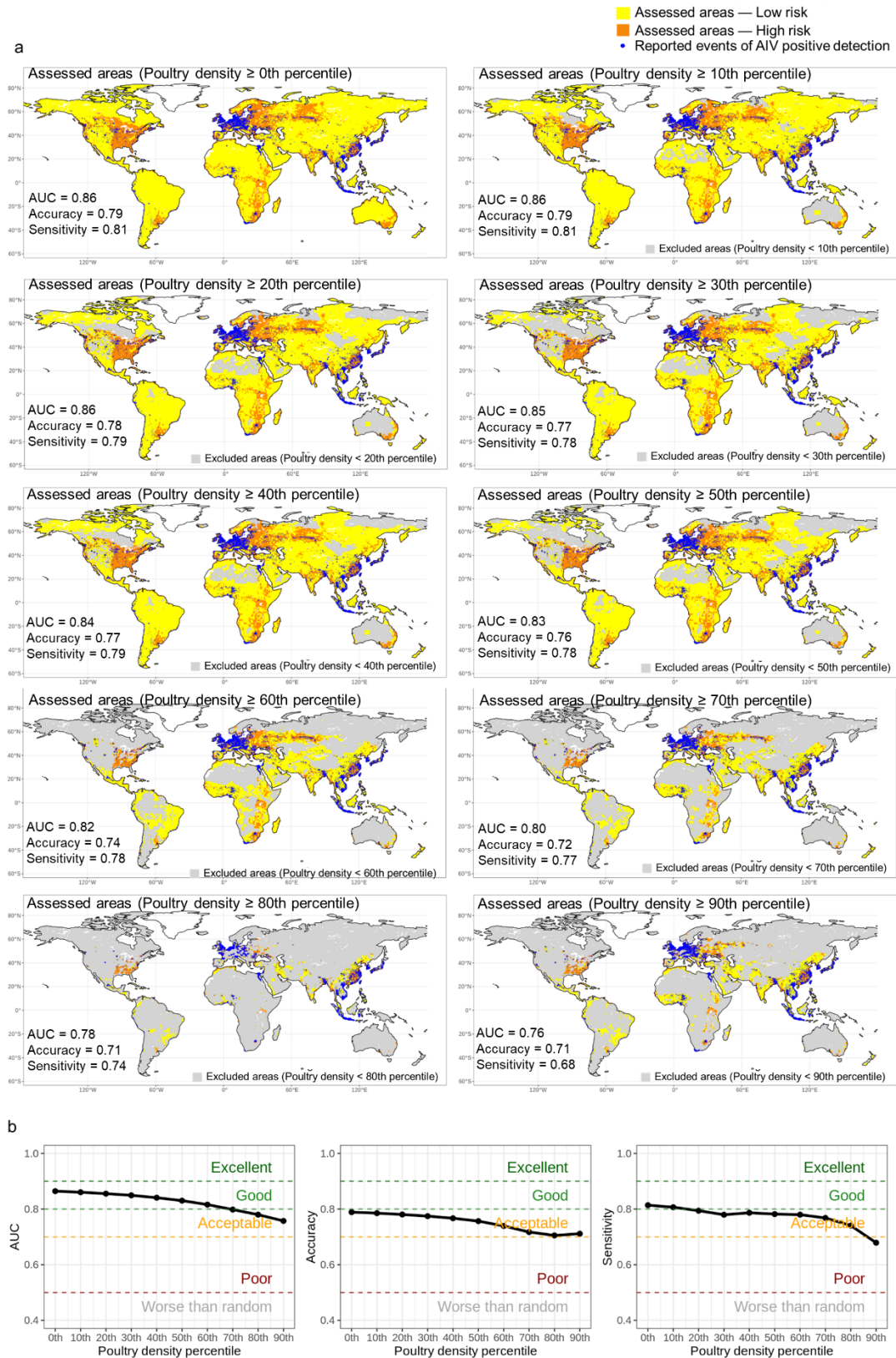


Supplementary Fig. 16 Drive analysis of waterbird activity entropy (WAE) in the key exposure countries/regions. (a) Pearson correlation statistics between WAE and the three groups of drivers. It was conducted across key exposure countries/regions: the United States (USA), the European Union (EU), China, and India. These drivers were categorized into three groups: geographic and climate factors, vegetation indicators, and human activity factors. **(b)** Relationships between WAE and human density, cattle density, and poultry density; both population densities were log-transformed. **(c)** Mantel tests and Pearson's

correlation matrix illustrating the relationships between WAEs of different waterbird functional groups and three types of drivers in the USA, EU, China, and India. Mantel tests were used to quantify the correlation between WAE and dependent drivers in five waterbird functional groups (seabirds, shorebirds, large wading birds, waterfowl and others). The line width corresponds to the partial Mantel's r statistic for the corresponding correlation, and the solid lines indicate statistical significance. The Pearson correlation coefficient matrix shows the relationships among the dependent drivers. Warm and cold colors represent negative and positive correlations, respectively. The significance levels of the Pearson correlations among the dependent drivers are indicated by the square size. The three types of drivers include longitude ($^{\circ}$), latitude ($^{\circ}$), precipitation (mm), temperature ($^{\circ}\text{C}$), number of days below 0°C (Frost days), gross primary productivity (GPP, $\text{g C m}^{-2} \text{ day}^{-1}$), gross primary productivity coefficient of variation (CV of GPP), net primary productivity (NPP, $\text{g C m}^{-2} \text{ day}^{-1}$), normalized difference vegetation index (NDVI), normalized difference water index (NDWI), leaf area index (LAI), nighttime lights (light density), road density (m per km^2), human density (log-transformed, number per km^2), and poultry density (log-transformed, number per km^2). All icons were retrieved from public domain sources and digitally processed using Adobe Photoshop.



Supplementary Fig. 17 Validation of waterbird activity entropy (WAE) for predicting avian influenza before and after complete filtering poultry-to-poultry transmission. (a) Spatial distribution of high and low binary exposure risk areas and locations of original cases from the raw dataset. The high- and low-exposure risk areas were divided by the optimal threshold of WAE (4.15), which was determined from the receiver operating characteristic (ROC) curve via the Youden index. **(b)** Spatial distribution of high and low binary exposure risk areas and locations of filtered cases from a 4-step filtering process (see Supplementary Fig. 7). The high- and low-exposure risk areas were divided by the optimal threshold of WAE (4.16), which was determined from the receiver operating characteristic (ROC) curve via the Youden index. The red points represent poultry cases; the blue points denote wild bird cases; the purple points indicate other types of cases.



Supplementary Fig. 18 Validation of waterbird activity entropy (WAE) as a predictor of poultry avian influenza detections across varying poultry density levels. (a) Spatial distribution and validation of risk areas mapped using the WAE

framework across ten poultry density gradient ranges. Assessed areas in each poultry density gradients were derived from regions where poultry density exceeds each percentile threshold (0th to 90th percentile, in 10-percentile increments). These percentiles were calculated using poultry density raster data (chickens and ducks, from the GLW4 dataset). Within each map, the blue points represent the validation cases, which were poultry AIV detections after two-step filtering and were restricted to their corresponding assessed areas. The orange area represents high-risk regions and the yellow area indicates relatively low-risk regions, based on consistent methods as global assessment. **(b)** Robustness evaluation of the WAE framework across a poultry density gradient. Line plots depict changes in the area under the curve (AUC), accuracy, and sensitivity across ten poultry density percentile gradients. AUC represents overall predictive performance, accuracy indicates the proportion of correct predictions, and sensitivity reflects the true positive detection rate. These metrics, derived from ROC analysis (pROC package, R), were used to comprehensively evaluate the robustness of the WAE framework.

Supplementary Tables

Supplementary Table 1 List of waterbird species. This table provides a detailed enumeration of the specific names and respective orders of the 779 waterbird species successfully simulated in this study.

