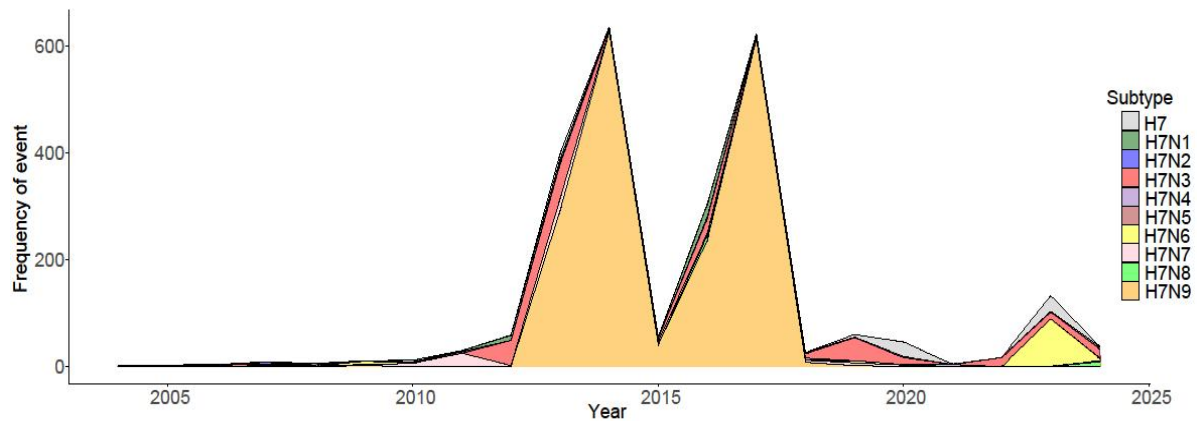
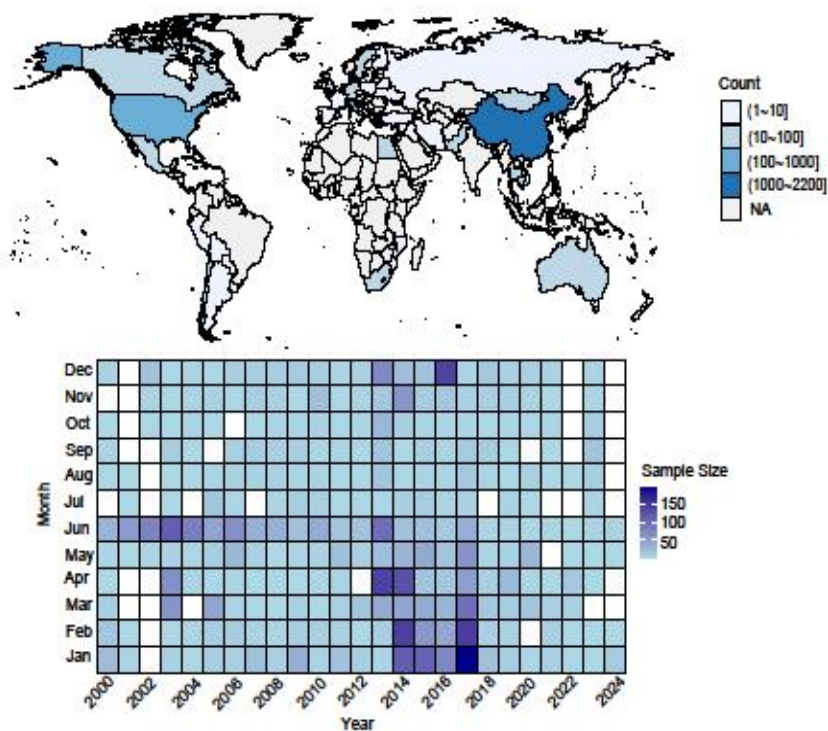


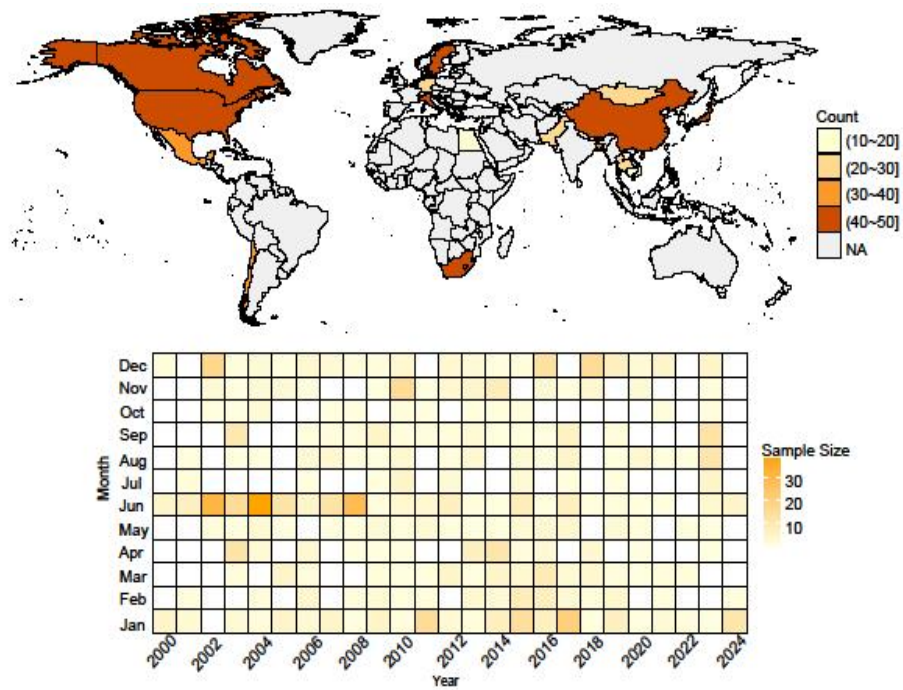
## Disentangling the Drivers and Host-Mediated Global Spread of H7 Influenza A Virus



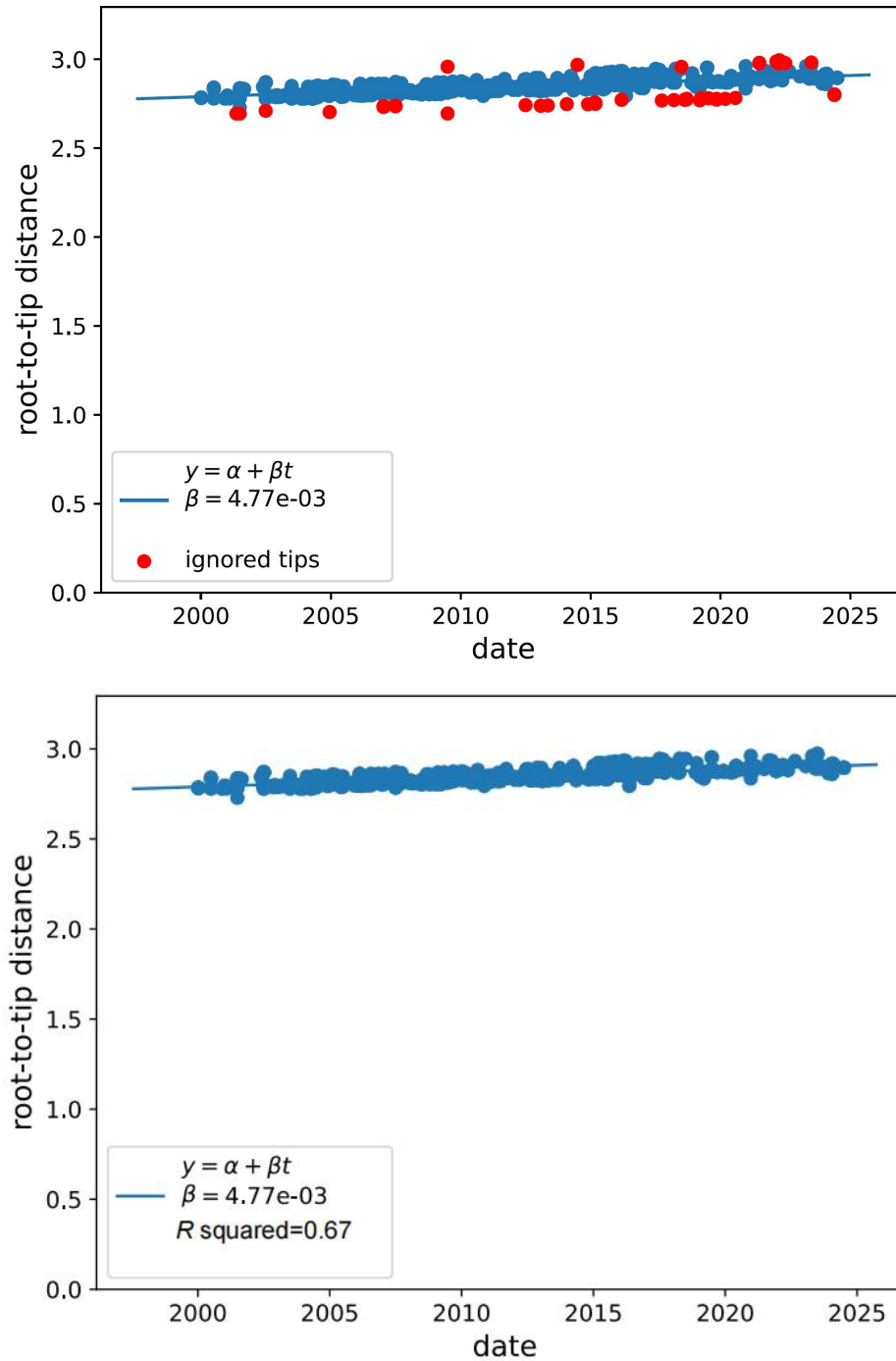
Supplementary Fig. 1. Temporal changes in H7Nx subtype prevalence estimated using observation dates of all reported cases submitted to the FAO from January 2000 to November 2024.



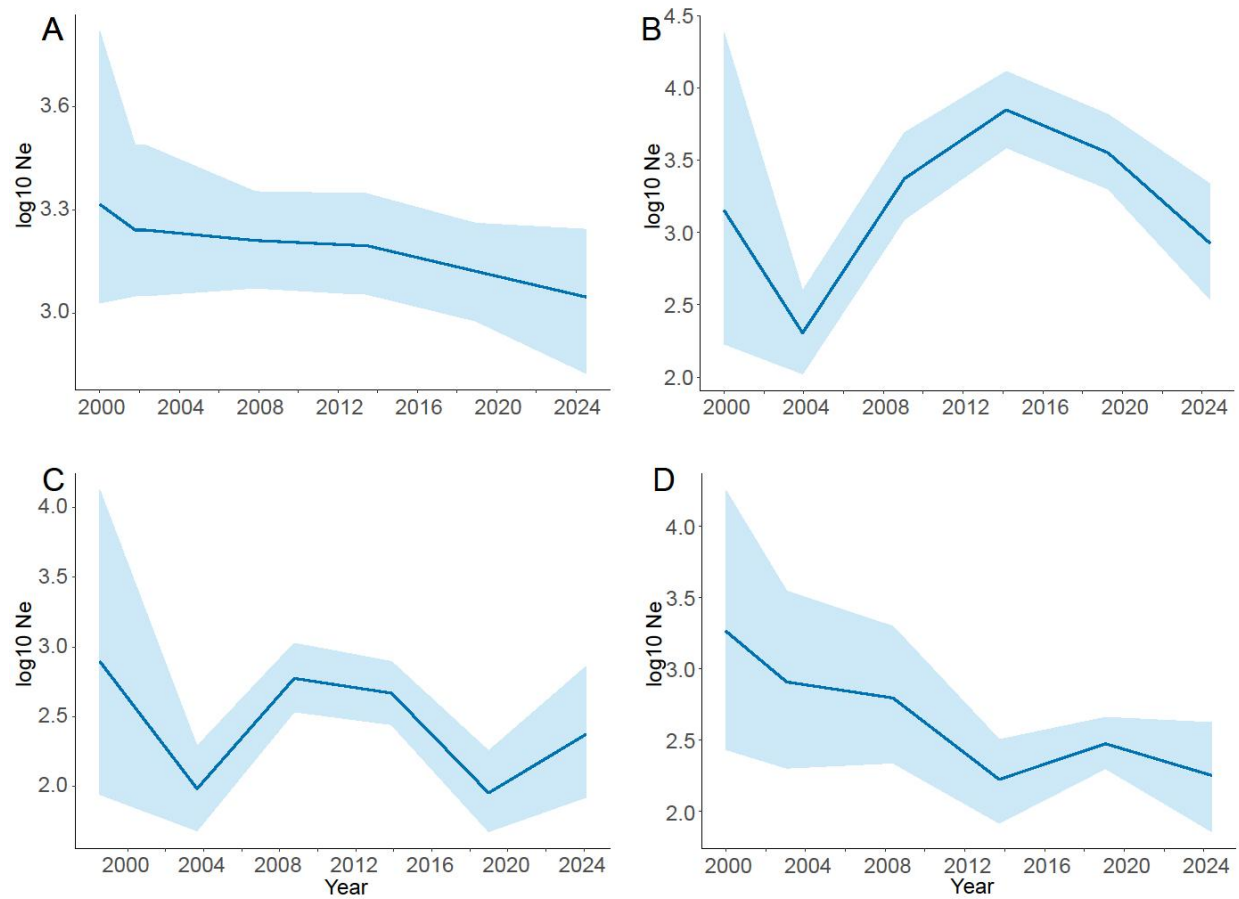
Supplementary Fig. 2. Distribution of sequences submitted to the GISAID and NCBI Influenza Virus Resource databases by region (top) and by month (bottom). Maps were generated using the R package `rnaturalearth` with data from Natural Earth (public domain, <https://www.naturalearthdata.com>).



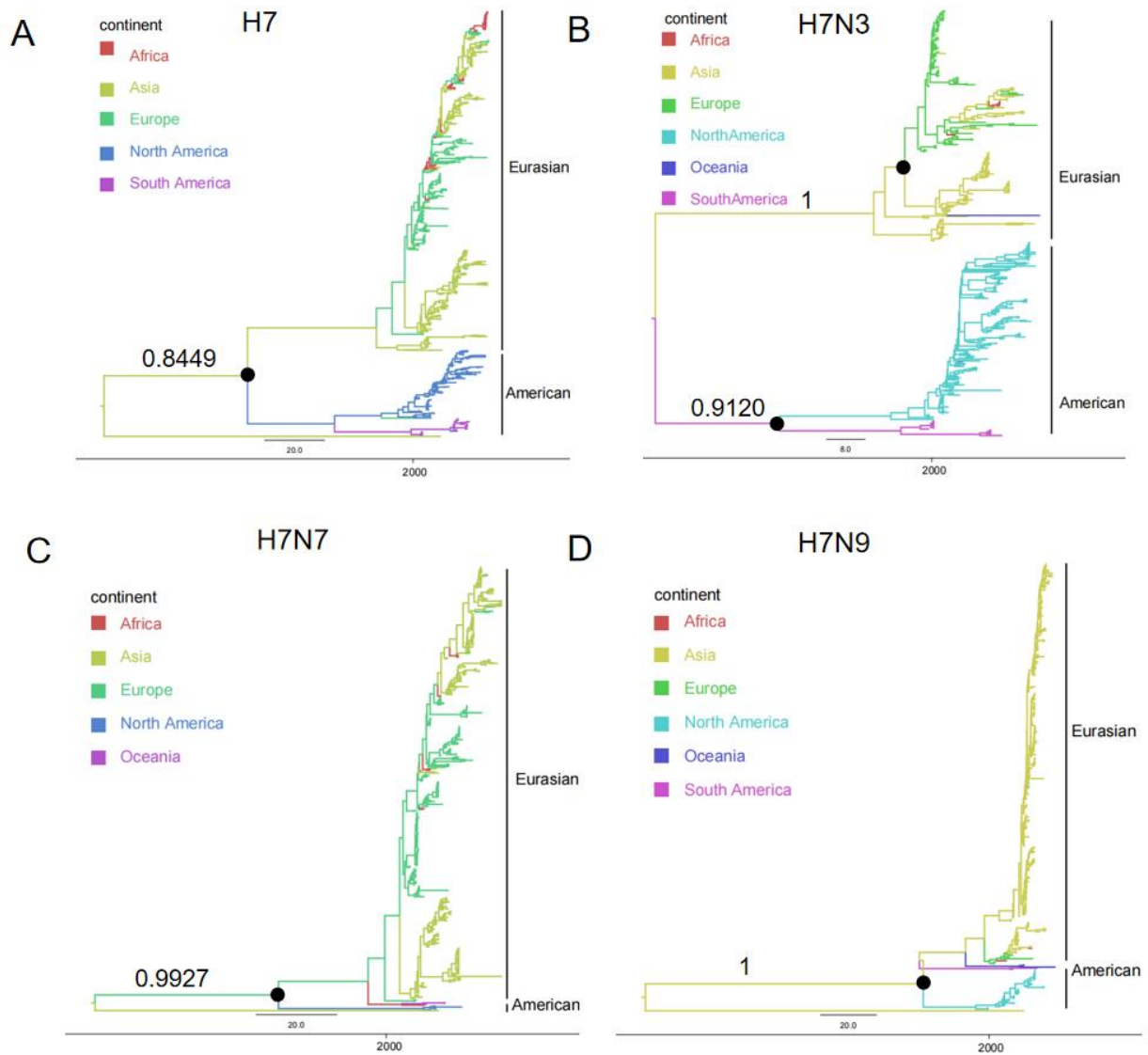
Supplementary Fig. 3. Distribution of sampled sequences submitted to the GISAID and NCBI Influenza Virus Resource databases by region (top) and by month (bottom). Maps were generated using the R package `rnaturalearth` with data from Natural Earth (public domain, <https://www.naturalearthdata.com>).



