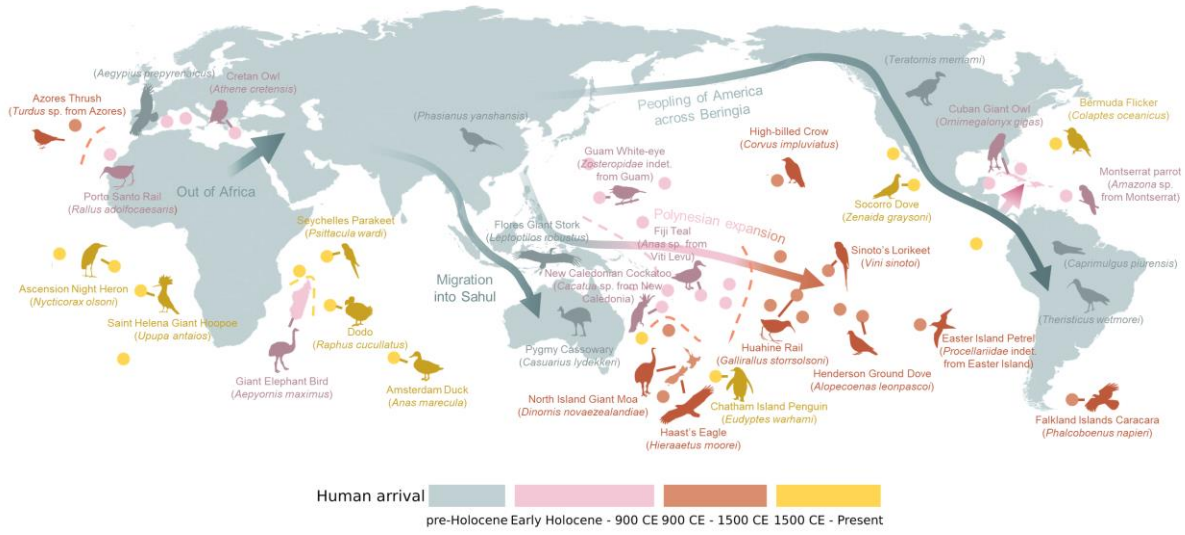
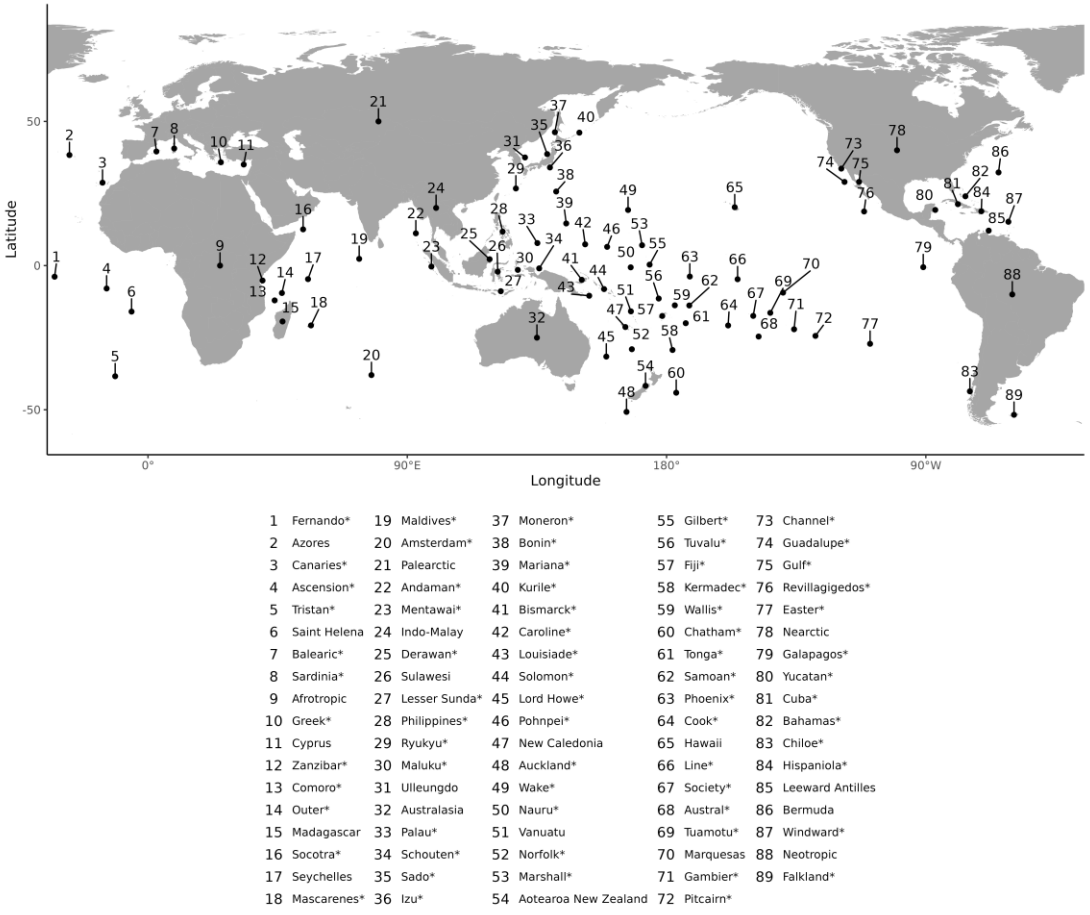
Undiscovered bird extinctions obscure the true magnitude of human-driven extinction waves

Supplementary Information



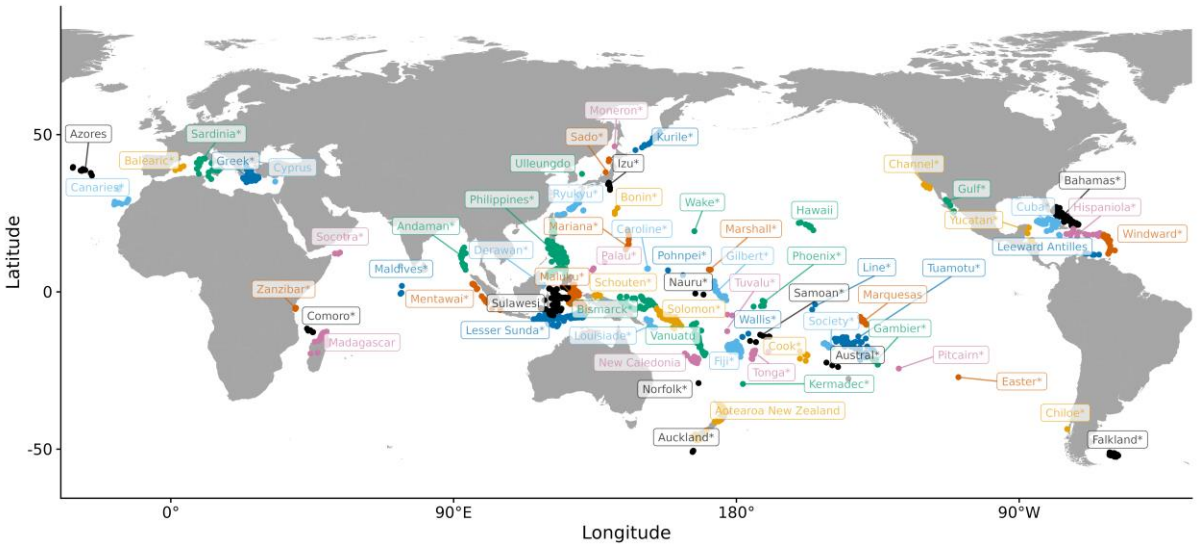
Supplementary Fig. 1: Human colonization of the globe, with additional detail. Human colonization is grouped into four major waves (see legend; pre-Holocene, Early Holocene - 900 CE, 900 CE - 1500 CE, 1500 CE - Present). Major human dispersal routes are indicated with arrows[1], with human migration into Eastern Polynesia estimated at 900 CE[2]. Regions are coloured based on their first human arrival; only regions with recorded (fossil or observed) bird extinctions are shown – see Supplementary Fig. 2 and Supplementary Data 1 for region locations and names. The map is centred on 145° E