Functional group (numbers of species)	Species
seabirds (206)	<i>Alca torda</i>, <i>Alle alle</i>, <i>Anous minutus</i>, <i>Anous stolidus</i>, <i>Aphrodroma brevirostris</i>, <i>Aptenodytes forsteri</i>, <i>Aptenodytes patagonicus</i>, <i>Brachyramphus marmoratus</i>, <i>Bulweria bulwerii</i>, <i>Calonectris diomedea</i>, <i>Calonectris leucomelas</i>, <i>Cephus carbo</i>, <i>Cephus columba</i>, <i>Cephus grylle</i>, <i>Cerorhinca monocerata</i>, <i>Chlidonias albostratus</i>, <i>Chlidonias hybrida</i>, <i>Chlidonias leucopterus</i>, <i>Chlidonias niger</i>, <i>Chroicocephalus brunnicephalus</i>, <i>Chroicocephalus bulleri</i>, <i>Chroicocephalus cirrocephalus</i>, <i>Chroicocephalus genei</i>, <i>Chroicocephalus hartlaubii</i>, <i>Chroicocephalus novaehollandiae</i>, <i>Chroicocephalus philadelphia</i>, <i>Chroicocephalus ridibundus</i>, <i>Daption capense</i>, <i>Diomedea antipodensis</i>, <i>Diomedea epomophora</i>, <i>Diomedea exulans</i>, <i>Diomedea sanfordi</i>, <i>Eudyptes chrysocome</i>, <i>Eudyptes chrysolophus</i>, <i>Eudyptes pachyrhynchus</i>, <i>Eudyptula minor</i>, <i>Fratercula arctica</i>, <i>Fratercula cirrhata</i>, <i>Fratercula corniculata</i>, <i>Fregata ariel</i>, <i>Fregata magnificens</i>, <i>Fregata minor</i>, <i>Fregatta tropica</i>, <i>Fulmarus glacialis</i>, <i>Fulmarus glacialisoides</i>, <i>Garrodia nereis</i>, <i>Gelochelidon macrotarsa</i>, <i>Gelochelidon nilotica</i>, <i>Glareola cinerea</i>, <i>Glareola ocularis</i>, <i>Gygis alba</i>, <i>Halobaena caerulea</i>, <i>Hydrobates melania</i>, <i>Hydrobates pelagicus</i>, <i>Hydrocoloeus minutus</i>, <i>Hydroprogne caspia</i>, <i>Ichthyaelus audouinii</i>, <i>Ichthyaelus hemprichii</i>, <i>Ichthyaelus ichthyaelus</i>, <i>Ichthyaelus leucophthalmus</i>, <i>Ichthyaelus melanocephalus</i>, <i>Larus argentatus</i>, <i>Larus arcticus</i>, <i>Larus cachinnans</i>, <i>Larus californicus</i>, <i>Larus canus</i>, <i>Larus crassirostris</i>, <i>Larus delawarensis</i>, <i>Larus dominicanus</i>, <i>Larus fuscus</i>, <i>Larus glaucescens</i>, <i>Larus glaucoideus</i>, <i>Larus heermanni</i>, <i>Larus hyperboreus</i>, <i>Larus livens</i>, <i>Larus marinus</i>, <i>Larus michahellis</i>, <i>Larus occidentalis</i>, <i>Larus pacificus</i>, <i>Larus schistisagus</i>, <i>Larus smithsonianus</i>, <i>Larus vegae</i>, <i>Leucophaeus atricilla</i>, <i>Macronectes giganteus</i>, <i>Macronectes halli</i>, <i>Megadyptes antipodes</i>, <i>Microcarbo africanus</i>, <i>Microcarbo coronatus</i>, <i>Microcarbo melanoleucos</i>, <i>Microcarbo niger</i>, <i>Microcarbo pygmaeus</i>, <i>Morus bassanus</i>, <i>Morus capensis</i>, <i>Morus serrator</i>, <i>Oceanites gracilis</i>, <i>Oceanites oceanicus</i>, <i>Onychoprion anaethetus</i>, <i>Onychoprion fuscatus</i>, <i>Pachyptila belcheri</i>, <i>Pachyptila desolata</i>, <i>Pachyptila salvini</i>, <i>Pachyptila turtur</i>, <i>Pagodroma nivea</i>, <i>Pagophila eburnea</i>, <i>Pelagodroma marina</i>, <i>Pelecanoides urinatrix</i>, <i>Phaethon aethereus</i>, <i>Phaethon lepturus</i>, <i>Phaethon rubricauda</i>, <i>Phaetusa simplex</i>, <i>Phalacrocorax aristotelis</i>, <i>Phalacrocorax auritus</i>, <i>Phalacrocorax brasilianus</i>, <i>Phalacrocorax capensis</i>, <i>Phalacrocorax capillatus</i>, <i>Phalacrocorax carbo</i>, <i>Phalacrocorax fuscus</i>, <i>Phalacrocorax fuscicollis</i>, <i>Phalacrocorax lucidus</i>, <i>Phalacrocorax pelagicus</i>, <i>Phalacrocorax penicillatus</i>, <i>Phalacrocorax punctatus</i>, <i>Phalacrocorax sulcirostris</i>, <i>Phalacrocorax urile</i>, <i>Phalacrocorax varius</i>, <i>Phoebastria albatrus</i>, <i>Phoebastria immutabilis</i>, <i>Phoebastria nigripes</i>, <i>Phoebastria palpebrata</i>, <i>Procellaria aequinoctialis</i>, <i>Procellaria cinerea</i>, <i>Procellaria parkinsoni</i>, <i>Procellaria westlandica</i>, <i>Pseudobulweria rostrata</i>, <i>Pterodroma cookii</i>, <i>Pterodroma inexpectata</i>, <i>Pterodroma lessonae</i>, <i>Pterodroma leucoptera</i>, <i>Pterodroma macroptera</i>, <i>Pterodroma nigripennis</i>, <i>Pterodroma solandri</i>, <i>Ptychoramphus aleuticus</i>, <i>Puffinus assimilis</i>, <i>Puffinus gavia</i>, <i>Puffinus huttoni</i>, <i>Puffinus lherminieri</i>, <i>Puffinus mauretanicus</i>, <i>Puffinus opisthomelas</i>, <i>Puffinus persicus</i>, <i>Puffinus puffinus</i>, <i>Puffinus yelkouan</i>, <i>Pygoscelis adeliae</i>, <i>Pygoscelis antarcticus</i>, <i>Pygoscelis papua</i>, <i>Rissa tridactyla</i>, <i>Spheniscus demersus</i>, <i>Spheniscus humboldti</i>, <i>Spheniscus magellanicus</i>, <i>Stercorarius antarcticus</i>, <i>Stercorarius longicaudus</i>, <i>Stercorarius maccormicki</i>, <i>Stercorarius parasiticus</i>, <i>Stercorarius pomarinus</i>, <i>Stercorarius skua</i>, <i>Sterna dougallii</i>, <i>Sterna forsteri</i>, <i>Sterna hirundinacea</i>, <i>Sterna hirundo</i>, <i>Sterna paradisaea</i>, <i>Sterna repressa</i>, <i>Sterna striata</i>, <i>Sterna sumatrana</i>, <i>Sterna trudeaui</i>, <i>Sterna vittata</i>, <i>Sternula albifrons</i>, <i>Sternula antillarum</i>, <i>Sternula balaenarum</i>, <i>Sternula nereis</i>, <i>Sternula superciliosa</i>,

Sula dactylatra, Sula granti, Sula leucogaster, Sula neboxii, Sula sula, Sula variegata, Synthliboramphus antiquus, Synthliboramphus craveri, Synthliboramphus scrippsi, Tachybaptus pelzelinii, Thalassarche bulleri, Thalassarche carteri, Thalassarche cauta, Thalassarche chlororhynchos, Thalassarche chrysostoma, Thalassarche impavida, Thalassarche melanophris, Thalassarche salvini, Thalasseus acufavidus, Thalasseus bengalensis, Thalasseus bergii, Thalasseus elegans, Thalasseus maximus, Thalasseus sandvicensis, Thalassoica antarctica, Uria aalge, Uria lomvia