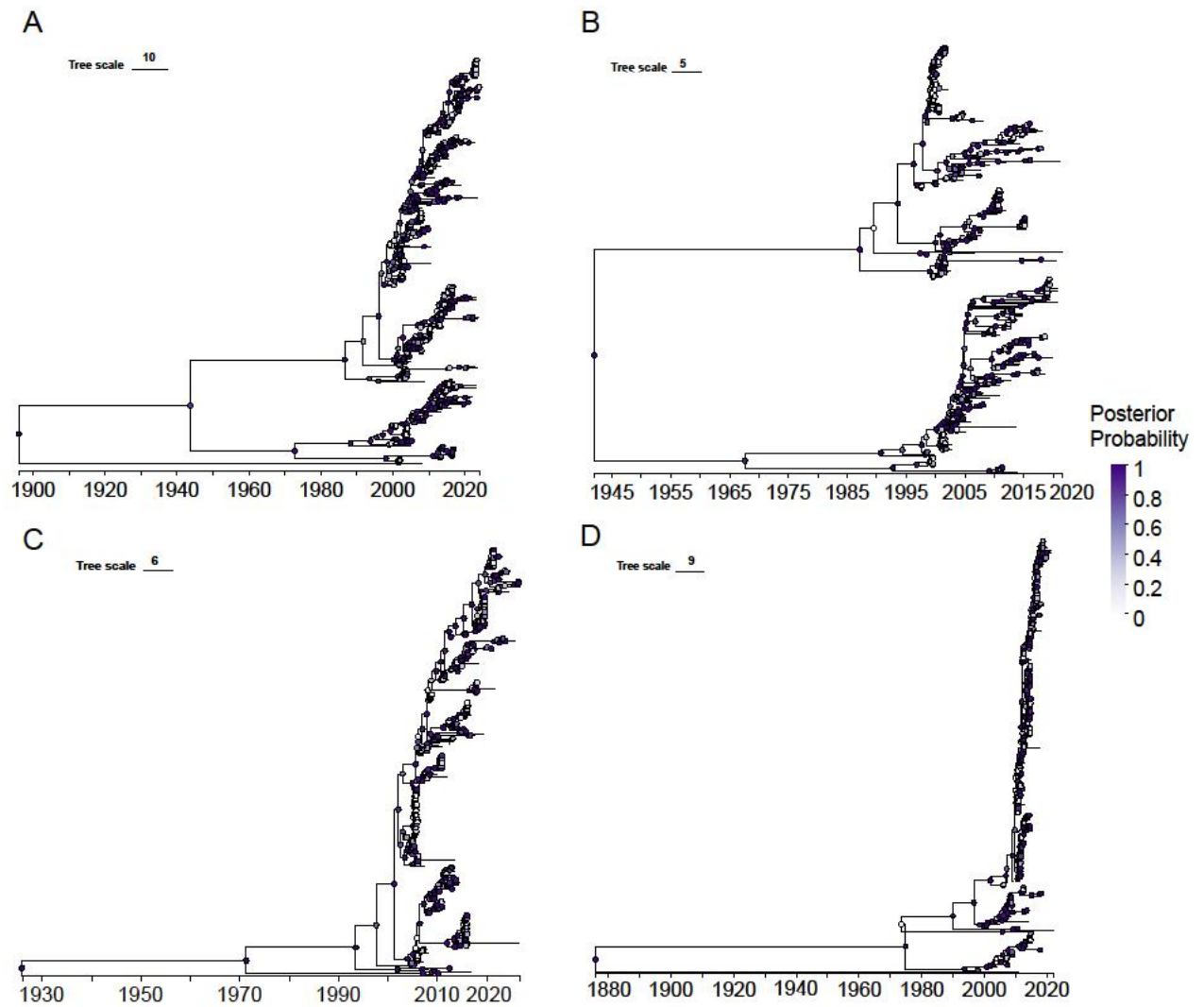
Supplementary Fig. 4. Strong temporal signal tested in Treetime of HA genes of H7 ( $R\text{ squared}=0.67$ ). The initial result of Treetime (Top). The red dots represent that this sequence does not have a time structure, and there are a total of 58 sequences that need to be excluded (Bottom).



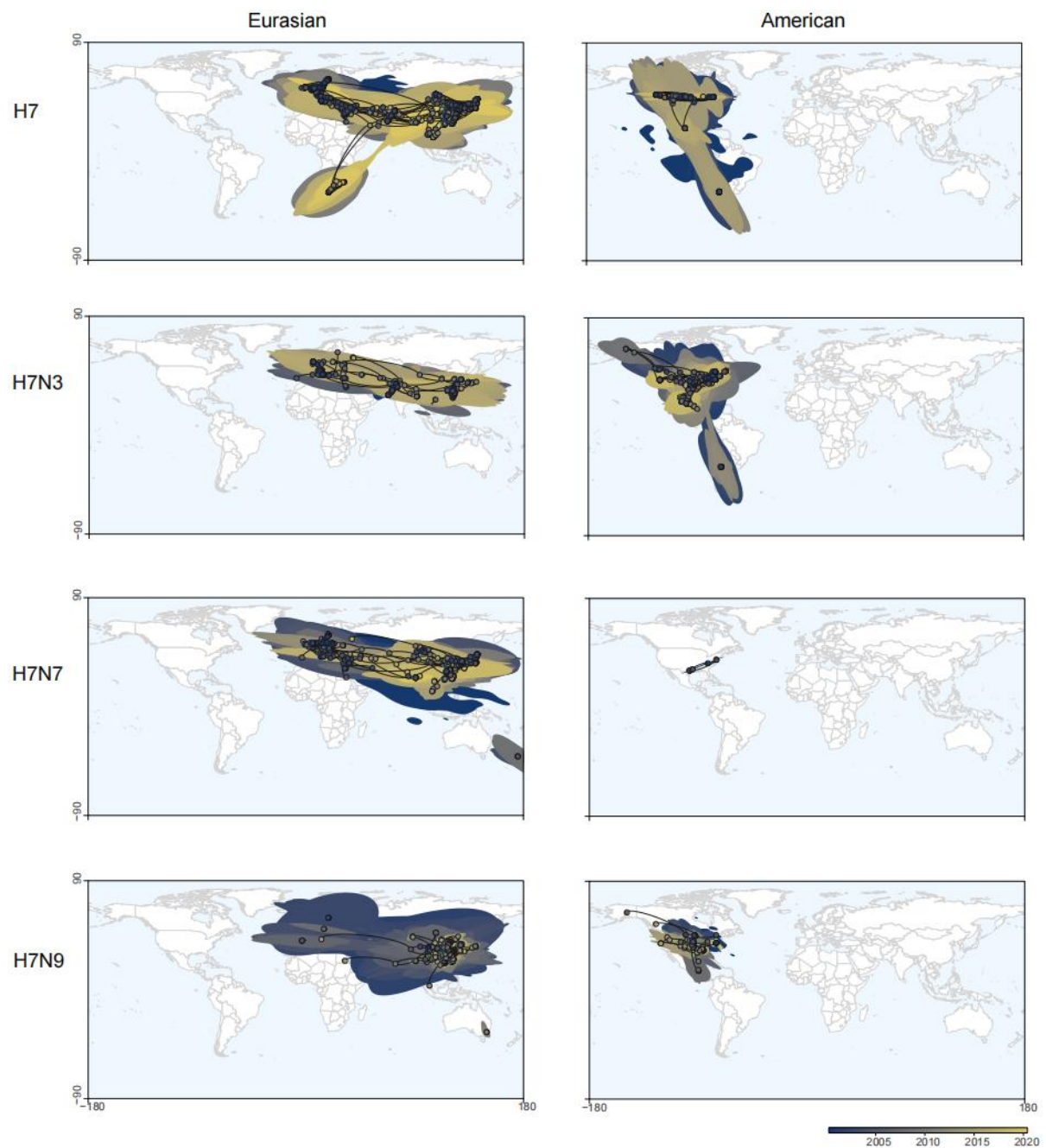
Supplementary Fig. 5. The solid (blue) line represents the posterior median of the population size over time, while the upper and lower lines indicate the 95% highest posterior density (HPD) interval. H7 (A), H7N3 (B), H7N7 (C), and H7N9 (D).



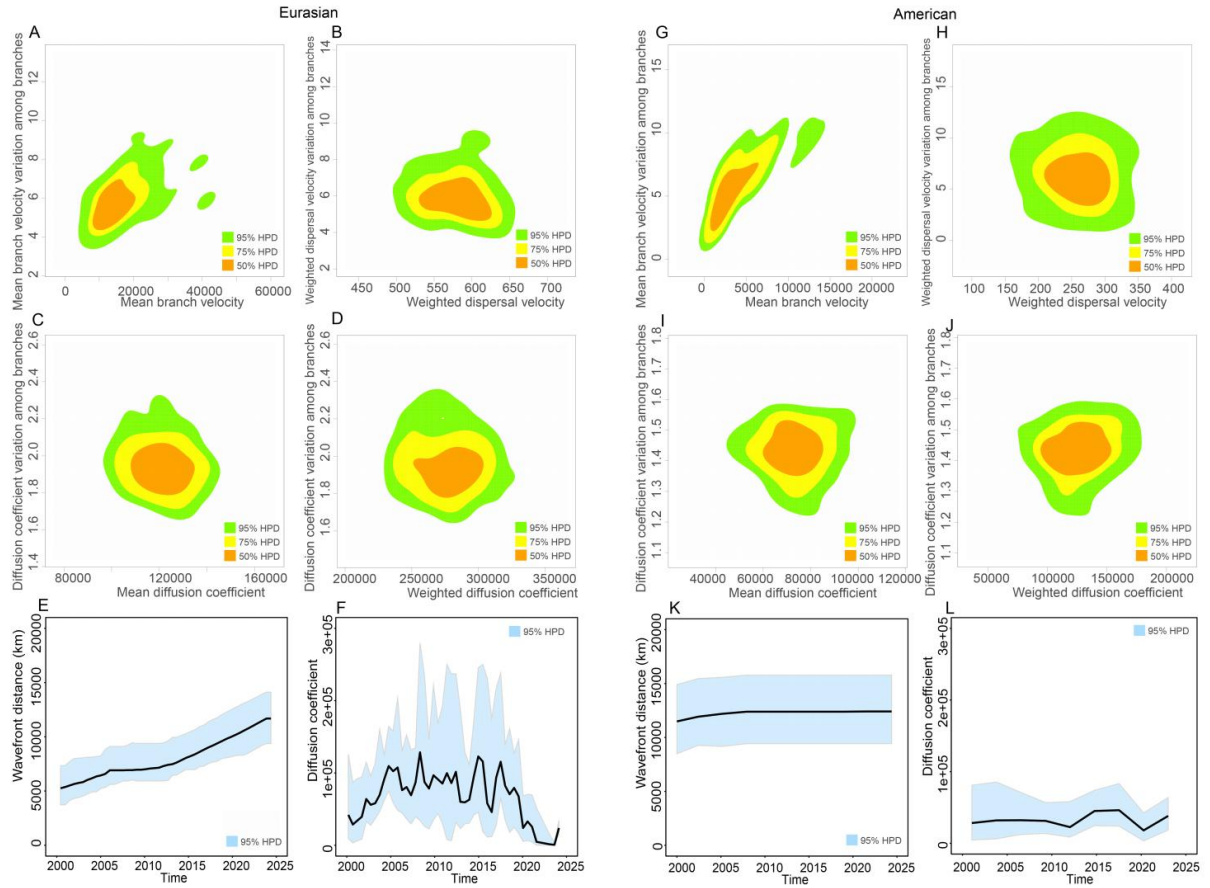
Supplementary Fig. 6. Time-scaled maximum clade credibility (MCC) trees of H7 HA genes sequences plotted by FigTree software, with branch colors representing geographic information. The number on the branch represents the posterior probability. H7 (A), H7N3 (B), H7N7 (C), and H7N9 (D).



Supplementary Fig. 7. Time-scaled maximum clade credibility (MCC) trees derived using Bayesian phylogenetic analysis, where the support rate of nodes is represented by posterior probability. Nodes with a posterior probability greater than 0.95 are considered highly reliable, while nodes below 0.75 have weaker support. H7 (A), H7N3 (B), H7N7 (C), and H7N9 (D).

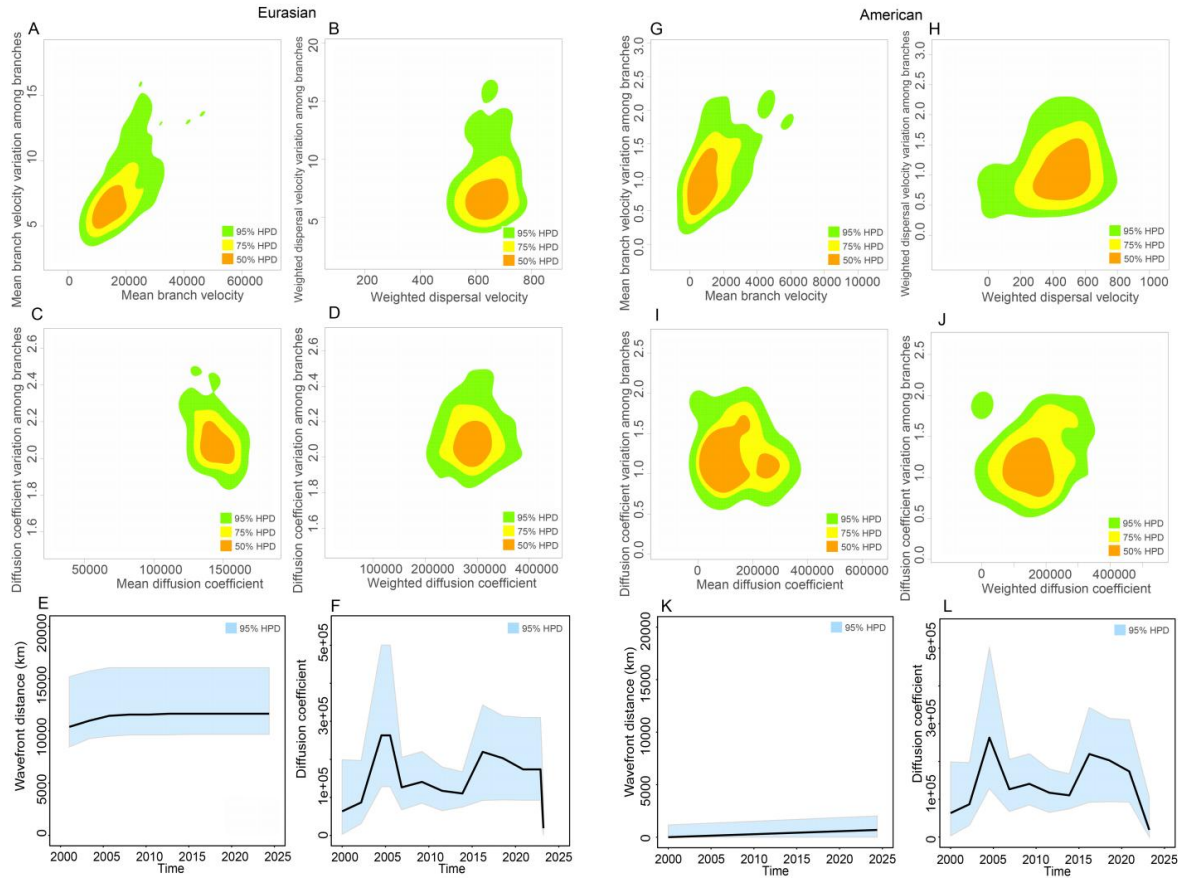


Supplementary Fig. 8. Continuous phylogeographic reconstruction of the spread of H7 and subtypes, with an interval of 80% HPD is depicted by shaded areas, illustrating the uncertainty of the phylogeographic estimates. The column on the left represent the Eurasian lineage, while the column on the right represent the American lineage. Maps were generated using the R package *rnaturalearth* with data from Natural Earth (public domain, <https://www.naturalearthdata.com>).