longitude. Icons show a range of example extinctions, with names. The icons are all from PhyloPic.org under Public Domain Dedication 1.0 licenses (see collection https://www.phylopic.org/collections/b2c5ed62-52af-0219-22e1-76a6538ce493). Creator credits: Birgit Lang (*Vini sinotoi* [*Psittacula derbiana*]), FJDegrange (*Colaptes oceanicus* [*Colaptes campestris*]), Ferran Sayol (*Amazona* sp. from

Montserrat [*Amazona aestiva*], *Athene cretensis* [*Athene noctua*], *Cacatua* sp. from New Caledonia [*Cacatua sulphurea*], *Caprimulgus piurensis* [*Caprimulgus*], *Casuarius lydekkeri* [*Casuarius casuarius*], *Leptoptilos robustus* [*Ciconia*], *Zenaida graysoni* [*Columba*], *Psittacula wardi* [*Cyanoliseus patagonus*], *Nycticorax olsoni* [*Nycticorax*], *Alopecoenas leonpascoi* [*Patagioenas*], *Rallus adolfocaesaris*, *Gallirallus storrsolsoni* [*Rallus*], *Upupa antaios* [*Upupa epops*], *Aegypius prepyrenaicus* [*Vultur gryphus*], *Zosteropidae* indet. from Guam [*Zosterops*]), Francesco "Architetto" Rollandin (*Turdus* sp. from Azores [*Turdidae*]), Juan Carlos Jerí (*Procellariidae* indet. from Easter Island [*Puffinus griseus*]), Mattia Menchetti (*Phasianus yanshansis* [*Phasianus colchicus*]), Peileppe (*Corvus impluviatus* [*Corvus brachyrhynchos*]), Rob Cooke (*Hieraaetus moorei* [*Accipitridae*], *Aepyornis maximus* [*Aepyornis maximus*], *Ornimegalonyx gigas* [*Ornimegalonyx gigas*], *Teratornis merriami* [*Teratornis merriami*], *Theristicus wetmorei* [*Theristicus wetmorei*]), Sean McCann (*Phalcoboenus napieri* [*Ibycter americanus*]), Sharon Wegner-Larsen (*Anas marecula*, *Anas* sp. from Viti Levu [*Anas fulvigula*]), and Steven Traver (*Eudyptes warhami* [*Aptenodytes patagonicus*], *Dinornis novaezealandiae* [*Dinornis novaezealandiae*], *Raphus cucullatus* [*Raphus cucullatus*]).

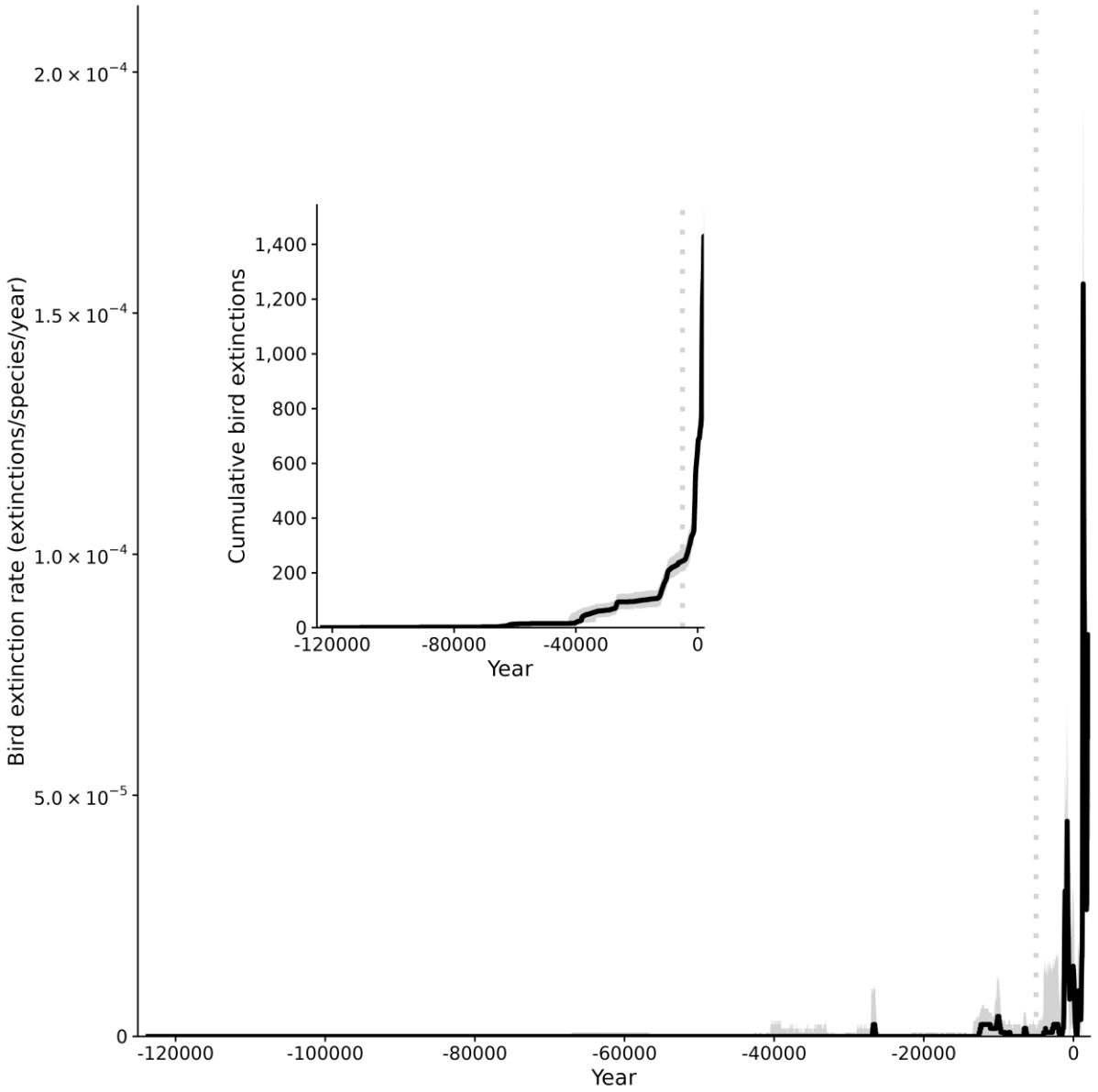


1	Fernando*	19	Maldives*	37	Moneron*	55	Gilbert*	73	Channel*
2	Azores	20	Amsterdam*	38	Bonin*	56	Tuvalu*	74	Guadalupe*
3	Canaries*	21	Palearctic	39	Mariana*	57	Fiji*	75	Gulf*
4	Ascension*	22	Andaman*	40	Kurile*	58	Kermadec*	76	Revillagigedos*
5	Tristan*	23	Mentawai*	41	Bismarck*	59	Wallis*	77	Easter*
6	Saint Helena	24	Indo-Malay	42	Caroline*	60	Chatham*	78	Nearctic
7	Balearic*	25	Derawan*	43	Louisiade*	61	Tonga*	79	Galapagos*
8	Sardinia*	26	Sulawesi	44	Solomon*	62	Samoan*	80	Yucatan*
9	Afrotropic	27	Lesser Sunda*	45	Lord Howe*	63	Phoenix*	81	Cuba*
10	Greek*	28	Philippines*	46	Pohnpei*	64	Cook*	82	Bahamas*
11	Cyprus	29	Ryukyu*	47	New Caledonia	65	Hawaii	83	Chiloe*