Actitis hypoleucos, *Actitis macularius*, *Actophilornis africanus*, *Amaurornis flavirostra*, *Anarhynchus frontalis*,
Arenaria interpres, *Arenaria melanocephala*, *Attagis gayi*, *Bartramia longicauda*, *Burhinus bistriatus*,
Burhinus capensis, *Burhinus grallarius*, *Burhinus indicus*, *Burhinus oedicephalus*, *Burhinus senegalensis*,
Burhinus vermiculatus, *Calidris acuminata*, *Calidris alba*, *Calidris alpina*, *Calidris bairdii*, *Calidris canutus*,
Calidris falcinellus, *Calidris ferruginea*, *Calidris fuscicollis*, *Calidris himantopus*, *Calidris maritima*, *Calidris*
mauri, *Calidris melanotos*, *Calidris minuta*, *Calidris minutilla*, *Calidris ptilocnemis*, *Calidris pugnax*,
Calidris pusilla, *Calidris pygmaea*, *Calidris ruficollis*, *Calidris subminuta*, *Calidris subruficollis*, *Calidris*
temminckii, *Calidris tenuirostris*, *Calidris virgata*, *Charadrius alexandrinus*, *Charadrius asiaticus*,
Charadrius bicinctus, *Charadrius collaris*, *Charadrius dealbatus*, *Charadrius dubius*, *Charadrius*
falklandicus, *Charadrius forbesi*, *Charadrius hiaticula*, *Charadrius leschenaultii*, *Charadrius marginatus*,
Charadrius melodus, *Charadrius modestus*, *Charadrius mongolus*, *Charadrius montanus*, *Charadrius*
nivosus, *Charadrius pallidus*, *Charadrius pecuarius*, *Charadrius peronii*, *Charadrius placidus*, *Charadrius*
ruficapillus, *Charadrius semipalmatus*, *Charadrius thoracicus*, *Charadrius tricollaris*, *Charadrius veredus*,
Charadrius vociferus, *Charadrius wilsonia*, *Chionis albus*, *Cladorhynchus leucocephalus*, *Cursorius*
coromandelicus, *Cursorius cursor*, *Cursorius rufus*, *Cursorius somalensis*, *Cursorius temminckii*, *Dromas*
ardeola, *Elseya melanops*, *Erythronyx cinctus*, *Esacus magnirostris*, *Esacus recurvirostris*, *Gallinago*
delicata, *Gallinago gallinago*, *Gallinago hardwickii*, *Gallinago macrodactyla*, *Gallinago media*, *Gallinago*
megala, *Gallinago nigripennis*, *Gallinago paraguanae*, *Gallinago stenura*, *Glareola lactea*, *Glareola*
maldivarum, *Glareola nordmanni*, *Glareola nuchalis*, *Glareola pratincola*, *Haematopus ater*, *Haematopus*
bachmani, *Haematopus finschi*, *Haematopus fuliginosus*, *Haematopus leucopodus*, *Haematopus longirostris*,
Haematopus moquini, *Haematopus ostralegus*, *Haematopus palliatus*, *Haematopus unicolor*, *Himantopus*
himantopus, *Himantopus leucocephalus*, *Himantopus mexicanus*, *Hoploxypterus cayanus*, *Hydrophasianus*
chirurgus, *Ibidorhynchos struthersii*, *Irediparra gallinacea*, *Jacana jacana*, *Jacana spinosa*, *Leucophaeus*
pipixcan, *Limnodromus griseus*, *Limnodromus scolopaceus*, *Limnodromus semipalmatus*, *Limosa fedoa*,
Limosa haemastica, *Limosa lapponica*, *Limosa limosa*, *Lymnocyrtus minimus*, *Metopidius indicus*,
Microparra capensis, *Numenius americanus*, *Numenius arquata*, *Numenius madagascariensis*, *Numenius*
minutus, *Numenius phaeopus*, *Nycticorax nycticorax*, *Oreopholus ruficollis*, *Pedionomus torquatus*,
Peltohyas australis, *Phalaropus fulicarius*, *Phalaropus lobatus*, *Plegadis falcinellus*, *Platalea ajaja*, *Platalea*
alba, *Platalea flavipes*, *Platalea leucorodia*, *Platalea minor*, *Platalea regia*, *Pluvialis apricaria*, *Pluvialis*
dominica, *Pluvialis fulva*, *Pluvialis squatarola*, *Pluvialis aegyptius*, *Recurvirostra americana*, *Recurvirostra*
andina, *Recurvirostra avosetta*, *Recurvirostra novaehollandiae*, *Rhinoptilus africanus*, *Rhinoptilus*
chalcophaps, *Rhinoptilus cinctus*, *Rostratula australis*, *Rostratula benghalensis*, *Rynchops albicollis*,
Rynchops flavirostris, *Rynchops niger*, *Scolopax minor*, *Scolopax rusticola*, *Sterna aurantia*, *Sterna isabellae*,
Thinocorus orbignyianus, *Thinocorus rumicivorus*, *Thinornis cucullatus*, *Tringa brevipes*, *Tringa erythropus*,
Tringa flavipes, *Tringa glareola*, *Tringa incana*, *Tringa melanoleuca*, *Tringa nebulosa*, *Tringa ochropus*,
Tringa semipalmata, *Tringa solitaria*, *Tringa stagnatilis*, *Tringa totanus*, *Turnix castanotus*, *Turnix*
hottentottus, *Turnix maculosus*, *Turnix melanogaster*, *Turnix nanus*, *Turnix nigricollis*, *Turnix pyrrhorostris*,
Turnix suscitator, *Turnix sylvaticus*, *Turnix varius*, *Turnix velox*, *Vanellus albiceps*, *Vanellus armatus*, *Vanellus*
chilensis, *Vanellus cinereus*, *Vanellus coronatus*, *Vanellus crassirostris*, *Vanellus duvaucelii*, *Vanellus*
gregarius, *Vanellus indicus*, *Vanellus leucurus*, *Vanellus lugubris*, *Vanellus malabaricus*, *Vanellus*
melanocephalus, *Vanellus miles*, *Vanellus resplendens*, *Vanellus senegalensis*, *Vanellus spinosus*, *Vanellus*
superciliosus, *Vanellus tectus*, *Vanellus tricolor*, *Vanellus vanellus*, *Xenus cinereus*