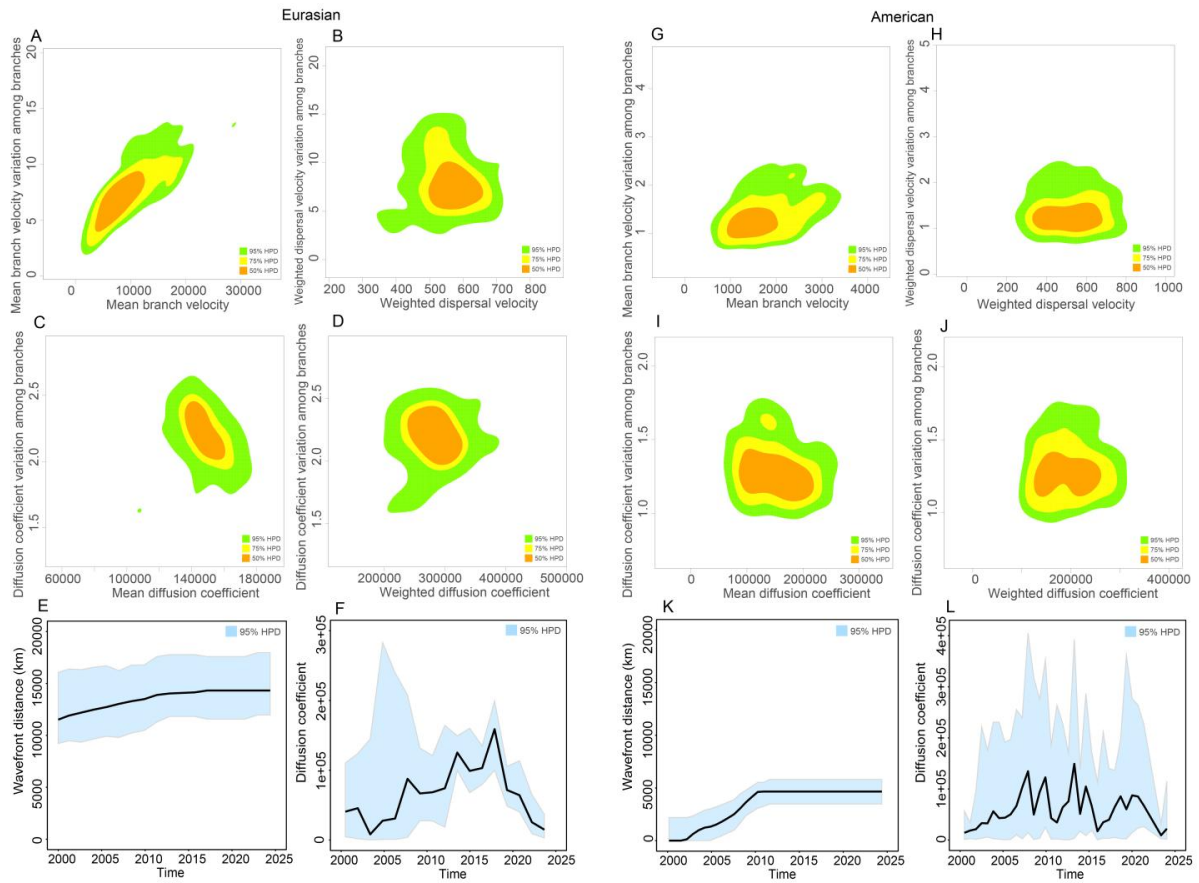
Supplementary Fig. 9. Estimated dispersal statistics for H7N3.

The two columns on the left represent the Eurasian lineage, while the two columns on the right represent the American lineage. A and G, kernel density estimates of mean branch dispersal velocity parameters. B and H, kernel density estimates of weighted branch dispersal velocity parameters. C and I, kernel density estimates of original diffusion coefficient parameters. D and J, kernel density estimates of weighted diffusion coefficient parameters. E and K, furthest extent of epidemic wavefront (spatial distance from epidemic origin). F and L, Evolution of weighted diffusion coefficient. For panels E, F, K, and L, solid lines represent the posterior median values of wavefront distance and diffusion coefficient, and shaded areas denote the 95% HPD intervals.



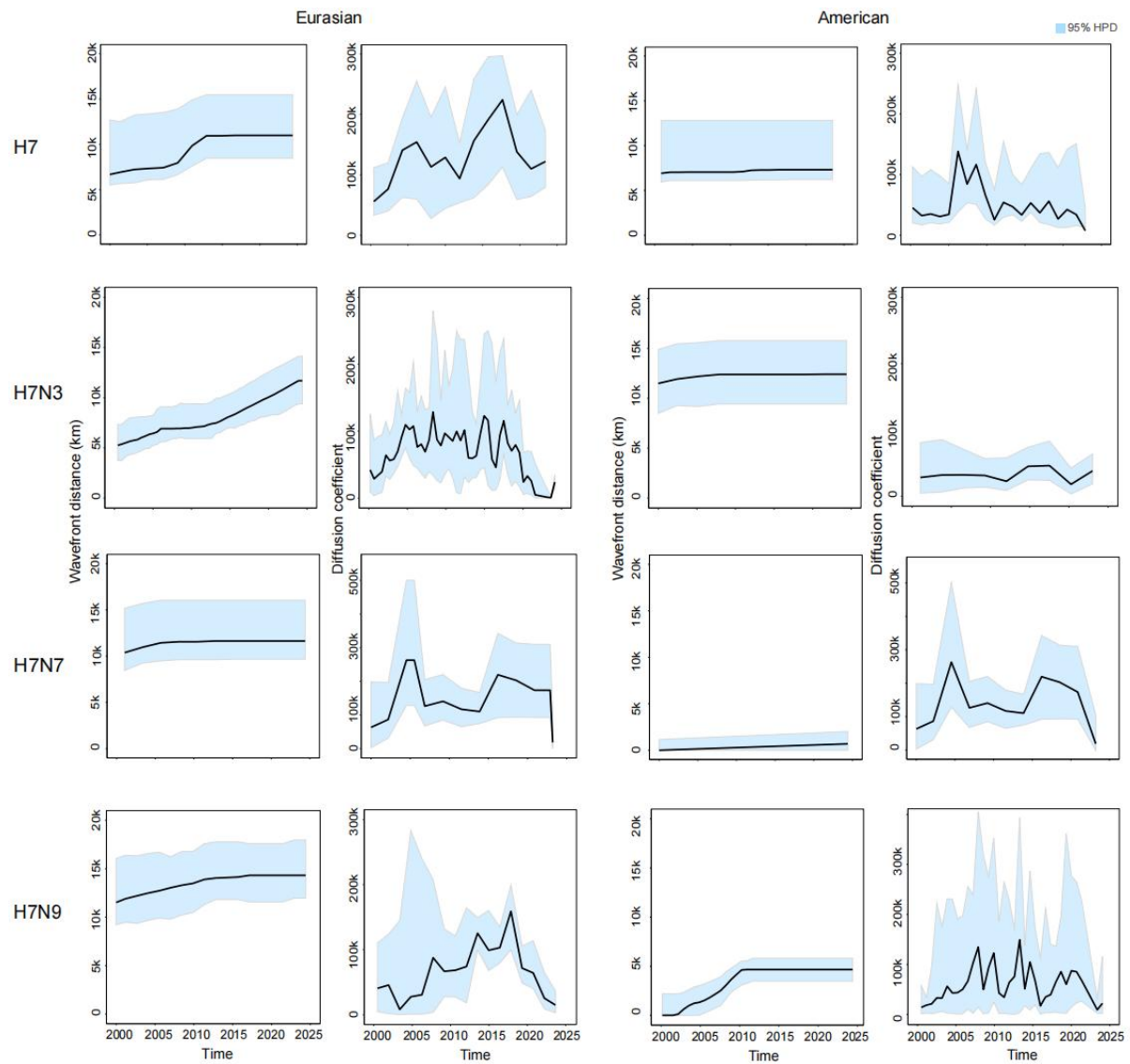
Supplementary Fig. 10. Estimated dispersal statistics for H7N7.

The two columns on the left represent the Eurasian lineage, while the two columns on the right represent the American lineage. A and G, kernel density estimates of mean branch dispersal velocity parameters. B and H, kernel density estimates of weighted branch dispersal velocity parameters. C and I, kernel density estimates of original diffusion coefficient parameters. D and J, kernel density estimates of weighted diffusion coefficient parameters. E and K, furthest extent of epidemic wavefront (spatial distance from epidemic origin). F and L, Evolution of weighted diffusion coefficient. For panels E, F, K, and L, solid lines represent the posterior median values of wavefront distance and diffusion coefficient, and shaded areas denote the 95% HPD intervals.

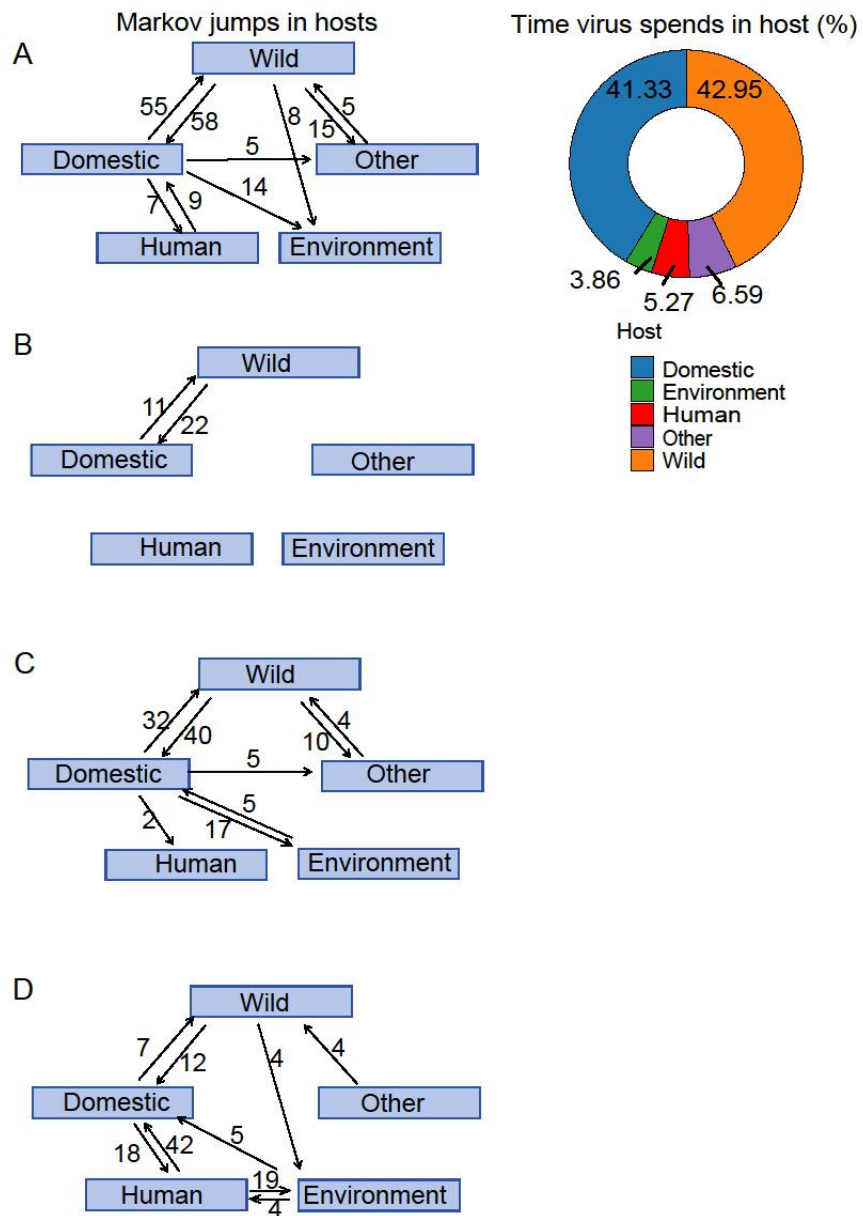


Supplementary Fig. 11. Estimated dispersal statistics for H7N9.

The two columns on the left represent the Eurasian lineage, while the two columns on the right represent the American lineage. A and G, kernel density estimates of mean branch dispersal velocity parameters. B and H, kernel density estimates of weighted branch dispersal velocity parameters. C and I, kernel density estimates of original diffusion coefficient parameters. D and J, kernel density estimates of weighted diffusion coefficient parameters. E and K, furthest extent of epidemic wavefront (spatial distance from epidemic origin). F and L, Evolution of weighted diffusion coefficient. For panels E, F, K, and L, solid lines represent the posterior median values of wavefront distance and diffusion coefficient, and shaded areas denote the 95% HPD intervals.



Supplementary Fig. 12. Estimated dispersal statistics of wavefront distance and diffusion coefficient for H7 and subtypes since 2000. Solid lines represent the posterior median values of wavefront distance and diffusion coefficient, and shaded areas denote the 95% HPD intervals.

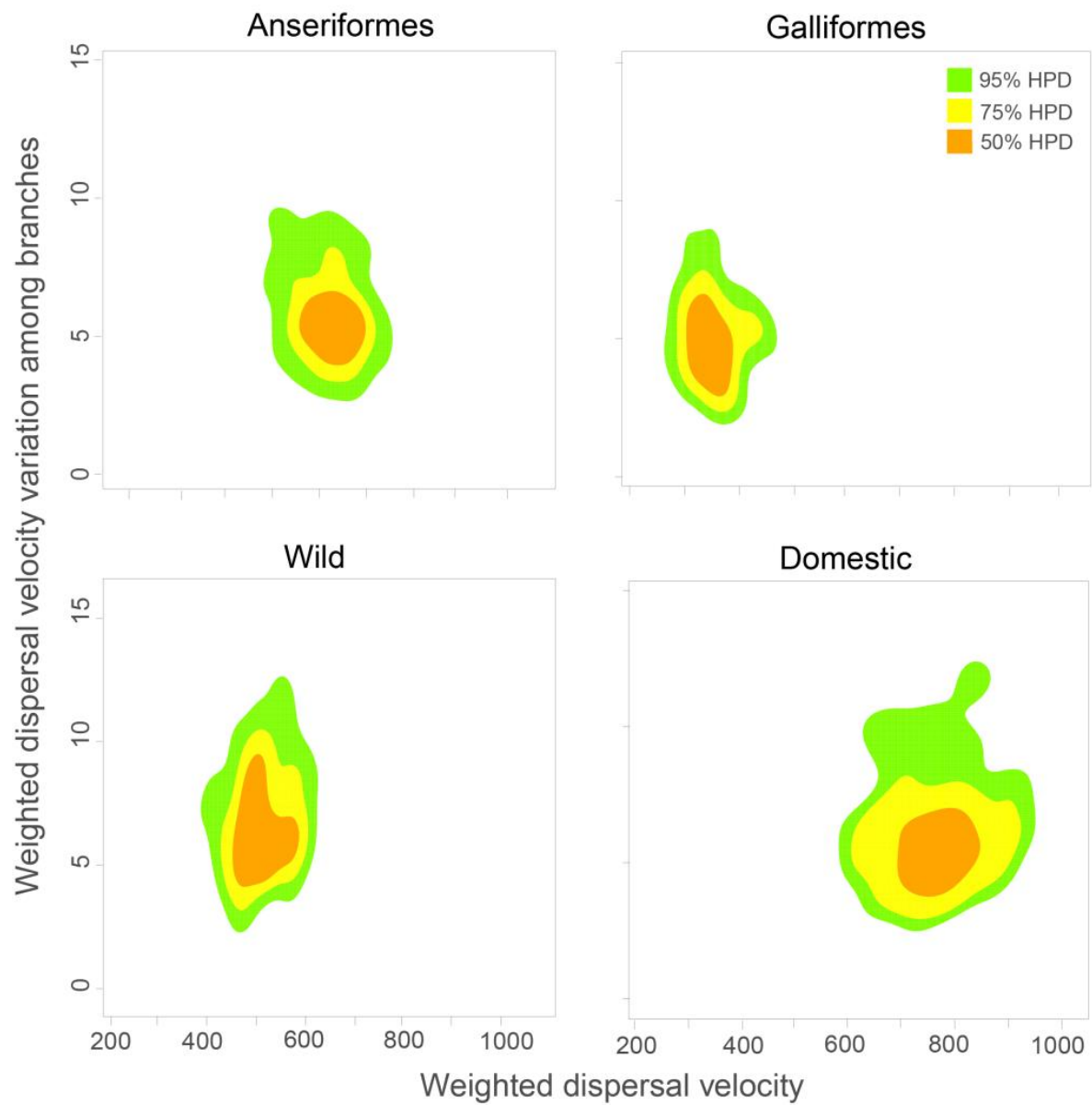


Supplementary Fig. 13. The contrasting host transmission patterns among H7 (A), H7N3 (B), H7N7 (C), and H7N9 (D) inferred from discrete-trait phylogenetics. From left to right, the figures represent host Markov jump counts and Markov rewards.