12	Zanzibar*	30	Maluku*	48	Auckland*	66	Line*	84	Hispaniola*
13	Comoro*	31	Ulleungdo	49	Wake*	67	Society*	85	Leeward Antilles
14	Outer*	32	Australasia	50	Nauru*	68	Austral*	86	Bermuda
15	Madagascar	33	Palau*	51	Vanuatu	69	Tuamotu*	87	Windward*
16	Socotra*	34	Schouten*	52	Norfolk*	70	Marquesas	88	Neotropic
17	Seychelles	35	Sado*	53	Marshall*	71	Gambier*	89	Falkland*
18	Mascarenes*	36	Izu*	54	Aotearoa New Zealand	72	Pitcairn*		

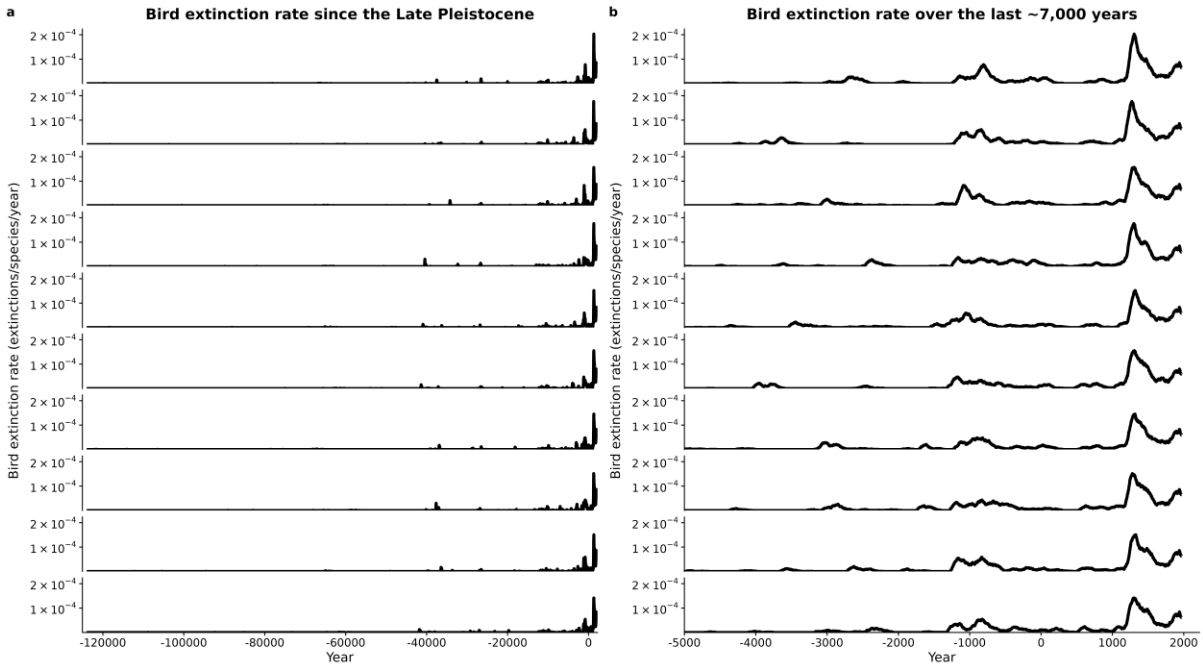
Supplementary Fig. 2: Global distribution of the 89 regions with bird extinctions. Includes all archipelagos and biogeographic realms[5] with bird extinctions. Archipelago names have been shortened for brevity where applicable – indicated with asterisks; for full archipelago names see Supplementary Data 1. The map is centred on 145° E longitude.