waterfowl (150)	<i>Aix galericulata</i>, <i>Aix sponsa</i>, <i>Alopochen aegyptiaca</i>, <i>Amazonetta brasiliensis</i>, <i>Anas acuta</i>, <i>Anas andium</i>, <i>Anas bahamensis</i>, <i>Anas bernieri</i>, <i>Anas capensis</i>, <i>Anas carolinensis</i>, <i>Anas castanea</i>, <i>Anas chlorotis</i>, <i>Anas crecca</i>, <i>Anas diazi</i>, <i>Anas erythrorhyncha</i>, <i>Anas flavirostris</i>, <i>Anas fulvigula</i>, <i>Anas georgica</i>, <i>Anas gibberifrons</i>, <i>Anas gracilis</i>, <i>Anas melleri</i>, <i>Anas platyrhynchos</i>, <i>Anas poecilorhyncha</i>, <i>Anas rubripes</i>, <i>Anas sparsa</i>, <i>Anas superciliosa</i>, <i>Anas undulata</i>, <i>Anas zonorhyncha</i>, <i>Anser albifrons</i>, <i>Anser anser</i>, <i>Anser brachyrhynchus</i>, <i>Anser caerulescens</i>, <i>Anser cygnoides</i>, <i>Anser erythropus</i>, <i>Anser fabalis</i>, <i>Anser indicus</i>, <i>Anser rossii</i>, <i>Anser serrirostris</i>, <i>Anseranas semipalmata</i>, <i>Aythya affinis</i>, <i>Aythya americana</i>, <i>Aythya australis</i>, <i>Aythya baeri</i>, <i>Aythya collaris</i>, <i>Aythya ferina</i>, <i>Aythya fuligula</i>, <i>Aythya marila</i>, <i>Aythya novaeseelandiae</i>, <i>Aythya nyroca</i>, <i>Aythya valisineria</i>, <i>Biziura lobata</i>, <i>Branta bernicla</i>, <i>Branta canadensis</i>, <i>Branta hutchinsii</i>, <i>Branta leucopsis</i>, <i>Branta ruficollis</i>, <i>Bucephala albeola</i>, <i>Bucephala clangula</i>, <i>Bucephala islandica</i>, <i>Cairina moschata</i>, <i>Callonetta leucophrys</i>, <i>Cereopsis novaehollandiae</i>, <i>Chauna torquata</i>, <i>Chenonetta jubata</i>, <i>Chloephaga hybrida</i>, <i>Chloephaga melanoptera</i>, <i>Chloephaga picta</i>, <i>Chloephaga poliocephala</i>, <i>Chloephaga rubidiceps</i>, <i>Clangula hyemalis</i>, <i>Coscoroba coscoroba</i>, <i>Cygnus atratus</i>, <i>Cygnus buccinator</i>, <i>Cygnus columbianus</i>, <i>Cygnus cygnus</i>, <i>Cygnus melancoryphus</i>, <i>Cygnus olor</i>, <i>Dendrocygna arcuata</i>, <i>Dendrocygna autumnalis</i>, <i>Dendrocygna bicolor</i>, <i>Dendrocygna eytoni</i>, <i>Dendrocygna guttata</i>, <i>Dendrocygna javanica</i>, <i>Dendrocygna viduata</i>, <i>Heteronetta atricapilla</i>, <i>Histrionicus histrionicus</i>, <i>Hymenolaimus malacorhynchos</i>, <i>Lophodytes cucullatus</i>, <i>Lophonetta specularioides</i>, <i>Malacorhynchus membranaceus</i>, <i>Mareca americana</i>, <i>Mareca falcata</i>, <i>Mareca penelope</i>, <i>Mareca sibilatrix</i>, <i>Mareca strepera</i>, <i>Marmaronetta angustirostris</i>, <i>Melanitta americana</i>, <i>Melanitta deglandi</i>, <i>Melanitta fusca</i>, <i>Melanitta nigra</i>, <i>Melanitta perspicillata</i>, <i>Melanitta stejnegeri</i>, <i>Merganetta armata</i>, <i>Mergellus albellus</i>, <i>Mergus merganser</i>, <i>Mergus serrator</i>, <i>Mergus squamatus</i>, <i>Netta erythrophthalma</i>, <i>Netta peposaca</i>, <i>Netta rufina</i>, <i>Nettapus auritus</i>, <i>Nettapus coromandelianus</i>, <i>Nettapus pulchellus</i>, <i>Nomonyx dominicus</i>, <i>Oxyura australis</i>, <i>Oxyura ferruginea</i>, <i>Oxyura jamaicensis</i>, <i>Oxyura leucocephala</i>, <i>Oxyura maccoa</i>, <i>Oxyura vittata</i>, <i>Plectropterus gambensis</i>, <i>Polysticta stelleri</i>, <i>Pteronetta hartlaubii</i>, <i>Radjah radjah</i>, <i>Sarkidiornis melanotos</i>, <i>Sarkidiornis sylvicola</i>, <i>Sibirionetta formosa</i>, <i>Somateria fischeri</i>, <i>Somateria mollissima</i>, <i>Somateria spectabilis</i>, <i>Spatula clypeata</i>, <i>Spatula cyanoptera</i>, <i>Spatula discors</i>, <i>Spatula hottentota</i>, <i>Spatula platalea</i>, <i>Spatula puna</i>, <i>Spatula querquedula</i>, <i>Spatula rhynchotis</i>, <i>Spatula smithii</i>, <i>Spatula versicolor</i>, <i>Speculanus specularis</i>, <i>Stictonetta naevosa</i>, <i>Tachyeres patachonicus</i>, <i>Tachyeres pteneres</i>, <i>Tadorna cana</i>, <i>Tadorna ferruginea</i>, <i>Tadorna tadorna</i>, <i>Tadorna tadornoides</i>, <i>Tadorna variegata</i>, <i>Thalassornis leuconotus</i>
large wading birds (140)	<i>Agamia agami</i>, <i>Anthropoides paradiseus</i>, <i>Anthropoides virgo</i>, <i>Aramides albiventris</i>, <i>Aramides saracura</i>, <i>Aramides ypecaha</i>, <i>Aramus guarauna</i>, <i>Ardea alba</i>, <i>Ardea cinerea</i>, <i>Ardea cocoi</i>, <i>Ardea goliath</i>, <i>Ardea herodias</i>, <i>Ardea humbloti</i>, <i>Ardea melanocephala</i>, <i>Ardea pacifica</i>, <i>Ardea purpurea</i>, <i>Ardea sumatrana</i>, <i>Ardeola bacchus</i>, <i>Ardeola grayii</i>, <i>Ardeola idae</i>, <i>Ardeola ralloides</i>, <i>Ardeola rufiventris</i>, <i>Ardeola speciosa</i>, <i>Balaeniceps rex</i>, <i>Balearica pavonina</i>, <i>Balearica regulorum</i>, <i>Bostrychia carunculata</i>, <i>Bostrychia hagedash</i>, <i>Bostrychia olivacea</i>, <i>Bostrychia rara</i>, <i>Botaurus lentiginosus</i>, <i>Botaurus pinnatus</i>, <i>Botaurus poiciloptilus</i>, <i>Botaurus stellaris</i>, <i>Bubulcus coromandus</i>, <i>Bubulcus ibis</i>, <i>Butorides striata</i>, <i>Butorides virescens</i>, <i>Cercibis oxycerca</i>, <i>Ciconia abdimii</i>, <i>Ciconia boyciana</i>, <i>Ciconia ciconia</i>, <i>Ciconia episcopus</i>, <i>Ciconia maguari</i>, <i>Ciconia microscelis</i>, <i>Ciconia nigra</i>, <i>Cochlearius cochlearius</i>, <i>Crex crex</i>, <i>Crex egregia</i>, <i>Dryolimnas cuvieri</i>, <i>Egretta ardesiaca</i>, <i>Egretta caerulea</i>, <i>Egretta dimorpha</i>, <i>Egretta eulophotes</i>, <i>Egretta garzetta</i>, <i>Egretta gularis</i>, <i>Egretta intermedia</i>, <i>Egretta novaehollandiae</i>, <i>Egretta picata</i>, <i>Egretta rufescens</i>, <i>Egretta sacra</i>, <i>Egretta thula</i>, <i>Egretta tricolor</i>, <i>Egretta vinaceigula</i>, <i>Eudocimus albus</i>, <i>Eudocimus ruber</i>, <i>Fulica americana</i>, <i>Fulica ardesiaca</i>, <i>Fulica armillata</i>, <i>Fulica atra</i>, <i>Fulica cristata</i>, <i>Fulica gigantea</i>, <i>Fulica leucoptera</i>, <i>Fulica rufifrons</i>, <i>Gallinula angulata</i>, <i>Gallinula chloropus</i>, <i>Gallinula tenebrosa</i>, <i>Gallirallus australis</i>, <i>Geronticus calvus</i>, <i>Geronticus eremita</i>, <i>Gorsachius leuconotus</i>, <i>Gorsachius melanolophus</i>, <i>Grus americana</i>, <i>Grus grus</i>, <i>Grus japonensis</i>, <i>Grus nigricollis</i>, <i>Ixobrychus cinnamomeus</i>, <i>Ixobrychus dubius</i>, <i>Ixobrychus eurhythmus</i>

Ixobrychus exilis, Ixobrychus involucris, Ixobrychus minutus, Ixobrychus sinensis, Ixobrychus sturmii, Laterallus albigularis, Laterallus melanophaius, Lewinia pectoralis, Lophotibis cristata, Mesembrinibis cayennensis, Nyctanassa violacea, Nycticorax caledonicus, Nycticorax nycticorax, Pardirallus maculatus, Pardirallus nigricans, Pardirallus sanguinolentus, Phimosus infuscatus, Pilherodius pileatus, Plegadis chihi, Plegadis falcinellus, Plegadis ridgwayi, Podica senegalensis, Porphyrio alleni, Porphyrio melanotus, Porphyrio porphyrio, Porzana carolina, Porzana fluminea, Porzana porzana, Pseudibis papillosa, Psophia crepitans, Rallina eurizonoides, Rallus aquaticus, Rallus caerulescens, Rallus crepitans, Rallus elegans, Rallus indicus, Rallus limicola, Rallus obsoletus, Sarothrura pulchra, Scopus umbretta, Syrigma sibilatrix, Theristicus caerulescens, Theristicus caudatus, Theristicus melanopis, Threskiornis bernieri, Tigrionis leucolopha, Tigrisoma fasciatum, Tigrisoma lineatum, Tigrisoma mexicanum, Zebrilus undulatus

others
(73)