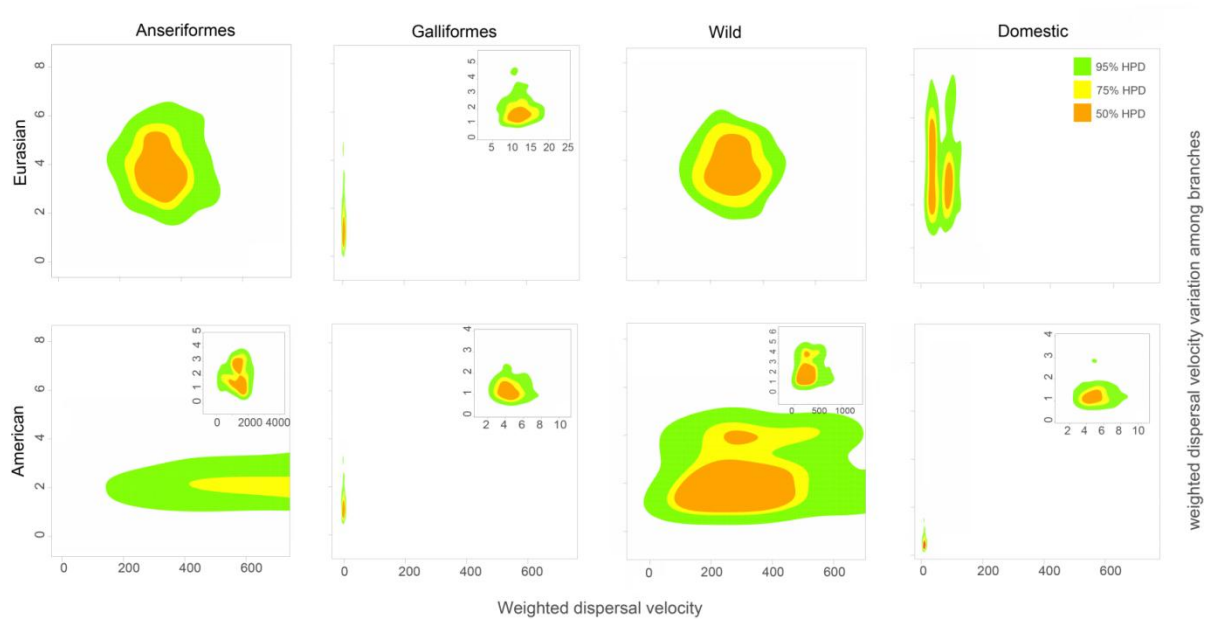
Supplementary Fig. 14. Host-specific dispersal velocity estimates for H7N3.

The top row represents the Eurasian lineage, while the bottom row represents the American lineage. Each panel shows dispersal velocities stratified by host type. Shaded contours represent the 50%, 75%, and 95% highest posterior density (HPD) regions, estimated via kernel density methods, with darker shades indicating higher certainty.



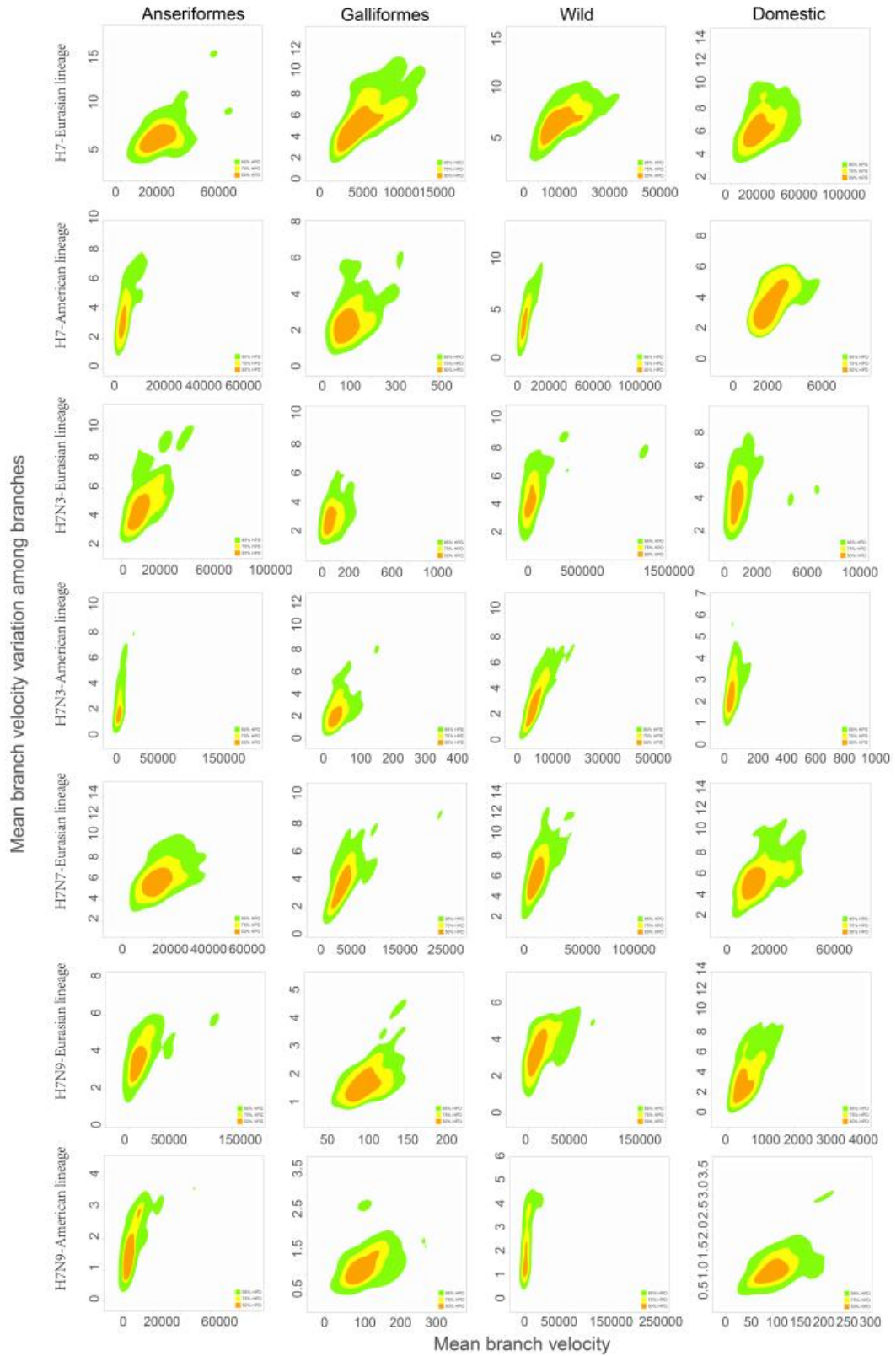
Supplementary Fig. 15. Host-specific dispersal velocity estimates for H7N7.

Each panel shows dispersal velocities stratified by host type. Shaded contours represent the 50%, 75%, and 95% highest posterior density (HPD) regions, estimated via kernel density methods, with darker shades indicating higher certainty.

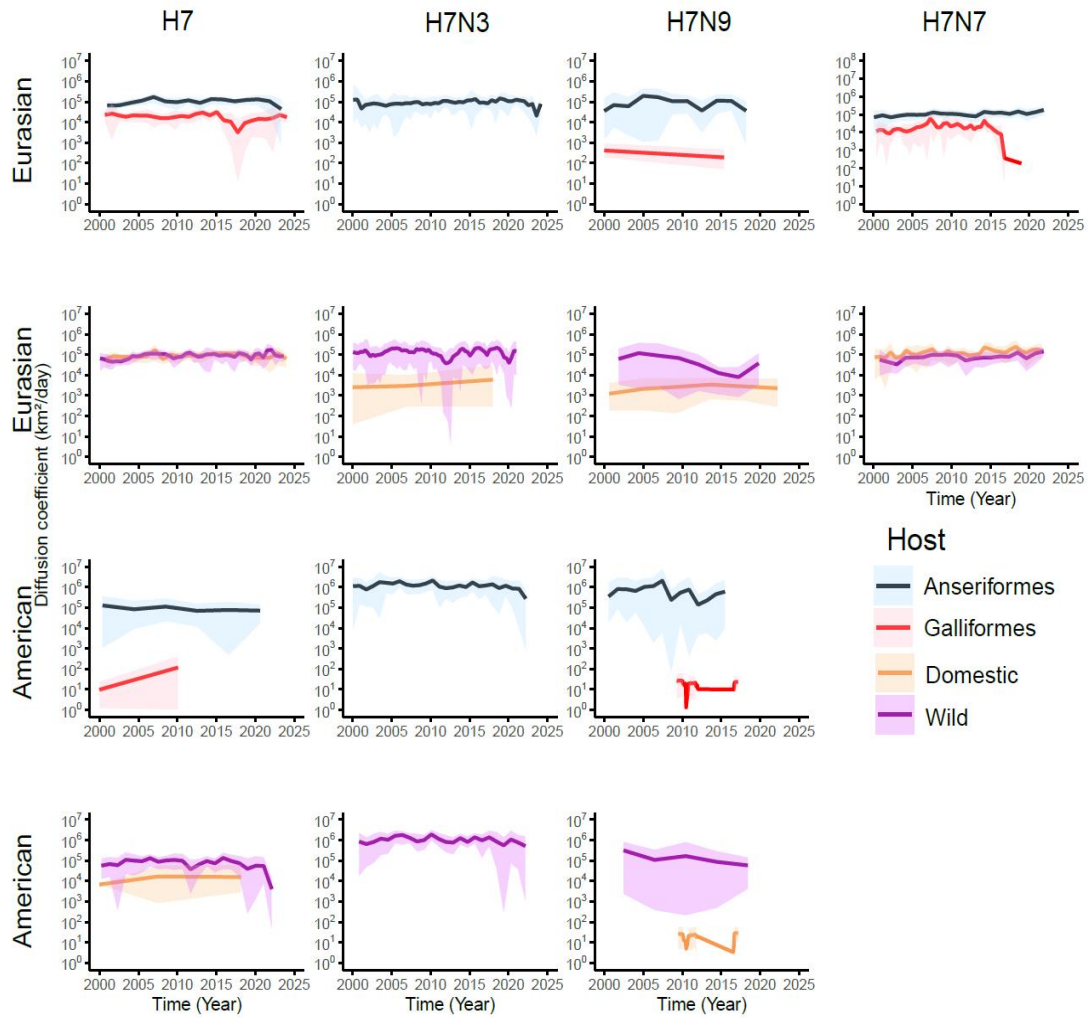


Supplementary Fig. 16. Host-specific dispersal velocity estimates for H7N9.

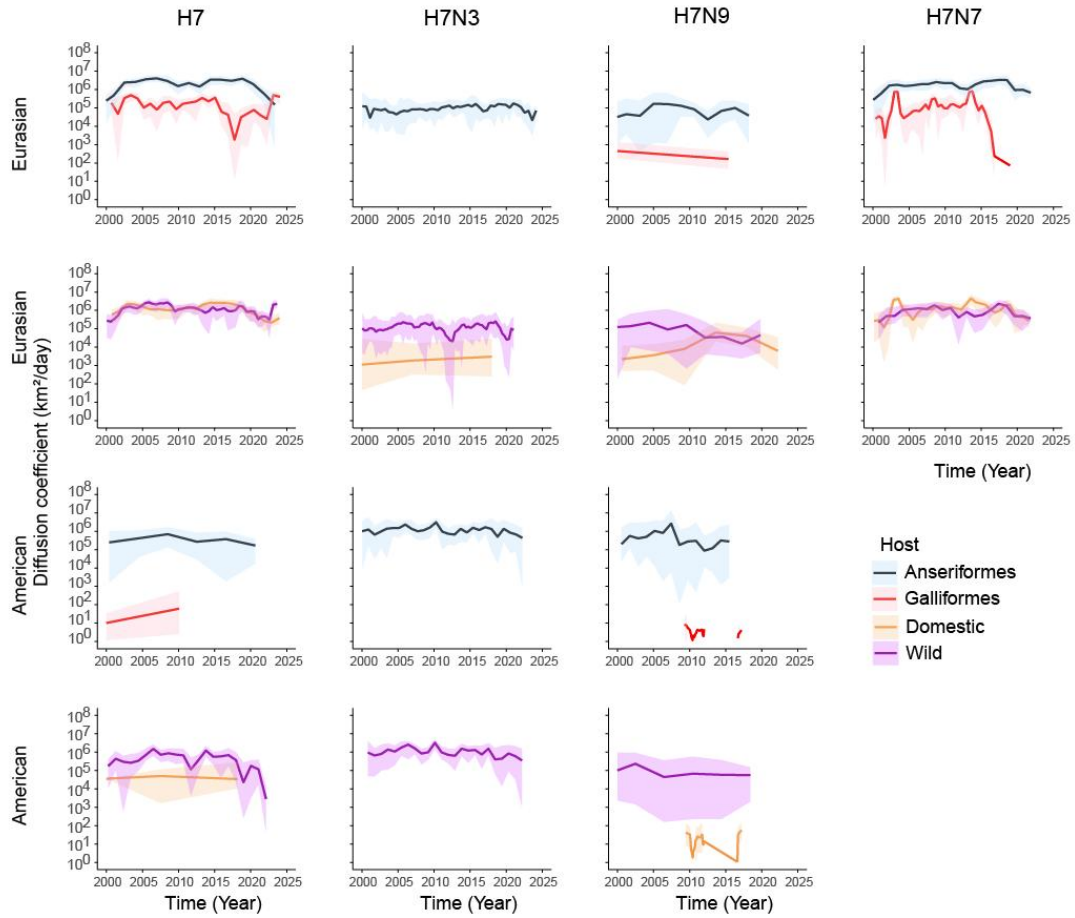
The top row represents the Eurasian lineage, while the bottom row represents the American lineage. Each panel shows dispersal velocities stratified by host type. Shaded contours represent the 50%, 75%, and 95% highest posterior density (HPD) regions, estimated via kernel density methods, with darker shades indicating higher certainty.