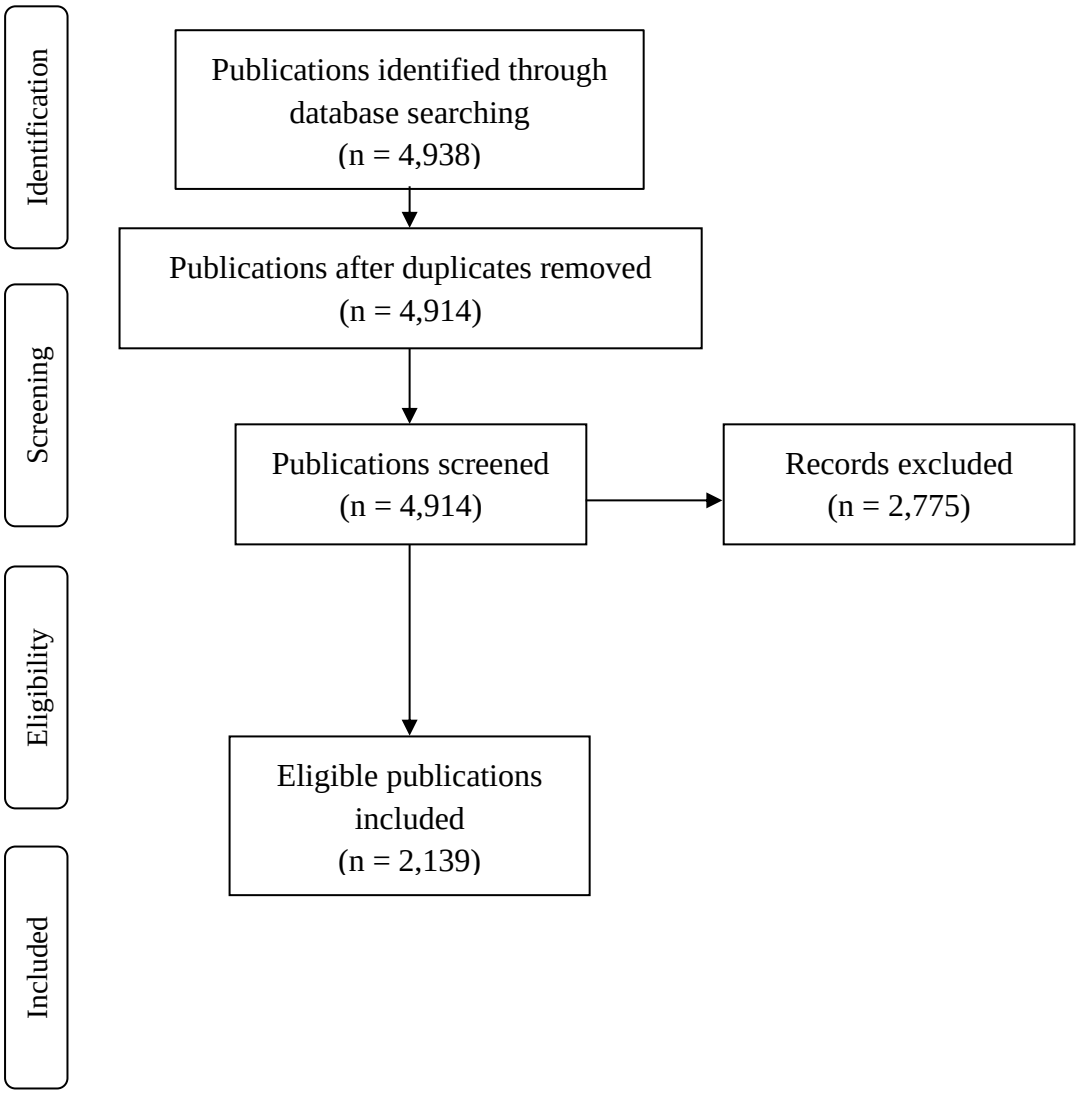
Supplementary Fig. 3: Archipelagos with the potential for undiscovered bird extinctions. We identified 1,488 islands (coloured areas/points) that were settled by humans pre-1500 CE, are >5 km^2, and were not covered by glaciers or connected to the mainland during the Last Glacial Maximum. We grouped these islands into 69 archipelagos. Aotearoa New Zealand is included for context, although we assume complete knowledge of the avifauna for Aotearoa New Zealand[3,4] and therefore zero undiscovered extinctions. Archipelago names have been shortened for brevity where applicable – indicated with asterisks; for full archipelago names see Supplementary Data 1. The map is centred on 145° E longitude.