Aechmophorus clarkii, Aechmophorus occidentalis, Amaurornis phoenicurus, Anastomus lamelligerus, Anastomus oscitans, Anhinga anhinga, Anhinga melanogaster, Anhinga novaehollandiae, Anhinga rufa, Ephippiorhynchus asiaticus, Ephippiorhynchus senegalensis, Eulabeornis castaneiventris, Gavia adamsii, Gavia arctica, Gavia immer, Gavia pacifica, Gavia stellata, Haliaeetus albicilla, Haliaeetus leucocephalus, Haliaeetus leucogaster, Haliaeetus leucoryphus, Haliaeetus pelagicus, Haliaeetus vocifer, Haliaeetus vociferoides, Himantornis haematopus, Jabiru mycteria, Ketupa ketupu, Ketupa zeylonensis, Leptoptilos crumenifer, Leptoptilos javanicus, Mentocrex kioloides, Mycteria americana, Mycteria ibis, Mycteria leucocephala, Pandion haliaetus, Pelecanus conspicillatus, Pelecanus crispus, Pelecanus erythrorhynchos, Pelecanus occidentalis, Pelecanus onocrotalus, Pelecanus philippensis, Pelecanus rufescens, Pelecanus thagus, Phoeniconaias minor, Phoenicoparrus andinus, Phoenicoparrus jamesi, Phoenicopterus chilensis, Phoenicopterus roseus, Phoenicopterus ruber, Podiceps auritus, Podiceps cristatus, Podiceps grisegena, Podiceps major, Podiceps nigricollis, Podiceps occipitalis, Podilymbus podiceps, Poliocephalus poliocephalus, Poliocephalus rufopectus, Rallus madagascariensis, Rollandia rolland, Sarothrura affinis, Sarothrura boehmi, Sarothrura elegans, Sarothrura insularis, Sarothrura rufa, Scotopelia bouvieri, Scotopelia peli, Tachybaptus dominicus, Tachybaptus novaehollandiae, Tachybaptus ruficollis, Threskiornis aethiopicus, Threskiornis melanocephalus, Threskiornis spinicollis

Supplementary Table 2 Data sources. This table outlines the diverse range of data sources utilized in our analysis, providing a detailed description of each covariate and the origin of the data.

Covariate	Description	Data source
Waterbird records	Observation records of waterbirds	GBIF
Water proportion	The ratio of water volume compared to the total volume in a given area	Copernicus Global Land Service
BirdLife data zone	The geographic area occupied by a bird species throughout its life cycle	BirdLife International
Wallace's realms	The biogeographic region defined by 19th-century British naturalist Alfred Russel Wallace	Wallace, 1876
Positive presence of AIV cases	Reported Avian Influenza Virus (AIV) cases	FAO
National GDP	Gross Domestic Product of a nation	Natural earth data
National human population	The total count of individuals in a nation	Natural earth data
Urban boundaries	Vector data for 258 countries in the world	Natural earth data
Human density	Human population density (people/km ²)	GPWv4
Poultry density	Chicken and duck population density (poultry/km ²)	GLW 4
Cattle density	Cattle population density (head/km ²)	GLW 4
Confirmed host	Waterbird species confirmed to be carriers of Avian Influenza Virus (AIV)	Shu and McCauley, 2017
GPP (monthly)	Gross Primary Productivity measured monthly	Zhang <i>et al.</i> , 2017
Precipitation	Annual precipitation (mm)	WorldClim V2.1
Temperature	Annual temperatures (° C)	WorldClim V2.1
Frost Days	Days per year when the temperature falls below 0 °C, calculated from annual temperatures	WorldClim V2.1
NPP	Net Primary Productivity	MOD17A3
NDVI	Normalized Difference Vegetation Index	MOD13A2 V6.1
NDWI	Normalized Difference Water Index	MOD09A1 V6.1
LAI	Leaf Area Index	NOAA-CDR
Nighttime lights density	The intensity of artificial nighttime lights in an area	Earth Observation Group
Road density	The length of roads per unit area	FAO

Supplementary Table 3 Relationships between waterbird activity entropy (WAE) and human, cattle or poultry density among different functional groups of confirmed hosts and all suspected hosts in the EU, China and India. ‘n_{CH}’ represents the number of confirmed hosts, and ‘N’ represents the number of all suspected waterbirds. ‘*r*’ represents the Pearson correlation coefficient, and ‘*Moran’s I*’ represents the global Bivariate Moran's I statistic.

Region	Functional Group	n _{CH}	N	n _{CH} /N	~ Human density (Log)				~ Cattle density (Log)				~ Poultry density (Log)			
					Confirmed Host		All Suspected Host		Confirmed Host		All Suspected Host		Confirmed Host		All Suspected Host	
					<i>r</i>	Moran's I	<i>r</i>	Moran's I	<i>r</i>	Moran's I	<i>r</i>	Moran's I	<i>r</i>	Moran's I	<i>r</i>	Moran's I
					<i>r</i>	Moran's I	<i>r</i>	Moran's I	<i>r</i>	Moran's I	<i>r</i>	Moran's I	<i>r</i>	Moran's I	<i>r</i>	Moran's I
EU	Seabirds	28	61	45.90%	0.32	0.14	0.25	0.13	0.28	0.26	0.22	0.25	0.21	0.14	0.14	0.14
	Shorebirds	12	44	27.27%	0.11	0.09	0.14	-0.05	0.24	0.28	0.03	0.04	0.05	0.15	0.11	0.07
	Waterfowl	40	45	88.89%	0.25	0.03	0.21	0.01	0.16	0.17	0.11	0.14	0.27	0.13	0.22	0.11
	Large wading birds	4	21	19.05%	0.11	0.03	0.30	0.13	0.10	-0.07	0.15	0.06	0.04	-0.04	0.35	0.13
	Others	10	17	58.82%	0.26	0.11	0.16	0.09	0.11	0.10	0.00	0.05	0.31	0.17	0.18	0.13
China	Seabirds	28	78	35.90%	0.58	0.33	0.65	0.39	0.11	0.10	0.20	0.19	0.66	0.36	0.71	0.44
	Shorebirds	12	69	17.39%	0.30	0.28	0.62	0.38	0.10	-0.13	0.18	0.14	0.41	0.20	0.72	0.39
	Waterfowl	38	47	80.85%	0.58	0.38	0.58	0.38	0.24	0.16	0.24	0.17	0.65	0.40	0.66	0.40
	Large wading birds	4	33	12.12%	0.46	0.27	0.62	0.35	0.01	0.02	0.27	0.13	0.47	0.24	0.71	0.40
	Others	9	21	42.86%	0.12	0.11	0.42	0.09	0.09	0.10	0.04	0.05	0.23	0.17	0.54	0.13
India	Seabirds	24	59	40.68%	0.14	0.10	0.14	0.15	0.09	0.14	0.12	0.20	0.21	0.10	0.15	0.13
	Shorebirds	12	68	17.65%	0.01	0.10	0.49	0.25	0.15	0.00	0.44	0.32	0.11	0.23	0.19	0.15
	Waterfowl	22	28	78.57%	0.20	0.16	0.28	0.19	0.22	0.30	0.25	0.31	0.02	0.07	0.04	0.11
	Large wading birds	4	33	12.12%	0.23	0.13	0.35	0.18	0.25	0.22	0.32	0.26	0.04	-0.01	0.29	0.14
	Others	7	22	31.82%	0.04	-0.01	0.43	0.19	0.07	-0.01	0.40	0.27	0.23	-0.05	0.15	0.08

Supplementary Table 4 Pearson correlation analysis between waterbird activity entropy (WAE) and socio-demographic predictors. This table summarizes the relationships between WAE (for both confirmed and all suspected host groups) and log-transformed human, cattle, and poultry densities across five regions (USA, EU, China, India, and Africa). Statistical significance was assessed using two-sided Pearson’s product-moment correlation tests. Because these analyses represent distinct hypotheses across different geographic regions and functional groups, no global correction for multiple comparisons was applied; exact *P*-values are reported to allow independent interpretation of effect sizes. For each test, the table reports the sample size (*n*, representing independent $0.5^{\circ} \times 0.5^{\circ}$ grid cells), the mean and standard deviation (*SD*), the Pearson correlation coefficient (*r*), the 95% confidence interval (*CI*), and the *t*-statistic with degrees of freedom (*df*).