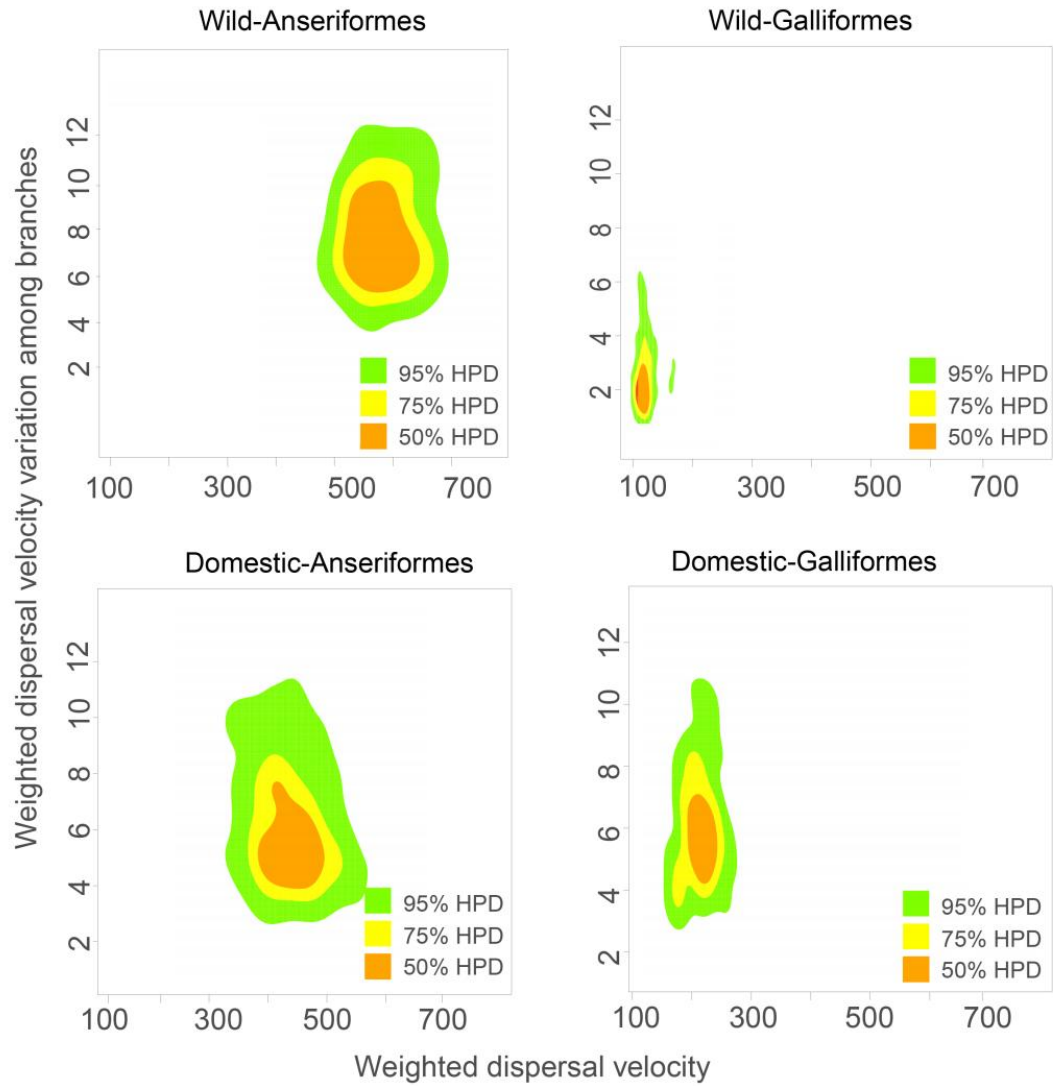
Supplementary Fig. 17. Host-specific mean dispersal velocity estimates for H7 and subtypes. For each graph, the three contours show, in shades of decreasing darkness, the 50%, 75%, and 95% HPD regions via kernel density estimation.



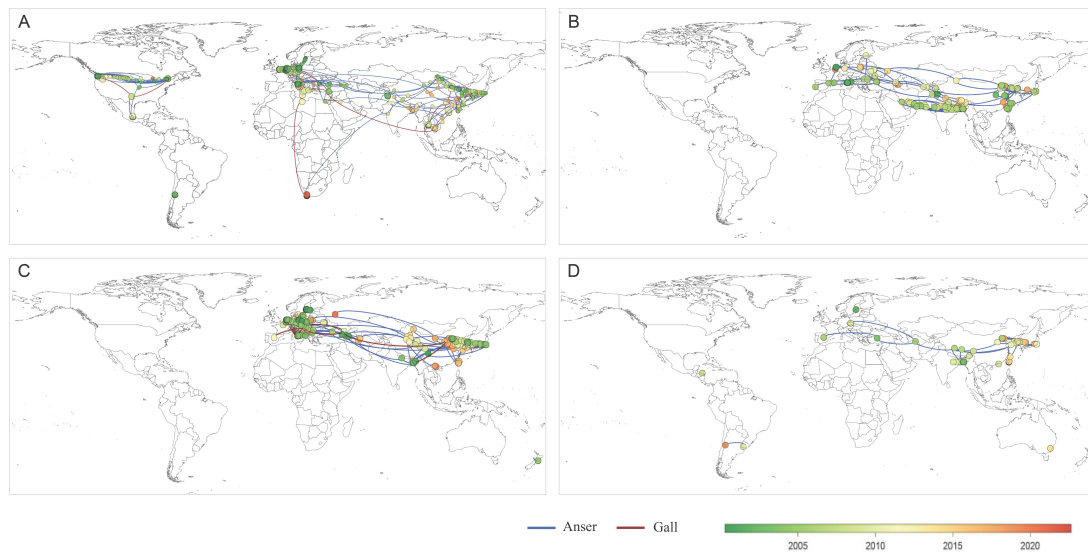
Supplementary Fig. 18. Host-specific and lineage-specific original diffusion coefficient estimates for H7 and subtypes ( $\text{km}^2/\text{day}$ ). The shaded areas denote the 95% HPD. Due to insufficient data, the American lineage of H7N7 was not included in the analysis.



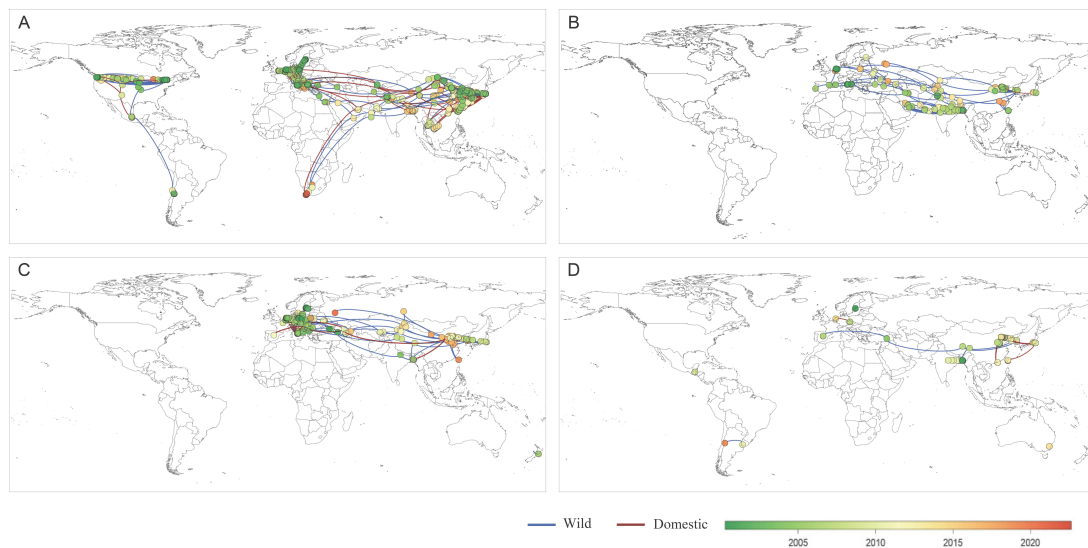
Supplementary Fig. 19. Host-specific and lineage-specific weighted diffusion coefficient estimates for H7 and subtypes (km<sup>2</sup>/day). The shaded areas denote the 95% HPD. Due to insufficient data, the American lineage of H7N7 was not included in the analysis. Diffusion estimates for certain years are omitted due to irregular values likely resulting from limited sampling.



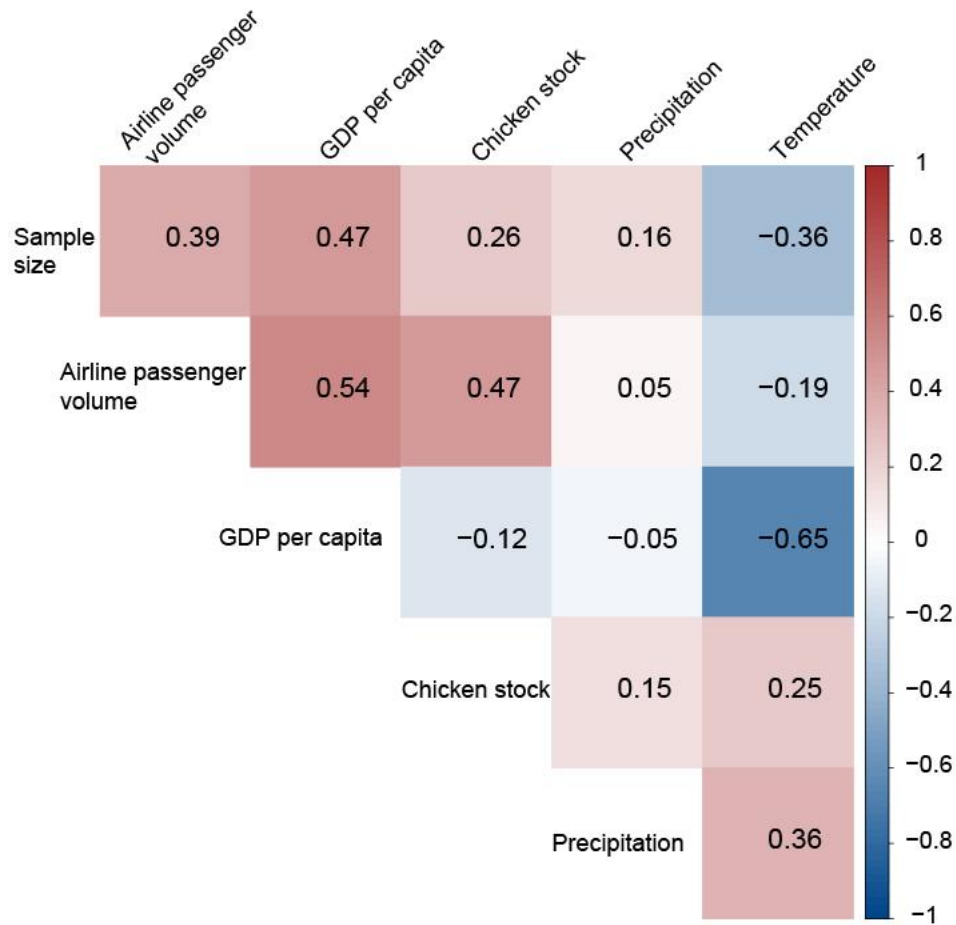
Supplementary Fig. 20. Host-specific weight dispersal velocity estimates for H7 virus. For each graph, the three contours show, in shades of decreasing darkness, the 50%, 75%, and 95% HPD regions via kernel density estimation.



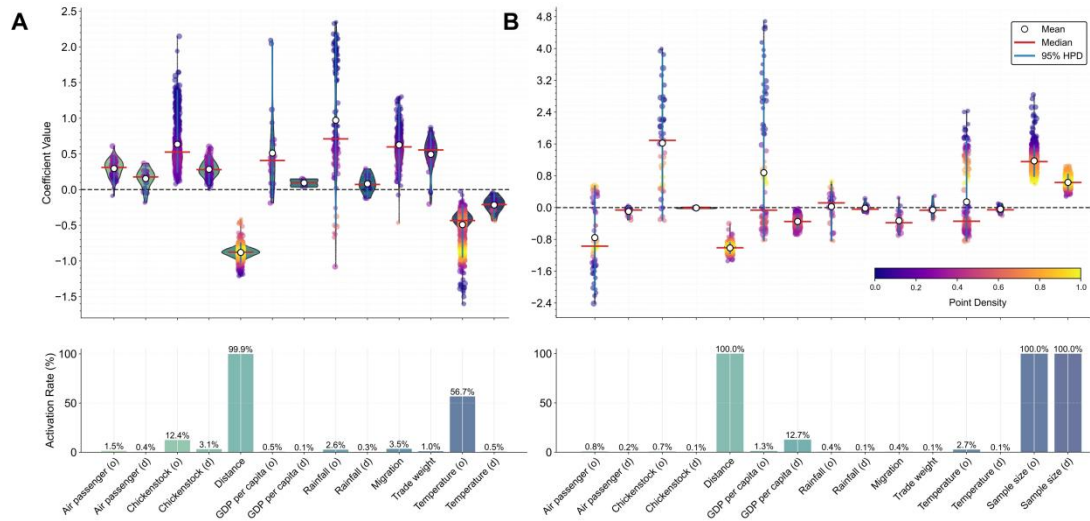
Supplementary Fig. 21. Dynamics of H7 transmission lineages (Anseriformes and Galliformes). H7 (A), H7N3 (B), H7N7 (C), and H7N9 (D). Virus lineage movements were inferred by continuous phylogeographic analysis for each subtype. Maps were generated using the R package *rnaturalearth* with data from Natural Earth (public domain, <https://www.naturalearthdata.com>).



Supplementary Fig. 22. Dynamics of H7 transmission lineages (Wild and domestic birds). H7 (A), H7N3 (B), H7N7 (C), and H7N9 (D). Virus lineage movements were inferred by continuous phylogeographic analysis for each subtype. Maps were generated using the R package *rnaturalearth* with data from Natural Earth (public domain, <https://www.naturalearthdata.com>).

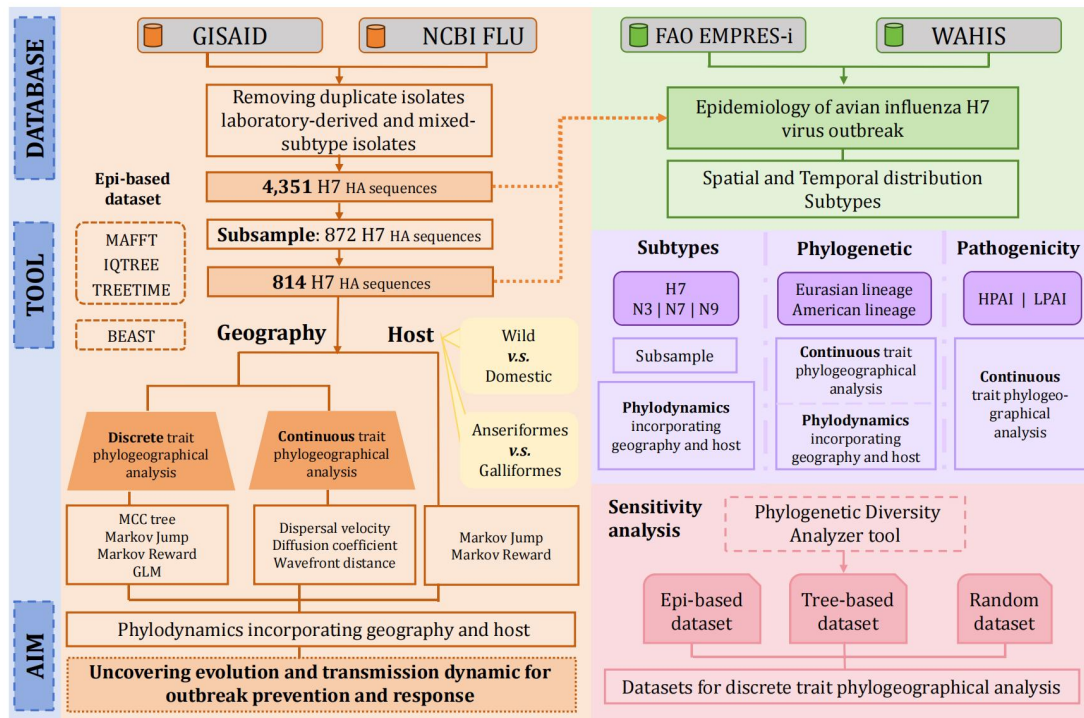


Supplementary Fig. 23. Correlation matrix of predictor variables for generalized linear model analysis. To adhere to a more stringent selection criterion, GDP per capita was excluded from the final model due to its moderate correlation with other variables (e.g., airline passenger volume,  $r = 0.54$ ; temperature,  $r = -0.65$ ). After the exclusion of GDP per capita, the absolute values of all remaining correlation coefficients are less than 0.5, indicating low inter-variable correlation and suitability for inclusion in the GLM.



Supplementary Fig. 24. Results for the included predictor GDP per capita in the global H7 virus diffusion analysis. Analyzed predictors include average inter-location distance, monthly airline passenger volume (2010 - 2018), bird migration routes, live poultry trade volume (1996-2016), chicken stock (2000-2023), GDP per capita (2000-2023), annual mean temperature, annual precipitation and sample size. “o” and “d” indicate origin and destination predictors, respectively. Predictor support is expressed as inclusion probability based on indicator expectations.

(A) Model excluding sample size; (B) Model including sample size as a distinctive predictor. Bars show the mean and 95% HPD of GLM coefficient ( $\beta$ ) on a log scale, conditioned on the inclusion of each predictor.