Regions	Group	Type	Predictor	Mean (WAE)	SD (WAE)	Mean (Predictor)	SD (Predictor)	<i>r</i>	95% <i>CI</i>	<i>t</i> (<i>df</i>)	<i>P</i>
USA	Seabirds	CH	Poultry (Log)	2.06	0.81	4.48	2.52	0.54	[0.51, 0.56]	29.93 (2224)	1.12E-165
USA	Shorebirds	CH	Poultry (Log)	1.26	0.53	4.52	2.54	0.46	[0.42, 0.49]	23.94 (2159)	1.45E-112
USA	Waterfowl	CH	Poultry (Log)	2.62	0.59	4.46	2.50	0.27	[0.23, 0.31]	13.41 (2269)	1.58E-39
USA	Large wading birds	CH	Poultry (Log)	1.57	0.35	4.63	2.67	0.41	[0.38, 0.45]	19.9 (1919)	2.85E-80
USA	Others	CH	Poultry (Log)	1.49	0.44	4.49	2.54	0.06	[0.02, 0.1]	2.67 (2197)	0.0076
USA	Seabirds	ASH	Poultry (Log)	2.32	0.91	4.46	2.48	0.53	[0.51, 0.56]	30.28 (2288)	1.08E-169
USA	Shorebirds	ASH	Poultry (Log)	2.61	0.62	4.47	2.51	0.35	[0.31, 0.38]	17.65 (2252)	2.06E-65
USA	Waterfowl	ASH	Poultry (Log)	2.70	0.59	4.45	2.50	0.27	[0.23, 0.31]	13.35 (2282)	3.32E-39
USA	Large wading birds	ASH	Poultry (Log)	2.20	0.47	4.63	2.67	0.56	[0.53, 0.59]	29.4 (1924)	3.00E-157
USA	Others	ASH	Poultry (Log)	1.57	0.42	4.49	2.54	0.00	[-0.04, 0.04]	0.03 (2198)	0.977
USA	Seabirds	CH	Human (Log)	2.10	0.80	1.28	2.88	0.62	[0.59, 0.64]	45.46 (3377)	0.00E+00
USA	Shorebirds	CH	Human (Log)	1.29	0.55	1.33	2.83	0.58	[0.56, 0.6]	41.22 (3354)	7.37E-301
USA	Waterfowl	CH	Human (Log)	2.72	0.46	1.22	2.93	0.52	[0.5, 0.55]	36 (3431)	5.39E-241
USA	Large wading birds	CH	Human (Log)	1.54	0.41	1.49	2.64	0.48	[0.46, 0.51]	31.61 (3271)	1.34E-191
USA	Others	CH	Human (Log)	1.57	0.36	1.25	2.89	0.23	[0.2, 0.26]	13.91 (3416)	7.70E-43
USA	Seabirds	ASH	Human (Log)	2.35	0.95	1.22	2.96	0.61	[0.58, 0.63]	44.45 (3409)	0.00E+00
USA	Shorebirds	ASH	Human (Log)	2.69	0.52	1.21	2.94	0.62	[0.6, 0.64]	45.98 (3440)	0.00E+00
USA	Waterfowl	ASH	Human (Log)	2.80	0.46	1.20	2.96	0.52	[0.49, 0.54]	35.42 (3439)	1.29E-234
USA	Large wading birds	ASH	Human (Log)	2.15	0.54	1.48	2.64	0.61	[0.59, 0.63]	43.79 (3282)	0.00E+00
USA	Others	ASH	Human (Log)	1.66	0.36	1.25	2.89	0.15	[0.11, 0.18]	8.6 (3416)	1.18E-17
USA	Seabirds	CH	Cattle (Log)	2.05	0.82	5.67	1.62	0.32	[0.28, 0.36]	16.95 (2510)	4.11E-61
USA	Shorebirds	CH	Cattle (Log)	1.27	0.53	5.76	1.56	0.37	[0.33, 0.4]	19.55 (2449)	3.15E-79
USA	Waterfowl	CH	Cattle (Log)	2.62	0.59	5.64	1.65	0.54	[0.51, 0.56]	32.24 (2565)	9.58E-192
USA	Large wading birds	CH	Cattle (Log)	1.58	0.36	6.13	1.17	0.30	[0.26, 0.34]	14.77 (2207)	3.93E-47
USA	Others	CH	Cattle (Log)	1.49	0.43	5.73	1.58	0.43	[0.39, 0.46]	23.49 (2489)	2.40E-110
USA	Seabirds	ASH	Cattle (Log)	2.30	0.92	5.60	1.67	0.25	[0.21, 0.29]	13.07 (2574)	7.57E-38
USA	Shorebirds	ASH	Cattle (Log)	2.62	0.60	5.67	1.62	0.58	[0.55, 0.6]	35.8 (2548)	1.07E-227
USA	Waterfowl	ASH	Cattle (Log)	2.70	0.58	5.63	1.65	0.50	[0.47, 0.53]	29.28 (2578)	5.60E-163
USA	Large wading birds	ASH	Cattle (Log)	2.20	0.48	6.12	1.17	0.27	[0.23, 0.31]	13.32 (2217)	5.16E-39
USA	Others	ASH	Cattle (Log)	1.57	0.42	5.73	1.58	0.33	[0.3, 0.37]	17.61 (2490)	1.54E-65
India	Seabirds	CH	Poultry (Log)	1.38	0.53	8.37	1.83	0.16	[0.09, 0.23]	4.3 (729)	1.97E-05

India	Shorebirds	CH	Poultry (Log)	0.42	0.50	8.41	1.82	0.05	[-0.03, 0.12]	1.24 (735)	0.2152
India	Waterfowl	CH	Poultry (Log)	1.54	0.51	8.40	1.82	0.02	[-0.05, 0.09]	0.57 (749)	0.5677
India	Large wading birds	CH	Poultry (Log)	1.08	0.34	8.47	1.76	0.03	[-0.05, 0.1]	0.68 (726)	0.4976
India	Others	CH	Poultry (Log)	0.66	0.35	8.40	1.80	-0.04	[-0.11, 0.04]	-0.98 (692)	0.3269
India	Seabirds	ASH	Poultry (Log)	2.00	0.53	8.39	1.83	0.15	[0.08, 0.22]	4.12 (751)	4.18E-05
India	Shorebirds	ASH	Poultry (Log)	2.96	0.42	8.39	1.83	0.19	[0.12, 0.26]	5.26 (751)	1.87E-07
India	Waterfowl	ASH	Poultry (Log)	1.86	0.42	8.40	1.82	0.10	[0.03, 0.17]	2.85 (749)	0.0045
India	Large wading birds	ASH	Poultry (Log)	2.43	0.38	8.40	1.82	0.28	[0.22, 0.35]	8.09 (749)	2.41E-15
India	Others	ASH	Poultry (Log)	2.11	0.35	8.41	1.81	0.16	[0.09, 0.23]	4.47 (747)	9.08E-06
India	Seabirds	CH	Human (Log)	1.39	0.57	5.48	1.28	0.30	[0.25, 0.36]	10.36 (1071)	4.94E-24
India	Shorebirds	CH	Human (Log)	0.49	0.56	5.64	1.01	0.10	[0.04, 0.16]	3.23 (1046)	0.0013
India	Waterfowl	CH	Human (Log)	1.54	0.51	5.48	1.26	0.36	[0.31, 0.41]	12.84 (1105)	2.71E-35
India	Large wading birds	CH	Human (Log)	1.09	0.34	5.64	1.02	0.29	[0.24, 0.35]	9.83 (1038)	7.41E-22
India	Others	CH	Human (Log)	0.67	0.36	5.65	0.98	0.17	[0.11, 0.23]	5.55 (993)	3.62E-08
India	Seabirds	ASH	Human (Log)	2.01	0.58	5.47	1.27	0.31	[0.25, 0.36]	10.67 (1109)	2.18E-25
India	Shorebirds	ASH	Human (Log)	2.87	0.66	5.47	1.27	0.69	[0.66, 0.72]	32.07 (1111)	2.94E-160
India	Waterfowl	ASH	Human (Log)	1.84	0.47	5.48	1.26	0.50	[0.45, 0.54]	19.06 (1106)	2.80E-70
India	Large wading birds	ASH	Human (Log)	2.41	0.49	5.57	1.11	0.52	[0.48, 0.57]	20.26 (1084)	1.15E-77
India	Others	ASH	Human (Log)	2.08	0.42	5.62	1.02	0.51	[0.47, 0.56]	19.51 (1067)	1.01E-72
India	Seabirds	CH	Cattle (Log)	1.39	0.53	8.20	0.85	0.10	[0.03, 0.17]	2.72 (733)	0.0066
India	Shorebirds	CH	Cattle (Log)	0.43	0.51	8.21	0.81	-0.09	[-0.16, -0.02]	-2.4 (739)	0.0166
India	Waterfowl	CH	Cattle (Log)	1.54	0.51	8.19	0.85	0.25	[0.18, 0.31]	6.97 (753)	6.96E-12
India	Large wading birds	CH	Cattle (Log)	1.08	0.34	8.22	0.82	0.24	[0.17, 0.31]	6.62 (730)	6.97E-11
India	Others	CH	Cattle (Log)	0.66	0.35	8.23	0.78	0.09	[0.01, 0.16]	2.3 (696)	0.0215
India	Seabirds	ASH	Cattle (Log)	2.00	0.53	8.19	0.85	0.12	[0.04, 0.19]	3.19 (755)	0.0015
India	Shorebirds	ASH	Cattle (Log)	2.96	0.42	8.19	0.85	0.44	[0.38, 0.49]	13.36 (755)	1.01E-36
India	Waterfowl	ASH	Cattle (Log)	1.86	0.42	8.19	0.85	0.27	[0.21, 0.34]	7.84 (753)	1.57E-14
India	Large wading birds	ASH	Cattle (Log)	2.44	0.38	8.20	0.83	0.36	[0.3, 0.42]	10.57 (753)	1.92E-24
India	Others	ASH	Cattle (Log)	2.11	0.35	8.20	0.82	0.40	[0.34, 0.46]	12.09 (751)	7.12E-31
EU	Seabirds	CH	Poultry (Log)	2.90	0.36	8.21	1.85	0.21	[0.16, 0.27]	7.33 (1151)	4.37E-13
EU	Shorebirds	CH	Poultry (Log)	1.65	0.25	8.21	1.85	0.01	[-0.05, 0.07]	0.29 (1151)	0.7682
EU	Waterfowl	CH	Poultry (Log)	2.40	0.43	8.21	1.85	0.28	[0.23, 0.33]	9.87 (1152)	4.23E-22
EU	Large wading birds	CH	Poultry (Log)	0.83	0.34	8.43	1.67	0.27	[0.22, 0.33]	9.27 (1076)	9.60E-20
EU	Others	CH	Poultry (Log)	1.38	0.35	8.21	1.85	0.33	[0.28, 0.38]	11.8 (1151)	2.05E-30
EU	Seabirds	ASH	Poultry (Log)	3.43	0.40	8.21	1.85	0.17	[0.12, 0.23]	5.94 (1152)	3.68E-09
EU	Shorebirds	ASH	Poultry (Log)	2.50	0.30	8.21	1.85	-0.07	[-0.13, -0.01]	-2.32 (1152)	0.0203
EU	Waterfowl	ASH	Poultry (Log)	2.52	0.42	8.21	1.85	0.23	[0.18, 0.29]	8.2 (1152)	6.30E-16
EU	Large wading birds	ASH	Poultry (Log)	2.21	0.59	8.21	1.85	0.53	[0.49, 0.57]	21.45 (1152)	3.64E-86
EU	Others	ASH	Poultry (Log)	1.62	0.30	8.21	1.85	0.21	[0.15, 0.26]	7.14 (1151)	1.66E-12
EU	Seabirds	CH	Human (Log)	2.88	0.38	3.53	1.80	0.41	[0.37, 0.44]	20.97 (2168)	5.08E-89
EU	Shorebirds	CH	Human (Log)	1.66	0.27	3.53	1.80	0.13	[0.09, 0.17]	6.12 (2168)	1.09E-09
EU	Waterfowl	CH	Human (Log)	2.45	0.45	3.53	1.80	0.04	[0, 0.08]	1.92 (2171)	0.0548
EU	Large wading birds	CH	Human (Log)	0.73	0.41	4.19	1.10	0.34	[0.3, 0.38]	15.1 (1762)	1.44E-48
EU	Others	CH	Human (Log)	1.31	0.44	3.53	1.80	0.40	[0.51, 0.57]	30.25 (2168)	5.44E-168

EU	Seabirds	ASH	Human (Log)	3.43	0.43	3.53	1.80	0.36	[0.33, 0.4]	18.23 (2171)	3.18E-69
EU	Shorebirds	ASH	Human (Log)	2.57	0.35	3.53	1.80	-0.18	[-0.22, -0.14]	-8.56 (2170)	2.06E-17
EU	Waterfowl	ASH	Human (Log)	2.58	0.45	3.53	1.80	-0.01	[-0.06, 0.03]	-0.66 (2172)	0.5122
EU	Large wading birds	ASH	Human (Log)	1.94	0.83	3.57	1.76	0.79	[0.78, 0.81]	60.2 (2148)	0.00E+00
EU	Others	ASH	Human (Log)	1.62	0.35	3.53	1.80	0.33	[0.29, 0.36]	16.03 (2170)	9.19E-55
EU	Seabirds	CH	Cattle (Log)	2.92	0.31	6.29	1.55	0.30	[0.25, 0.35]	10.64 (1145)	2.93E-25
EU	Shorebirds	CH	Cattle (Log)	1.67	0.22	6.29	1.55	0.19	[0.13, 0.24]	6.47 (1145)	1.45E-10
EU	Waterfowl	CH	Cattle (Log)	2.43	0.42	6.29	1.55	0.10	[0.04, 0.16]	3.44 (1146)	0.0006
EU	Large wading birds	CH	Cattle (Log)	0.83	0.34	6.68	0.98	0.02	[-0.04, 0.08]	0.72 (1026)	0.4706
EU	Others	CH	Cattle (Log)	1.37	0.36	6.29	1.55	0.27	[0.21, 0.32]	9.44 (1145)	2.07E-20
EU	Seabirds	ASH	Cattle (Log)	3.45	0.36	6.29	1.55	0.25	[0.2, 0.3]	8.76 (1146)	6.89E-18
EU	Shorebirds	ASH	Cattle (Log)	2.53	0.28	6.29	1.55	-0.10	[-0.16, -0.05]	-3.57 (1146)	0.0004
EU	Waterfowl	ASH	Cattle (Log)	2.55	0.41	6.29	1.55	0.05	[-0.01, 0.11]	1.7 (1146)	0.0889
EU	Large wading birds	ASH	Cattle (Log)	2.13	0.70	6.29	1.55	0.70	[0.67, 0.73]	33.57 (1146)	1.30E-172
EU	Others	ASH	Cattle (Log)	1.62	0.29	6.29	1.55	0.08	[0.02, 0.13]	2.59 (1145)	0.0097
China	Seabirds	CH	Poultry (Log)	1.29	1.12	7.90	3.18	0.71	[0.68, 0.73]	47.56 (2280)	0.00E+00
China	Shorebirds	CH	Poultry (Log)	0.80	0.69	9.38	2.27	0.51	[0.47, 0.54]	23.8 (1636)	9.56E-108
China	Waterfowl	CH	Poultry (Log)	1.29	0.88	7.57	3.13	0.74	[0.72, 0.76]	58.24 (2786)	0.00E+00
China	Large wading birds	CH	Poultry (Log)	0.70	0.49	9.48	2.17	0.70	[0.67, 0.72]	39.32 (1630)	2.03E-238
China	Others	CH	Poultry (Log)	0.79	0.51	9.68	2.00	0.39	[0.34, 0.43]	16.02 (1472)	2.17E-53
China	Seabirds	ASH	Poultry (Log)	1.74	1.18	7.82	3.12	0.69	[0.67, 0.71]	46.86 (2464)	0.00E+00
China	Shorebirds	ASH	Poultry (Log)	1.31	1.02	7.72	3.18	0.71	[0.69, 0.73]	50.28 (2538)	0.00E+00
China	Waterfowl	ASH	Poultry (Log)	1.35	0.90	7.57	3.13	0.73	[0.71, 0.74]	55.75 (2791)	0.00E+00
China	Large wading birds	ASH	Poultry (Log)	1.41	1.02	8.17	2.91	0.79	[0.78, 0.81]	63.13 (2381)	0.00E+00
China	Others	ASH	Poultry (Log)	1.05	0.63	9.23	2.28	0.60	[0.57, 0.63]	31.48 (1730)	2.41E-172
China	Seabirds	CH	Human (Log)	1.43	1.14	3.47	2.54	0.66	[0.64, 0.68]	46.36 (2770)	0.00E+00
China	Shorebirds	CH	Human (Log)	0.87	0.71	4.38	2.00	0.49	[0.45, 0.52]	25.29 (2068)	3.64E-123
China	Waterfowl	CH	Human (Log)	1.36	0.92	3.08	2.64	0.71	[0.69, 0.73]	58.38 (3336)	0.00E+00
China	Large wading birds	CH	Human (Log)	0.74	0.49	4.62	1.70	0.64	[0.62, 0.67]	37.61 (2013)	6.13E-235
China	Others	CH	Human (Log)	0.85	0.52	4.73	1.62	0.33	[0.29, 0.37]	15.23 (1841)	1.93E-49
China	Seabirds	ASH	Human (Log)	1.87	1.23	3.36	2.55	0.67	[0.65, 0.69]	49.64 (2965)	0.00E+00
China	Shorebirds	ASH	Human (Log)	1.39	1.06	3.28	2.56	0.67	[0.65, 0.69]	50.37 (3071)	0.00E+00
China	Waterfowl	ASH	Human (Log)	1.43	0.93	3.08	2.63	0.70	[0.68, 0.72]	56.79 (3343)	0.00E+00
China	Large wading birds	ASH	Human (Log)	1.43	1.05	3.41	2.53	0.78	[0.77, 0.79]	67.97 (2982)	0.00E+00
China	Others	ASH	Human (Log)	1.08	0.65	4.27	2.04	0.60	[0.57, 0.62]	34.92 (2188)	9.00E-213
China	Seabirds	CH	Cattle (Log)	1.30	1.12	5.42	1.43	0.27	[0.23, 0.31]	13.47 (2293)	6.94E-40
China	Shorebirds	CH	Cattle (Log)	0.81	0.69	5.60	1.45	0.07	[0.02, 0.11]	2.66 (1646)	0.0079
China	Waterfowl	CH	Cattle (Log)	1.29	0.89	5.16	1.60	0.30	[0.27, 0.34]	16.82 (2799)	1.41E-60
China	Large wading birds	CH	Cattle (Log)	0.70	0.49	5.72	1.38	0.31	[0.26, 0.35]	13.09 (1638)	2.49E-37
China	Others	CH	Cattle (Log)	0.79	0.51	5.81	1.36	-0.04	[-0.09, 0.01]	-1.46 (1480)	0.1454
China	Seabirds	ASH	Cattle (Log)	1.74	1.18	5.35	1.45	0.33	[0.3, 0.37]	17.46 (2477)	1.68E-64
China	Shorebirds	ASH	Cattle (Log)	1.31	1.02	5.30	1.53	0.28	[0.24, 0.31]	14.46 (2551)	1.31E-45
China	Waterfowl	ASH	Cattle (Log)	1.35	0.90	5.16	1.60	0.31	[0.27, 0.34]	17.17 (2804)	6.61E-63
China	Large wading birds	ASH	Cattle (Log)	1.41	1.02	5.26	1.64	0.43	[0.4, 0.46]	23.46 (2393)	9.64E-110