Supplementary Fig. 25. Overview of the analytic pipeline for dataset collection, analytical method and model development evaluation.

Supplementary Table 1. Number of sequences by administrative region.

| Continent     | Location                | Number of sequences<br>before/after down-sampling |
|---------------|-------------------------|---------------------------------------------------|
| Asia          | Bangladesh              | 33/33                                             |
| Europe        | Belgium                 | 21/21                                             |
| Asia          | Cambodia                | 14/14                                             |
| North America | Canada                  | 50/50                                             |
| South America | Chile                   | 33/33                                             |
| Asia          | China                   | 2075/49                                           |
| Africa        | Egypt                   | 21/20                                             |
| Europe        | Germany                 | 29/29                                             |
| Asia          | Hong Kong (SAR) (China) | 28/28                                             |
| Europe        | Italy                   | 227/50                                            |
| Asia          | Japan                   | 91/50                                             |
| Asia          | South Korea             | 132/50                                            |
| North America | Mexico                  | 63/31                                             |
| Asia          | Mongolia                | 28/28                                             |
| Europe        | Netherlands             | 234/50                                            |
| Asia          | Pakistan                | 29/27                                             |
| Africa        | South Africa            | 62/50                                             |
| Europe        | Sweden                  | 52/50                                             |
| Asia          | Taiwan (China)          | 48/47                                             |
| Asia          | Thailand                | 29/29                                             |
| Europe        | United Kingdom          | 25/25                                             |
| North America | USA                     | 921/50                                            |

Supplementary Table 2. Bayes factor supports. Comparison of Bayes factor supports for individual transitions between discrete states inferred from the three distinct down-sampled datasets (Epi-based, tree-based and random) of each H7 subtype. Bayes factors >3 and Posterior probability >0.5 are marked in bold.

| Virus | FROM          | TO            | Epi-based        |                       | Tree-based       |                       | Random           |                       |
|-------|---------------|---------------|------------------|-----------------------|------------------|-----------------------|------------------|-----------------------|
|       |               |               | Bayes factor     | Posterior probability | Bayes factor     | Posterior probability | Bayes factor     | Posterior probability |
| H7    | Africa        | Europe        | <b>10176.897</b> | <b>1.000</b>          | <b>62.064</b>    | <b>0.974</b>          | 1.682            | <b>0.598</b>          |
|       | Asia          | Europe        | <b>10176.897</b> | <b>1.000</b>          | <b>14712.719</b> | <b>1.000</b>          | <b>10176.897</b> | <b>1.000</b>          |
|       | North America | Europe        | <b>10176.897</b> | <b>1.000</b>          | 2.143            | <b>0.567</b>          | <b>10176.897</b> | <b>1.000</b>          |
|       | South America | Europe        | <b>10176.897</b> | <b>1.000</b>          | 0.148            | 0.083                 | 1.682            | <b>0.598</b>          |
|       | Africa        | Asia          | <b>1271.123</b>  | <b>0.999</b>          | <b>14712.719</b> | <b>1.000</b>          | <b>37.717</b>    | <b>0.971</b>          |
|       | South America | North America | <b>1271.123</b>  | <b>0.999</b>          | <b>62.064</b>    | <b>0.974</b>          | <b>37.717</b>    | <b>0.971</b>          |
|       | Asia          | Africa        | <b>61.311</b>    | <b>0.982</b>          | 0.110            | 0.063                 | <b>725.871</b>   | <b>0.998</b>          |
|       | North America | South America | <b>61.311</b>    | <b>0.982</b>          | 0.074            | 0.043                 | <b>725.871</b>   | <b>0.998</b>          |
|       | Asia          | North America | <b>10.609</b>    | <b>0.904</b>          | 0.214            | 0.116                 | 0.361            | 0.242                 |
|       | North America | Asia          | <b>10.609</b>    | <b>0.904</b>          | 0.224            | 0.121                 | 0.361            | 0.242                 |
|       | Europe        | Asia          | 0.539            | 0.323                 | 0.074            | 0.043                 | 0.425            | 0.273                 |
|       | Europe        | North America | 0.539            | 0.323                 | 2.143            | <b>0.567</b>          | 0.425            | 0.273                 |
|       | Europe        | Africa        | 0.241            | 0.175                 | <b>14712.719</b> | <b>1.000</b>          | 0.614            | 0.352                 |
|       | Europe        | South America | 0.241            | 0.175                 | 0.224            | 0.121                 | 0.614            | 0.352                 |
|       | Asia          | South America | 0.182            | 0.139                 | <b>11.828</b>    | <b>0.879</b>          | 0.457            | 0.288                 |
|       | North America | Africa        | 0.182            | 0.139                 | 0.989            | 0.377                 | 0.457            | 0.288                 |
|       | Africa        | South America | 0.173            | 0.132                 | 0.190            | 0.104                 | 0.354            | 0.239                 |
|       | South America | Africa        | 0.173            | 0.132                 | 0.199            | 0.108                 | 0.354            | 0.239                 |
|       | Africa        | North America | 0.153            | 0.119                 | 0.148            | 0.083                 | 0.264            | 0.189                 |
|       | South America | Asia          | 0.153            | 0.119                 | 0.190            | 0.104                 | 0.264            | 0.189                 |
|       | Africa        | Oceania       | -                | -                     | 0.199            | 0.108                 | -                | -                     |

|      |               |               |                  |              |                  |              |                  |              |
|------|---------------|---------------|------------------|--------------|------------------|--------------|------------------|--------------|
|      | Asia          | Oceania       | -                | -            | 0.200            | 0.109        | -                | -            |
|      | Europe        | Oceania       | -                | -            | 0.989            | 0.377        | -                | -            |
|      | North America | Oceania       | -                | -            | <b>14712.719</b> | <b>1.000</b> | -                | -            |
|      | Oceania       | Africa        | -                | -            | 0.200            | 0.109        | -                | -            |
|      | Oceania       | Asia          | -                | -            | <b>11.828</b>    | <b>0.879</b> | -                | -            |
|      | Oceania       | Europe        | -                | -            | 0.214            | 0.116        | -                | -            |
|      | Oceania       | North America | -                | -            | <b>14712.719</b> | <b>1.000</b> | -                | -            |
|      | Oceania       | South America | -                | -            | 0.110            | 0.063        | -                | -            |
|      | South America | Oceania       | -                | -            | <b>14712.719</b> | <b>1.000</b> | -                | -            |
| H7N3 | Asia          | Europe        | <b>14712.719</b> | <b>1.000</b> | <b>14712.719</b> | <b>1.000</b> | <b>14712.719</b> | <b>1.000</b> |
|      | Oceania       | North America | <b>14712.719</b> | <b>1.000</b> | <b>14712.719</b> | <b>1.000</b> | <b>14712.719</b> | <b>1.000</b> |
|      | Europe        | Africa        | <b>979.322</b>   | <b>0.998</b> | <b>3676.954</b>  | <b>1.000</b> | <b>3676.954</b>  | <b>1.000</b> |
|      | North America | South America | <b>979.322</b>   | <b>0.998</b> | <b>3676.954</b>  | <b>1.000</b> | <b>3676.954</b>  | <b>1.000</b> |
|      | Africa        | Asia          | <b>9.658</b>     | <b>0.855</b> | <b>20.004</b>    | <b>0.924</b> | <b>19.877</b>    | <b>0.924</b> |
|      | South America | Oceania       | <b>9.658</b>     | <b>0.855</b> | <b>20.004</b>    | <b>0.924</b> | <b>19.877</b>    | <b>0.924</b> |
|      | Asia          | Oceania       | <b>4.131</b>     | <b>0.716</b> | 1.887            | <b>0.536</b> | 1.485            | 0.476        |
|      | Oceania       | Asia          | <b>4.131</b>     | <b>0.716</b> | 1.887            | <b>0.536</b> | 1.485            | 0.476        |
|      | Africa        | Europe        | <b>4.120</b>     | <b>0.716</b> | 1.467            | 0.473        | 1.341            | 0.451        |
|      | South America | North America | <b>4.120</b>     | <b>0.716</b> | 1.467            | 0.473        | 1.341            | 0.451        |
|      | Asia          | South America | 1.041            | 0.389        | 0.454            | 0.217        | 0.393            | 0.194        |
|      | Oceania       | Africa        | 1.041            | 0.389        | 0.454            | 0.217        | 0.393            | 0.194        |
|      | Europe        | Oceania       | 0.524            | 0.243        | 0.677            | 0.293        | 0.876            | 0.349        |
|      | North America | Asia          | 0.524            | 0.243        | 0.677            | 0.293        | 0.876            | 0.349        |
|      | Asia          | North America | 0.505            | 0.236        | 0.577            | 0.261        | 0.532            | 0.245        |
|      | Oceania       | Europe        | 0.505            | 0.236        | 0.577            | 0.261        | 0.532            | 0.245        |
|      | Europe        | South America | 0.498            | 0.233        | 0.350            | 0.177        | 0.358            | 0.180        |

|      |               |               |                  |              |                  |              |                  |              |
|------|---------------|---------------|------------------|--------------|------------------|--------------|------------------|--------------|
| H7N7 | North America | Africa        | 0.498            | 0.233        | 0.350            | 0.177        | 0.358            | 0.180        |
|      | Africa        | Oceania       | 0.432            | 0.209        | 0.501            | 0.235        | 0.491            | 0.231        |
|      | South America | Asia          | 0.432            | 0.209        | 0.501            | 0.235        | 0.491            | 0.231        |
|      | Africa        | South America | 0.373            | 0.186        | 0.311            | 0.160        | 0.315            | 0.162        |
|      | South America | Africa        | 0.373            | 0.186        | 0.311            | 0.160        | 0.315            | 0.162        |
|      | Asia          | Africa        | 0.348            | 0.176        | 0.600            | 0.268        | 0.630            | 0.278        |
|      | Oceania       | South America | 0.348            | 0.176        | 0.600            | 0.268        | 0.630            | 0.278        |
|      | Europe        | North America | 0.279            | 0.146        | 0.366            | 0.183        | 0.393            | 0.194        |
|      | North America | Europe        | 0.279            | 0.146        | 0.366            | 0.183        | 0.393            | 0.194        |
|      | Africa        | North America | 0.215            | 0.116        | 0.271            | 0.142        | 0.253            | 0.134        |
|      | South America | Europe        | 0.215            | 0.116        | 0.271            | 0.142        | 0.253            | 0.134        |
|      | Europe        | Asia          | 0.199            | 0.108        | 0.573            | 0.260        | 0.655            | 0.286        |
|      | North America | Oceania       | 0.199            | 0.108        | 0.573            | 0.260        | 0.655            | 0.286        |
|      | Africa        | Europe        | <b>10176.897</b> | <b>1.000</b> | <b>1130.239</b>  | <b>0.999</b> | <b>523.878</b>   | <b>0.997</b> |
|      | Asia          | Europe        | <b>10176.897</b> | <b>1.000</b> | <b>14712.719</b> | <b>1.000</b> | <b>14712.719</b> | <b>1.000</b> |
|      | North America | Europe        | <b>10176.897</b> | <b>1.000</b> | <b>3.483</b>     | <b>0.681</b> | <b>12.834</b>    | <b>0.887</b> |
|      | Oceania       | Europe        | <b>10176.897</b> | <b>1.000</b> | 0.254            | 0.135        | 0.189            | 0.104        |
|      | Africa        | Oceania       | <b>3.755</b>     | <b>0.769</b> | 1.095            | 0.401        | 0.769            | 0.320        |
|      | Oceania       | Africa        | <b>3.755</b>     | <b>0.769</b> | 0.346            | 0.175        | 0.351            | 0.177        |
|      | Africa        | Asia          | 2.419            | <b>0.681</b> | <b>4.996</b>     | <b>0.753</b> | <b>5.722</b>     | <b>0.778</b> |
|      | Oceania       | North America | 2.419            | <b>0.681</b> | <b>14712.719</b> | <b>1.000</b> | <b>14712.719</b> | <b>1.000</b> |
|      | Europe        | Asia          | 0.887            | 0.440        | 0.370            | 0.184        | 0.206            | 0.112        |
|      | Europe        | North America | 0.887            | 0.440        | <b>3.483</b>     | <b>0.681</b> | <b>12.834</b>    | <b>0.887</b> |
|      | Africa        | North America | 0.835            | 0.425        | 0.427            | 0.207        | 0.257            | 0.136        |
|      | Oceania       | Asia          | 0.835            | 0.425        | 0.260            | 0.137        | <b>3.377</b>     | <b>0.674</b> |
|      | Europe        | Africa        | 0.502            | 0.307        | 0.648            | 0.284        | 0.770            | 0.320        |

|      |               |               |                |              |                 |              |                |              |
|------|---------------|---------------|----------------|--------------|-----------------|--------------|----------------|--------------|
|      | Europe        | Oceania       | 0.502          | 0.307        | 2.434           | <b>0.598</b> | 0.859          | 0.344        |
|      | Asia          | North America | 0.444          | 0.282        | 0.254           | 0.135        | 0.189          | 0.104        |
|      | North America | Asia          | 0.444          | 0.282        | 2.434           | <b>0.598</b> | 0.859          | 0.344        |
|      | Asia          | Africa        | 0.300          | 0.210        | 0.603           | 0.270        | 0.288          | 0.150        |
|      | North America | Oceania       | 0.300          | 0.210        | 0.370           | 0.184        | 0.206          | 0.112        |
|      | Asia          | Oceania       | 0.167          | 0.129        | 0.260           | 0.137        | <b>3.377</b>   | <b>0.674</b> |
|      | North America | Africa        | 0.167          | 0.129        | 1.078           | 0.397        | 1.510          | 0.480        |
|      | Africa        | South America | -              | -            | 0.613           | 0.273        | 0.535          | 0.247        |
|      | Asia          | South America | -              | -            | 0.346           | 0.175        | 0.351          | 0.177        |
|      | Europe        | South America | -              | -            | 1.078           | 0.397        | 1.510          | 0.480        |
|      | North America | South America | -              | -            | 0.648           | 0.284        | 0.770          | 0.320        |
|      | Oceania       | South America | -              | -            | 0.603           | 0.270        | 0.288          | 0.150        |
|      | South America | Africa        | -              | -            | 0.613           | 0.273        | 0.535          | 0.247        |
|      | South America | Asia          | -              | -            | 1.095           | 0.401        | 0.769          | 0.320        |
|      | South America | Europe        | -              | -            | 0.427           | 0.207        | 0.257          | 0.136        |
|      | South America | North America | -              | -            | <b>1130.239</b> | <b>0.999</b> | <b>523.878</b> | <b>0.997</b> |
|      | South America | Oceania       | -              | -            | <b>4.996</b>    | <b>0.753</b> | <b>5.722</b>   | <b>0.778</b> |
| H7N9 | Asia          | Europe        | <b>918.012</b> | <b>0.998</b> | <b>124.129</b>  | <b>0.987</b> | <b>23.095</b>  | <b>0.934</b> |
|      | Oceania       | North America | <b>918.012</b> | <b>0.998</b> | <b>124.129</b>  | <b>0.987</b> | <b>23.095</b>  | <b>0.934</b> |
|      | Asia          | North America | <b>18.945</b>  | <b>0.921</b> | <b>22.213</b>   | <b>0.931</b> | 0.506          | 0.236        |
|      | Oceania       | Europe        | <b>18.945</b>  | <b>0.921</b> | <b>22.213</b>   | <b>0.931</b> | 0.506          | 0.236        |
|      | Africa        | Europe        | <b>5.592</b>   | <b>0.774</b> | <b>6.778</b>    | <b>0.806</b> | <b>8.065</b>   | <b>0.831</b> |
|      | South America | North America | <b>5.592</b>   | <b>0.774</b> | <b>6.778</b>    | <b>0.806</b> | <b>8.065</b>   | <b>0.831</b> |
|      | Africa        | Asia          | <b>3.074</b>   | <b>0.653</b> | 2.769           | <b>0.629</b> | 0.723          | 0.307        |
|      | South America | Oceania       | <b>3.074</b>   | <b>0.653</b> | 2.769           | <b>0.629</b> | 0.723          | 0.307        |
|      | Europe        | Africa        | <b>3.041</b>   | <b>0.650</b> | <b>3.681</b>    | <b>0.692</b> | <b>4.064</b>   | <b>0.713</b> |

|               |               |              |              |              |              |              |              |
|---------------|---------------|--------------|--------------|--------------|--------------|--------------|--------------|
| North America | South America | <b>3.041</b> | <b>0.650</b> | <b>3.681</b> | <b>0.692</b> | <b>4.064</b> | <b>0.713</b> |
| Europe        | Oceania       | 1.235        | 0.430        | 0.601        | 0.269        | 0.577        | 0.261        |
| North America | Asia          | 1.235        | 0.430        | 0.601        | 0.269        | 0.577        | 0.261        |
| Asia          | Oceania       | 0.930        | 0.363        | 1.165        | 0.416        | <b>6.769</b> | <b>0.805</b> |
| Oceania       | Asia          | 0.930        | 0.363        | 1.165        | 0.416        | <b>6.769</b> | <b>0.805</b> |
| Europe        | Asia          | 0.687        | 0.296        | 1.325        | 0.448        | 0.442        | 0.213        |
| North America | Oceania       | 0.687        | 0.296        | 1.325        | 0.448        | 0.442        | 0.213        |
| Europe        | South America | 0.547        | 0.251        | 0.418        | 0.204        | 0.995        | 0.378        |
| North America | Africa        | 0.547        | 0.251        | 0.418        | 0.204        | 0.995        | 0.378        |
| Europe        | North America | 0.542        | 0.249        | 0.377        | 0.188        | 1.372        | 0.456        |
| North America | Europe        | 0.542        | 0.249        | 0.377        | 0.188        | 1.372        | 0.456        |
| Asia          | South America | 0.498        | 0.234        | 0.459        | 0.219        | 0.437        | 0.211        |
| Oceania       | Africa        | 0.498        | 0.234        | 0.459        | 0.219        | 0.437        | 0.211        |
| Asia          | Africa        | 0.485        | 0.229        | 0.740        | 0.312        | 0.450        | 0.216        |
| Oceania       | South America | 0.485        | 0.229        | 0.740        | 0.312        | 0.450        | 0.216        |
| Africa        | Oceania       | 0.464        | 0.221        | 0.423        | 0.206        | 0.454        | 0.217        |
| South America | Asia          | 0.464        | 0.221        | 0.423        | 0.206        | 0.454        | 0.217        |
| Africa        | South America | 0.352        | 0.177        | 0.362        | 0.181        | 0.658        | 0.287        |
| South America | Africa        | 0.352        | 0.177        | 0.362        | 0.181        | 0.658        | 0.287        |
| Africa        | North America | 0.306        | 0.158        | 0.342        | 0.173        | 0.690        | 0.297        |
| South America | Europe        | 0.306        | 0.158        | 0.342        | 0.173        | 0.690        | 0.297        |

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Supplementary Table 3. The Markov jumps for H7 and subtypes by region for epi-based dataset.

| Subtype | Region Transition |               |              |                |
|---------|-------------------|---------------|--------------|----------------|
|         | Region (from)     | Region (to)   | Markov Jumps | Percentage (%) |
| H7      | Africa            | Asia          | 2.3950       | 0.0720         |
|         | Africa            | Europe        | 2.1780       | 0.0654         |
|         | Africa            | North America | 0.0461       | 0.0014         |
|         | Africa            | South America | 0.0432       | 0.0013         |
|         | Asia              | Africa        | 3.5640       | 0.1071         |
|         | Asia              | Europe        | 7.9860       | 0.2399         |
|         | Asia              | North America | 1.7280       | 0.0519         |
|         | Asia              | South America | 0.0784       | 0.0024         |
|         | Europe            | Africa        | 4.4260       | 0.1330         |
|         | Europe            | Asia          | 6.9080       | 0.2075         |
|         | Europe            | North America | 0.1010       | 0.0030         |
|         | Europe            | South America | 0.2800       | 0.0084         |
|         | North America     | Africa        | 0.0401       | 0.0012         |
|         | North America     | Asia          | 0.8980       | 0.0270         |
|         | North America     | Europe        | 0.2970       | 0.0089         |
|         | North America     | South America | 1.0050       | 0.0302         |
|         | South America     | Africa        | 0.0167       | 0.0005         |
|         | South America     | Asia          | 0.0329       | 0.0010         |
|         | South America     | Europe        | 0.0644       | 0.0019         |
|         | South America     | North America | 1.1990       | 0.0360         |
| H7N3    | Africa            | Asia          | 0.32         | 1.6913         |
|         | Africa            | Europe        | 0.16         | 0.8457         |
|         | Africa            | South America | 0.08         | 0.4228         |
|         | Africa            | North America | 0.04         | 0.2114         |
|         | Africa            | Oceania       | 0.13         | 0.6871         |
|         | Asia              | South America | 0.08         | 0.4228         |
|         | Asia              | Africa        | 1.53         | 8.0867         |
|         | Asia              | Europe        | 5.37         | 28.3827        |
|         | Asia              | North America | 0.18         | 0.9514         |
|         | Asia              | Oceania       | 0.79         | 4.1755         |
|         | Europe            | South America | 0.19         | 1.0042         |
|         | Europe            | Africa        | 0.96         | 5.0740         |
|         | Europe            | Asia          | 4.84         | 25.5814        |
|         | Europe            | North America | 0.09         | 0.4757         |
|         | Europe            | Oceania       | 0.21         | 1.1099         |
|         | North America     | South America | 0.11         | 0.5814         |
|         | North America     | Africa        | 0.05         | 0.2643         |
|         | North America     | Asia          | 0.18         | 0.9514         |
|         | North America     | Europe        | 0.07         | 0.3700         |

|      |               |               |         |         |
|------|---------------|---------------|---------|---------|
| H7N7 | North America | Oceania       | 0.04    | 0.2114  |
|      | Oceania       | South America | 1.73    | 9.1438  |
|      | Oceania       | Africa        | 0.04    | 0.2114  |
|      | Oceania       | Asia          | 0.15    | 0.7928  |
|      | Oceania       | Europe        | 0.05    | 0.2643  |
|      | Oceania       | North America | 0.04    | 0.2114  |
|      | South America | Africa        | 0.08    | 0.4228  |
|      | South America | Asia          | 0.26    | 1.3742  |
|      | South America | Europe        | 0.13    | 0.6871  |
|      | South America | North America | 0.92    | 4.8626  |
|      | South America | Oceania       | 0.10    | 0.5285  |
|      | Africa        | Asia          | 0.64    | 2.7495  |
|      | Africa        | Europe        | 1.27    | 5.5034  |
|      | Africa        | North America | 0.38    | 1.6342  |
|      | Africa        | Oceania       | 0.82    | 3.5493  |
|      | Asia          | Africa        | 1.20    | 5.1705  |
|      | Asia          | Europe        | 5.76    | 24.8798 |
|      | Asia          | North America | 0.23    | 0.9943  |
|      | Asia          | Oceania       | 0.07    | 0.2955  |
|      | Europe        | Africa        | 5.67    | 24.5080 |
|      | Europe        | Asia          | 5.56    | 24.0368 |
|      | Europe        | North America | 0.40    | 1.7422  |
|      | Europe        | Oceania       | 0.31    | 1.3359  |
|      | North America | Africa        | 0.14    | 0.6052  |
|      | North America | Asia          | 0.10    | 0.4410  |
|      | North America | Europe        | 0.15    | 0.6528  |
|      | North America | Oceania       | 0.06    | 0.2745  |
|      | Oceania       | Africa        | 0.16    | 0.6787  |
|      | Oceania       | Asia          | 0.03    | 0.1456  |
|      | Oceania       | Europe        | 0.07    | 0.3186  |
|      | Oceania       | North America | 0.11    | 0.4842  |
| H7N9 | Africa        | Asia          | 0.245   | 1.4944  |
|      | Africa        | Europe        | 0.329   | 2.0067  |
|      | Africa        | North America | 0.0681  | 0.4154  |
|      | Africa        | Oceania       | 0.151   | 0.9210  |
|      | Africa        | South America | 0.09799 | 0.5977  |
|      | Asia          | Africa        | 1.15    | 7.0144  |
|      | Asia          | Europe        | 3.181   | 19.4023 |
|      | Asia          | North America | 2.056   | 12.5405 |
|      | Asia          | Oceania       | 0.391   | 2.3849  |
|      | Asia          | South America | 0.219   | 1.3358  |
|      | Europe        | Africa        | 1.479   | 9.0211  |
|      | Europe        | Asia          | 2.706   | 16.5051 |

|               |               |         |        |
|---------------|---------------|---------|--------|
| Europe        | North America | 0.276   | 1.6834 |
| Europe        | Oceania       | 0.462   | 2.8179 |
| Europe        | South America | 0.222   | 1.3541 |
| North America | Africa        | 0.09343 | 0.5699 |
| North America | Asia          | 0.836   | 5.0991 |
| North America | Europe        | 0.176   | 1.0735 |
| North America | Oceania       | 0.289   | 1.7627 |
| North America | South America | 0.756   | 4.6112 |
| Oceania       | Africa        | 0.07166 | 0.4371 |
| Oceania       | Asia          | 0.11    | 0.6709 |
| Oceania       | Europe        | 0.152   | 0.9271 |
| Oceania       | North America | 0.144   | 0.8783 |
| Oceania       | South America | 0.134   | 0.8173 |
| South America | Africa        | 0.05055 | 0.3083 |
| South America | Asia          | 0.06821 | 0.4160 |
| South America | Europe        | 0.09399 | 0.5733 |
| South America | North America | 0.261   | 1.5920 |
| South America | Oceania       | 0.126   | 0.7685 |

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Supplementary Table 4. The Markov rewards for H7 and subtypes by region.

| Subtype | Region        | Reward Time (year) | Percentage (%) |
|---------|---------------|--------------------|----------------|
| H7      | Africa        | 62.908             | 4.80           |
|         | Asia          | 558.194            | 42.63          |
|         | Europe        | 349.981            | 26.73          |
|         | North America | 275.364            | 21.03          |
|         | South America | 62.908             | 4.80           |

Supplementary Table 5. The Markov jumps for H7 and subtypes by host (Anseriformes and Galliformes).

| Subtype               | Host Transition |              |              |                |
|-----------------------|-----------------|--------------|--------------|----------------|
|                       | Host (from)     | Host (to)    | Markov Jumps | Percentage (%) |
| H7-Eurasian lineage   | Anseriformes    | Environment  | 23.930       | 23.50          |
|                       | Anseriformes    | Galliformes  | 29.370       | 28.85          |
|                       | Anseriformes    | Human        | 1.129        | 1.11           |
|                       | Anseriformes    | Other        | 13.096       | 12.86          |
|                       | Environment     | Anseriformes | 3.352        | 3.29           |
|                       | Environment     | Galliformes  | 0.015        | 0.01           |
|                       | Environment     | Human        | 0.011        | 0.01           |
|                       | Environment     | Other        | 0.018        | 0.02           |
|                       | Galliformes     | Anseriformes | 14.812       | 14.55          |
|                       | Galliformes     | Environment  | 0.014        | 0.01           |
|                       | Galliformes     | Human        | 2.958        | 2.91           |
|                       | Galliformes     | Other        | 0.347        | 0.34           |
|                       | Human           | Anseriformes | 2.832        | 2.78           |
|                       | Human           | Environment  | 0.011        | 0.01           |
|                       | Human           | Galliformes  | 7.099        | 6.97           |
|                       | Human           | Other        | 0.016        | 0.02           |
|                       | Other           | Anseriformes | 2.618        | 2.57           |
|                       | Other           | Environment  | 0.014        | 0.01           |
|                       | Other           | Galliformes  | 0.160        | 0.16           |
|                       | Other           | Human        | 0.012        | 0.01           |
| H7-American lineage   | Anseriformes    | Galliformes  | 8.011        | 35.21          |
|                       | Anseriformes    | Human        | 0.033        | 0.15           |
|                       | Anseriformes    | Other        | 4.143        | 18.21          |
|                       | Galliformes     | Anseriformes | 3.640        | 16.00          |
|                       | Galliformes     | Human        | 2.991        | 13.15          |
|                       | Galliformes     | Other        | 2.282        | 10.03          |
|                       | Human           | Anseriformes | 0.015        | 0.07           |
|                       | Human           | Galliformes  | 0.491        | 2.16           |
|                       | Human           | Other        | 0.028        | 0.12           |
|                       | Other           | Anseriformes | 0.608        | 2.67           |
|                       | Other           | Galliformes  | 0.464        | 2.04           |
|                       | Other           | Human        | 0.044        | 0.19           |
| H7N3-Eurasian lineage | Anseriformes    | Galliformes  | 9.903        | 48.42          |
|                       | Anseriformes    | Other        | 5.316        | 25.99          |
|                       | Galliformes     | Anseriformes | 4.532        | 22.16          |
|                       | Galliformes     | Other        | 0.031        | 0.15           |
|                       | Other           | Anseriformes | 0.642        | 3.14           |
|                       | Other           | Galliformes  | 0.028        | 0.14           |
| H7N3-American lineage | Anseriformes    | Environment  | 0.850        | 3.36           |
|                       | Anseriformes    | Galliformes  | 6.583        | 26.03          |

|                       |              |              |        |       |
|-----------------------|--------------|--------------|--------|-------|
| H7N7-Eurasian lineage | Anseriformes | Other        | 12.110 | 47.89 |
|                       | Environment  | Anseriformes | 0.054  | 0.21  |
|                       | Environment  | Galliformes  | 0.019  | 0.07  |
|                       | Environment  | Other        | 0.022  | 0.09  |
|                       | Galliformes  | Anseriformes | 2.134  | 8.44  |
|                       | Galliformes  | Environment  | 0.073  | 0.29  |
|                       | Galliformes  | Other        | 0.729  | 2.88  |
|                       | Other        | Anseriformes | 2.369  | 9.37  |
|                       | Other        | Environment  | 0.161  | 0.64  |
|                       | Other        | Galliformes  | 0.184  | 0.73  |
|                       | Anseriformes | Environment  | 17.334 | 22.06 |
|                       | Anseriformes | Galliformes  | 18.437 | 23.46 |
|                       | Anseriformes | Human        | 0.006  | 0.01  |
|                       | Anseriformes | Other        | 23.540 | 29.95 |
|                       | Environment  | Anseriformes | 3.732  | 4.75  |
|                       | Environment  | Galliformes  | 0.011  | 0.01  |
|                       | Environment  | Human        | 0.004  | 0.00  |
|                       | Environment  | Other        | 0.429  | 0.55  |
|                       | Galliformes  | Anseriformes | 4.995  | 6.36  |
|                       | Galliformes  | Environment  | 0.011  | 0.01  |
|                       | Galliformes  | Human        | 2.091  | 2.66  |
|                       | Galliformes  | Other        | 0.838  | 1.07  |
|                       | Human        | Anseriformes | 0.006  | 0.01  |
|                       | Human        | Environment  | 0.005  | 0.01  |
|                       | Human        | Galliformes  | 0.027  | 0.03  |
|                       | Human        | Other        | 0.006  | 0.01  |
|                       | Other        | Anseriformes | 6.143  | 7.82  |
|                       | Other        | Environment  | 0.371  | 0.47  |
|                       | Other        | Galliformes  | 0.603  | 0.77  |
|                       | Other        | Human        | 0.005  | 0.01  |
| H7N9-Eurasian lineage | Anseriformes | Environment  | 4.162  | 4.05  |
|                       | Anseriformes | Galliformes  | 1.849  | 1.80  |
|                       | Anseriformes | Human        | 2.965  | 2.88  |
|                       | Anseriformes | Other        | 3.493  | 3.40  |
|                       | Environment  | Anseriformes | 1.185  | 1.15  |
|                       | Environment  | Galliformes  | 0.754  | 0.73  |
|                       | Environment  | Human        | 4.007  | 3.90  |
|                       | Environment  | Other        | 0.229  | 0.22  |
|                       | Galliformes  | Anseriformes | 2.114  | 2.06  |
|                       | Galliformes  | Environment  | 2.091  | 2.03  |
|                       | Galliformes  | Human        | 16.205 | 15.76 |
|                       | Galliformes  | Other        | 0.171  | 0.17  |
|                       | Human        | Anseriformes | 5.308  | 5.16  |
|                       | Human        | Environment  | 19.766 | 19.22 |

|                       |              |              |        |       |
|-----------------------|--------------|--------------|--------|-------|
| H7N9-American lineage | Human        | Galliformes  | 32.893 | 31.99 |
|                       | Human        | Other        | 3.849  | 3.74  |
|                       | Other        | Anseriformes | 1.412  | 1.37  |
|                       | Other        | Environment  | 0.071  | 0.07  |
|                       | Other        | Galliformes  | 0.022  | 0.02  |
|                       | Other        | Human        | 0.284  | 0.28  |
|                       | Anseriformes | Environment  | 1.061  | 8.53  |
|                       | Anseriformes | Galliformes  | 4.182  | 33.64 |
|                       | Anseriformes | Human        | 0.512  | 4.12  |
|                       | Anseriformes | Other        | 1.044  | 8.40  |
|                       | Environment  | Anseriformes | 0.166  | 1.34  |
|                       | Environment  | Galliformes  | 0.025  | 0.20  |
|                       | Environment  | Human        | 0.120  | 0.97  |
|                       | Environment  | Other        | 0.082  | 0.66  |
|                       | Galliformes  | Anseriformes | 2.828  | 22.75 |
|                       | Galliformes  | Environment  | 0.144  | 1.16  |
|                       | Galliformes  | Human        | 0.406  | 3.27  |
|                       | Galliformes  | Other        | 0.240  | 1.93  |
|                       | Human        | Anseriformes | 0.088  | 0.71  |
|                       | Human        | Environment  | 0.044  | 0.35  |
|                       | Human        | Galliformes  | 0.043  | 0.34  |
|                       | Human        | Other        | 0.082  | 0.66  |
|                       | Other        | Anseriformes | 0.890  | 7.16  |
|                       | Other        | Environment  | 0.113  | 0.91  |
|                       | Other        | Galliformes  | 0.186  | 1.50  |
|                       | Other        | Human        | 0.176  | 1.42  |