China	Others	ASH	Cattle (Log)	1.05	0.63	5.59	1.50	0.25	[0.2, 0.29]	10.55 (1738)	2.84E-25
Africa	Seabirds	CH	Poultry (Log)	0.66	0.73	7.30	1.83	0.28	[0.25, 0.31]	16.89 (3455)	1.41E-61
Africa	Shorebirds	CH	Poultry (Log)	0.21	0.52	7.70	1.69	0.25	[0.21, 0.28]	12.43 (2369)	2.18E-34
Africa	Waterfowl	CH	Poultry (Log)	0.60	0.53	7.32	1.79	0.25	[0.22, 0.28]	15.76 (3605)	3.64E-54
Africa	Large wading birds	CH	Poultry (Log)	0.64	0.49	7.43	1.79	0.21	[0.18, 0.25]	11.33 (2660)	4.21E-29
Africa	Others	CH	Poultry (Log)	0.42	0.50	7.54	1.75	0.18	[0.14, 0.22]	8.89 (2401)	1.20E-18
Africa	Seabirds	ASH	Poultry (Log)	1.45	0.82	7.11	1.74	0.31	[0.29, 0.34]	23.34 (4979)	2.09E-114
Africa	Shorebirds	ASH	Poultry (Log)	2.59	0.60	7.08	1.75	0.15	[0.12, 0.17]	10.53 (5108)	1.17E-25
Africa	Waterfowl	ASH	Poultry (Log)	1.23	0.66	7.17	1.80	0.14	[0.11, 0.17]	9.23 (4333)	4.11E-20
Africa	Large wading birds	ASH	Poultry (Log)	2.47	0.53	7.08	1.75	0.06	[0.04, 0.09]	4.5 (5086)	6.91E-06
Africa	Others	ASH	Poultry (Log)	1.55	0.69	7.08	1.75	0.12	[0.09, 0.15]	8.57 (5014)	1.32E-17
Africa	Seabirds	CH	Human (Log)	0.72	0.77	2.56	2.09	0.32	[0.29, 0.34]	25.16 (5626)	1.68E-132
Africa	Shorebirds	CH	Human (Log)	0.28	0.57	2.94	1.99	0.18	[0.15, 0.21]	11.38 (3863)	1.56E-29
Africa	Waterfowl	CH	Human (Log)	0.64	0.55	2.74	1.96	0.19	[0.16, 0.21]	14.47 (5632)	1.33E-46
Africa	Large wading birds	CH	Human (Log)	0.68	0.49	3.06	1.73	0.25	[0.22, 0.28]	16.61 (4176)	4.67E-60
Africa	Others	CH	Human (Log)	0.43	0.49	2.85	2.01	0.19	[0.16, 0.22]	12.16 (3909)	1.96E-33
Africa	Seabirds	ASH	Human (Log)	1.31	0.88	1.71	2.40	0.48	[0.47, 0.5]	54.09 (9652)	0.00E+00
Africa	Shorebirds	ASH	Human (Log)	2.32	0.92	1.92	2.34	0.57	[0.55, 0.58]	65.75 (9159)	0.00E+00
Africa	Waterfowl	ASH	Human (Log)	1.23	0.69	2.56	2.02	0.20	[0.18, 0.22]	16.82 (6765)	3.15E-62
Africa	Large wading birds	ASH	Human (Log)	2.40	0.60	2.01	2.32	0.35	[0.33, 0.37]	35.38 (8793)	1.62E-256
Africa	Others	ASH	Human (Log)	1.39	0.82	2.10	2.25	0.49	[0.47, 0.51]	51.7 (8488)	0.00E+00
Africa	Seabirds	CH	Cattle (Log)	0.66	0.74	5.80	2.04	0.11	[0.07, 0.14]	6.24 (3266)	5.02E-10
Africa	Shorebirds	CH	Cattle (Log)	0.21	0.52	6.30	1.77	0.00	[-0.05, 0.04]	-0.22 (2255)	0.8231
Africa	Waterfowl	CH	Cattle (Log)	0.63	0.53	5.74	2.14	0.19	[0.16, 0.22]	11.21 (3395)	1.14E-28
Africa	Large wading birds	CH	Cattle (Log)	0.66	0.50	5.84	2.22	0.30	[0.26, 0.33]	15.4 (2455)	3.91E-51
Africa	Others	CH	Cattle (Log)	0.42	0.51	6.11	1.96	0.12	[0.08, 0.16]	5.99 (2305)	2.39E-09
Africa	Seabirds	ASH	Cattle (Log)	1.45	0.81	5.87	2.07	0.14	[0.11, 0.17]	9.57 (4719)	1.73E-21
Africa	Shorebirds	ASH	Cattle (Log)	2.59	0.61	5.82	2.12	0.14	[0.12, 0.17]	10.02 (4807)	2.01E-23
Africa	Waterfowl	ASH	Cattle (Log)	1.26	0.66	5.73	2.18	0.13	[0.1, 0.16]	8.33 (4077)	1.05E-16
Africa	Large wading birds	ASH	Cattle (Log)	2.46	0.54	5.84	2.11	0.03	[0, 0.06]	1.94 (4785)	0.0519
Africa	Others	ASH	Cattle (Log)	1.55	0.70	5.86	2.10	-0.05	[-0.08, -0.02]	-3.53 (4715)	0.0004

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