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Supplementary Table 6. The Markov rewards for H7 and subtypes by host (Anseriformes and Galliformes).

| Subtype               | Host         | Reward Time (year) | Percentage (%) |
|-----------------------|--------------|--------------------|----------------|
| H7-Eurasian lineage   | Anseriformes | 543.875            | 56.03          |
|                       | Galliformes  | 52.105             | 5.37           |
|                       | Environment  | 228.241            | 23.51          |
|                       | Human        | 67.025             | 6.90           |
|                       | Other        | 79.433             | 8.18           |
| H7-American lineage   | Anseriformes | 149.095            | 43.24          |
|                       | Galliformes  | 148.555            | 43.08          |
|                       | Human        | 27.308             | 7.92           |
|                       | Other        | 19.849             | 5.76           |
| H7N3-Eurasian lineage | Anseriformes | 224.138            | 60.61          |
|                       | Galliformes  | 139.26             | 37.66          |
|                       | Other        | 6.408              | 1.73           |
| H7N3-American lineage | Anseriformes | 299.621            | 57.67          |
|                       | Environment  | 2.937              | 0.57           |
|                       | Galliformes  | 177.599            | 34.18          |
|                       | Other        | 39.43              | 7.59           |
| H7N7-Eurasian lineage | Anseriformes | 355.89             | 74.13          |
|                       | Environment  | 23.605             | 4.92           |
|                       | Galliformes  | 66.035             | 13.75          |
|                       | Human        | 0.654              | 0.14           |
|                       | Other        | 33.901             | 7.06           |
| H7N9-Eurasian lineage | Anseriformes | 135.309            | 36.93          |
|                       | Environment  | 19.199             | 5.24           |
|                       | Galliformes  | 95.244             | 26.00          |
|                       | Human        | 103.006            | 28.11          |
|                       | Other        | 13.628             | 3.72           |
| H7N9-American lineage | Anseriformes | 33.636             | 62.21          |
|                       | Environment  | 0.943              | 1.74           |
|                       | Galliformes  | 8.657              | 16.01          |
|                       | Human        | 2.64               | 4.88           |
|                       | Other        | 8.193              | 15.15          |

Supplementary Table 7. The Markov jumps for H7 and subtypes by host (Wild and Domestic).

| Subtype               | Host Transition |             |              |                |
|-----------------------|-----------------|-------------|--------------|----------------|
|                       | Host (from)     | Host (to)   | Markov Jumps | Percentage (%) |
| H7-Eurasian lineage   | Environment     | Domestic    | 2.091        | 1.49           |
|                       | Environment     | Human       | 0.003        | 0.00           |
|                       | Environment     | Other       | 0.954        | 0.68           |
|                       | Environment     | Wild        | 2.766        | 1.96           |
|                       | Domestic        | Environment | 13.969       | 9.92           |
|                       | Domestic        | Human       | 4.622        | 3.28           |
|                       | Domestic        | Other       | 4.279        | 3.04           |
|                       | Domestic        | Wild        | 37.344       | 26.53          |
|                       | Human           | Environment | 0.003        | 0.00           |
|                       | Human           | Domestic    | 8.301        | 5.90           |
|                       | Human           | Other       | 0.036        | 0.03           |
|                       | Human           | Wild        | 0.004        | 0.00           |
|                       | Other           | Environment | 0.861        | 0.61           |
|                       | Other           | Domestic    | 1.005        | 0.71           |
|                       | Other           | Human       | 0.004        | 0.00           |
|                       | Other           | Wild        | 3.635        | 2.58           |
|                       | Wild            | Environment | 8.514        | 6.05           |
|                       | Wild            | Domestic    | 43.941       | 31.21          |
|                       | Wild            | Human       | 0.003        | 0.00           |
|                       | Wild            | Other       | 8.439        | 5.99           |
| H7-American lineage   | Domestic        | Human       | 3.013        | 11.15          |
|                       | Domestic        | Other       | 1.284        | 4.75           |
|                       | Domestic        | Wild        | 6.631        | 24.54          |
|                       | human           | Domestic    | 0.423        | 1.57           |
|                       | Human           | Other       | 0.016        | 0.06           |
|                       | hman            | Wild        | 0.018        | 0.06           |
|                       | Other           | Domestic    | 0.175        | 0.65           |
|                       | Other           | Human       | 0.025        | 0.09           |
|                       | Other           | Wild        | 0.092        | 0.34           |
|                       | Wild            | Domestic    | 14.453       | 53.49          |
|                       | Wild            | Human       | 0.047        | 0.17           |
|                       | Wild            | Other       | 0.846        | 3.13           |
| H7N3-Eurasian lineage | Domestic        | Wild        | 7.249        | 35.49          |
|                       | Wild            | Domestic    | 13.178       | 64.51          |
| H7N3-American lineage | Environment     | Domestic    | 0.036        | 0.32           |
|                       | Environment     | Wild        | 0.077        | 0.69           |
|                       | Domestic        | Environment | 0.152        | 1.37           |
|                       | Domestic        | Wild        | 1.870        | 16.88          |
|                       | Wild            | Environment | 0.959        | 8.66           |
|                       | Wild            | Domestic    | 7.983        | 72.07          |
| H7N7-Eurasian lineage | Environment     | Domestic    | 3.288        | 3.01           |

|                       |             |             |        |       |
|-----------------------|-------------|-------------|--------|-------|
| H7N9-Eurasian lineage | Environment | Human       | 0.001  | 0.00  |
|                       | Environment | Other       | 1.290  | 1.18  |
|                       | Environment | Wild        | 0.084  | 0.08  |
|                       | Domestic    | Environment | 16.598 | 15.22 |
|                       | Domestic    | Human       | 2.106  | 1.93  |
|                       | Domestic    | Other       | 4.308  | 3.95  |
|                       | Domestic    | Wild        | 30.756 | 28.20 |
|                       | Human       | Environment | 0.001  | 0.00  |
|                       | Human       | Domestic    | 0.020  | 0.02  |
|                       | Human       | Other       | 0.001  | 0.00  |
|                       | Human       | Wild        | 0.001  | 0.00  |
|                       | Other       | Environment | 0.634  | 0.58  |
|                       | Other       | Domestic    | 0.541  | 0.50  |
|                       | Other       | Human       | 0.001  | 0.00  |
|                       | Other       | Wild        | 3.141  | 2.88  |
|                       | Wild        | Environment | 0.226  | 0.21  |
|                       | Wild        | Domestic    | 36.802 | 33.74 |
|                       | Wild        | Human       | 0.002  | 0.00  |
|                       | Wild        | Other       | 9.262  | 8.49  |
|                       | Environment | Domestic    | 1.648  | 1.63  |
|                       | Environment | Human       | 3.690  | 3.65  |
|                       | Environment | Other       | 0.760  | 0.75  |
|                       | Environment | Wild        | 1.127  | 1.12  |
|                       | Domestic    | Environment | 4.224  | 4.18  |
|                       | Domestic    | Human       | 17.976 | 17.79 |
|                       | Domestic    | Other       | 0.062  | 0.06  |
|                       | Domestic    | Wild        | 2.021  | 2.00  |
|                       | Human       | Environment | 18.554 | 18.37 |
|                       | Human       | Domestic    | 37.956 | 37.57 |
|                       | Human       | Other       | 0.164  | 0.16  |
|                       | Human       | Wild        | 1.824  | 1.81  |
|                       | Other       | Environment | 0.012  | 0.01  |
|                       | Other       | Domestic    | 0.006  | 0.01  |
|                       | Other       | Human       | 0.005  | 0.00  |
|                       | Other       | Wild        | 0.008  | 0.01  |
|                       | Wild        | Environment | 3.455  | 3.42  |
|                       | Wild        | Domestic    | 6.262  | 6.20  |
|                       | Wild        | Human       | 1.235  | 1.22  |
|                       | Wild        | Other       | 0.038  | 0.04  |
| H7N9-American lineage | Environment | Human       | 0.158  | 1.82  |
|                       | Environment | Domestic    | 0.032  | 0.37  |
|                       | Environment | Wild        | 0.124  | 1.43  |
|                       | Human       | Environment | 0.060  | 0.70  |
|                       | Human       | Domestic    | 0.044  | 0.50  |

|          |             |       |       |
|----------|-------------|-------|-------|
| Human    | Wild        | 0.059 | 0.68  |
| Domestic | Environment | 0.171 | 1.97  |
| Domestic | Human       | 0.431 | 4.98  |
| Domestic | Wild        | 1.916 | 22.12 |
| Wild     | Environment | 1.062 | 12.26 |
| Wild     | Human       | 0.554 | 6.40  |
| Wild     | Domestic    | 4.051 | 46.77 |

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Supplementary Table 8. The Markov rewards for H7 and subtypes by host (Wild and Domestic).

| Subtype               | Host        | Reward Time (year) | Percentage (%) |
|-----------------------|-------------|--------------------|----------------|
| H7-Eurasian lineage   | Environment | 42.326             | 4.86           |
|                       | Domestic    | 330.607            | 37.94          |
|                       | Human       | 53.887             | 6.18           |
|                       | Other       | 105.758            | 12.14          |
|                       | Wild        | 338.797            | 38.88          |
| H7-American lineage   | Domestic    | 119.238            | 34.45          |
|                       | Human       | 24.638             | 7.12           |
|                       | Other       | 3.753              | 1.08           |
|                       | Wild        | 198.529            | 57.35          |
| H7N3-Eurasian lineage | Domestic    | 236.546            | 64.89          |
|                       | Wild        | 127.976            | 35.11          |
| H7N3-American lineage | Environment | 2.154              | 0.47           |
|                       | Domestic    | 163.181            | 35.52          |
|                       | Wild        | 294.104            | 64.01          |
| H7N7-Eurasian lineage | Environment | 25.248             | 5.13           |
|                       | Domestic    | 196.911            | 40.03          |
|                       | Human       | 0.648              | 0.13           |
|                       | Other       | 22.226             | 4.52           |
|                       | Wild        | 246.891            | 50.19          |
| H7N9-Eurasian lineage | Environment | 22.996             | 6.14           |
|                       | Domestic    | 127.272            | 33.99          |
|                       | Human       | 106.318            | 28.39          |
|                       | Other       | 2.78               | 0.74           |
|                       | Wild        | 115.088            | 30.73          |
| H7N9-Eurasian lineage | Environment | 0.872              | 1.54           |
|                       | Human       | 2.856              | 5.04           |
|                       | Domestic    | 7.193              | 12.70          |
|                       | Wild        | 45.719             | 80.72          |

Supplementary Table 9. The comparison of the weighted branch dispersal velocity (median value, 95% HPD).

| Subtype               | Anseriformes                  | Galliformes                | <i>W</i> | <i>P</i>  | Wild                          | Domestic                   | <i>W</i> | <i>P</i>  |
|-----------------------|-------------------------------|----------------------------|----------|-----------|-------------------------------|----------------------------|----------|-----------|
| H7-Eurasian lineage   | 586.51<br>(518.91, 682.14)    | 294.44<br>(253.42, 343.79) | 10000    | < 2.2e-16 | 654.60<br>(595.14, 751.59)    | 581.32<br>(478.06, 653.14) | 1016     | < 2.2e-16 |
| H7-American lineage   | 189.66<br>(112.79, 929.07)    | 8.34<br>(2.29, 19.94)      | 10000    | < 2.2e-16 | 408.41<br>(304.88, 511.47)    | 172.85<br>(87.74, 513.66)  | 167      | 0.0005459 |
| H7N3-Eurasian lineage | 594.388<br>(516.63, 691.75)   | 2.94<br>(1.30, 10.37)      | 10000    | < 2.2e-16 | 677.24<br>(560.01, 805.16)    | 43.02<br>(22.82, 305.56)   | 0        | < 2.2e-16 |
| H7N3-American lineage | 1561.18<br>(1293.88, 1881.26) | 3.15<br>(1.46, 5.91)       | 10000    | < 2.2e-16 | 1602.18<br>(1274.80, 1859.94) | 3.70<br>(2.23, 9.42)       | 0        | < 2.2e-16 |
| H7N7-Eurasian lineage | 621.22<br>(503.67, 707.20)    | 346.68<br>(271.21, 429.61) | 9999     | < 2.2e-16 | 507.47<br>(416.94, 609.94)    | 766.87<br>(631.36, 943.98) | 9982     | < 2.2e-16 |
| H7N9-Eurasian lineage | 338.39<br>(205.39, 497.05)    | 12.10<br>(7.49, 17.44)     | 10000    | < 2.2e-16 | 275.37<br>(105.04, 451.31)    | 56.62<br>(34.74, 122.20)   | 87       | < 2.2e-16 |
| H7N9-Eurasian lineage | 1444.47<br>(201.08, 2198.11)  | 4.36<br>(2.68, 6.51)       | 10000    | < 2.2e-16 | 296.41<br>(54.74, 760.83)     | 4.90<br>(3.05, 7.52)       | 0        | < 2.2e-16 |

Note: Statistical significance was assessed using the two-sided Mann-Whitney U test (Wilcoxon rank-sum test), as the data did not meet the assumption of normality (Shapiro–Wilk test,  $p < 0.05$  for at least one group). No adjustment was made for multiple comparisons across subtypes. Test statistics (*W*) and exact p-values are reported. p-values are displayed as "< 2.2e-16" due to computational precision limits in R. All analyses were based on independent virus isolates.

Supplementary Table 10. The weighted branch dispersal velocity of high and low pathogenic H7 viruses and subtypes in different hosts (median value, 95% HPD).

| Subtype   | Anseriformes            | Galliformes             | Wild                     | Domestic                |
|-----------|-------------------------|-------------------------|--------------------------|-------------------------|
| H7-HPAI   | -                       | 175.42 (129.97, 211.20) | 274.63 (144.90, 1121.37) | 196.67 (153.66, 256.48) |
| H7-LPAI   | 651.40 (581.88, 719.04) | 156.14 (115.70, 199.84) | 465.09 (122, 655.54)     | 540.60 (474.40, 610.32) |
| H7N3-HPAI | -                       | 33.13 (18.49, 54.49)    | -                        | 37.30 (21.77, 55.83)    |
| H7N3-LPAI | 497.21 (430.18, 569.87) | 77.06 (21.23, 126.09)   | 494.84 (413.20, 574.23)  | 282.04 (218.76, 376.17) |
| H7N7-HPAI | -                       | 353.08 (279.38, 429.86) | -                        | 364.20 (278.78, 430.15) |
| H7N7-LPAI | 600.54 (508.59, 691.17) | 144.85 (104.33, 212.12) | 471.99 (395.99, 567.30)  | 774.76 (652.39, 860.32) |
| H7N9-HPAI | -                       | 330.54 (252.64, 425.51) | -                        | 290.48 (194.47, 396.10) |
| H7N9-LPAI | 425.46 (313.98, 529.27) | 247.20 (145.30, 349.14) | 358.86 (263.01, 491.65)  | 335.67 (240.19, 461.93) |

Note: HPAI, high-pathogenic avian influenza; LPAI, low-pathogenic avian influenza. "-" indicates insufficient data for calculation.