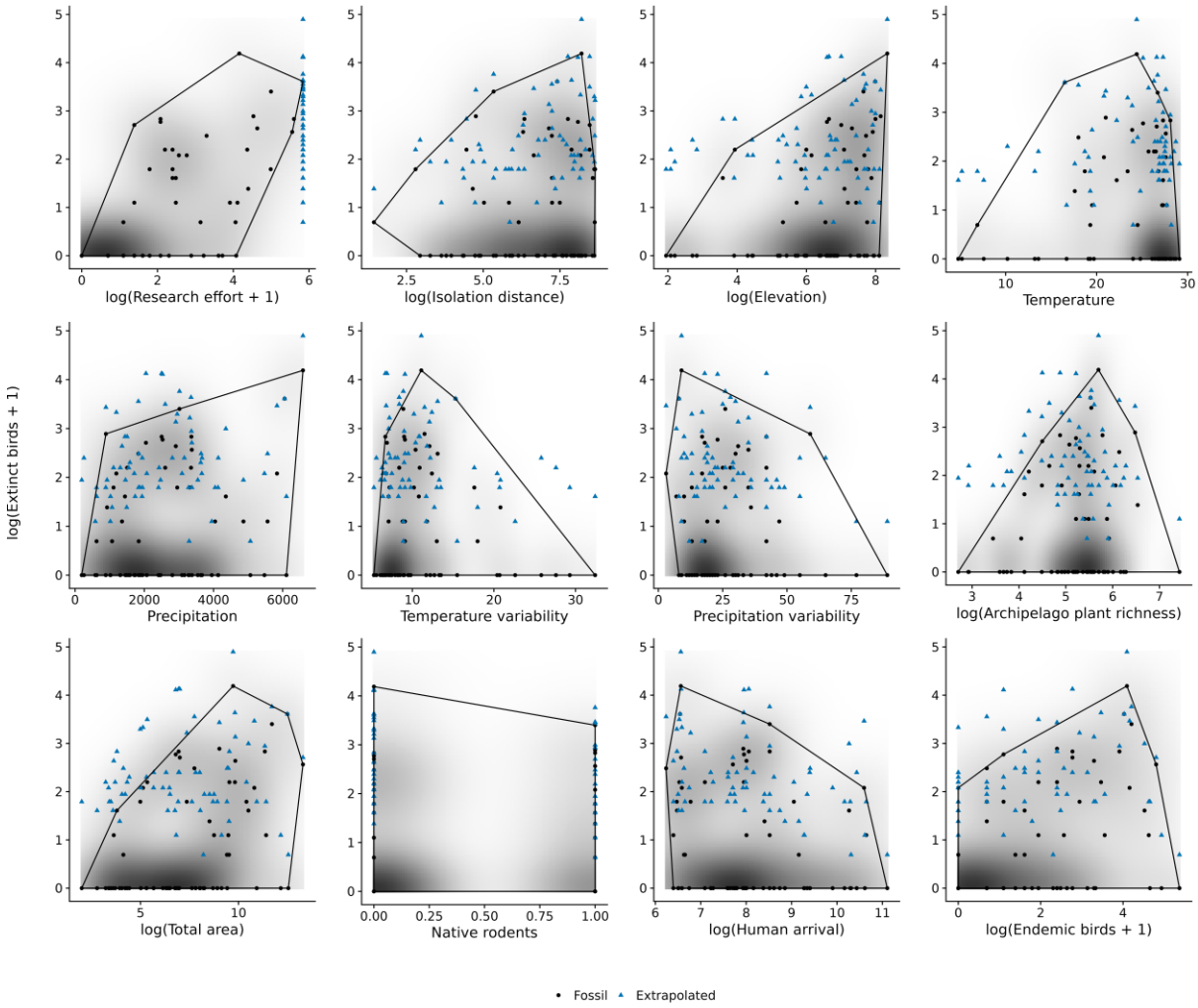
Supplementary Fig. 4: Bird extinction rate since the Late Pleistocene. Bird extinction rate is the median number of extinctions per species per year (extinctions/species/year) across 1,000 estimates of rolling means (100-year moving window; Supplementary Fig. 5); envelopes represent 95% credible intervals (n = 1,000). The inset shows cumulative bird extinctions since the Late Pleistocene. The dotted lines show the start of the focal period for Fig. 3 (5000 BCE). Source data are provided.



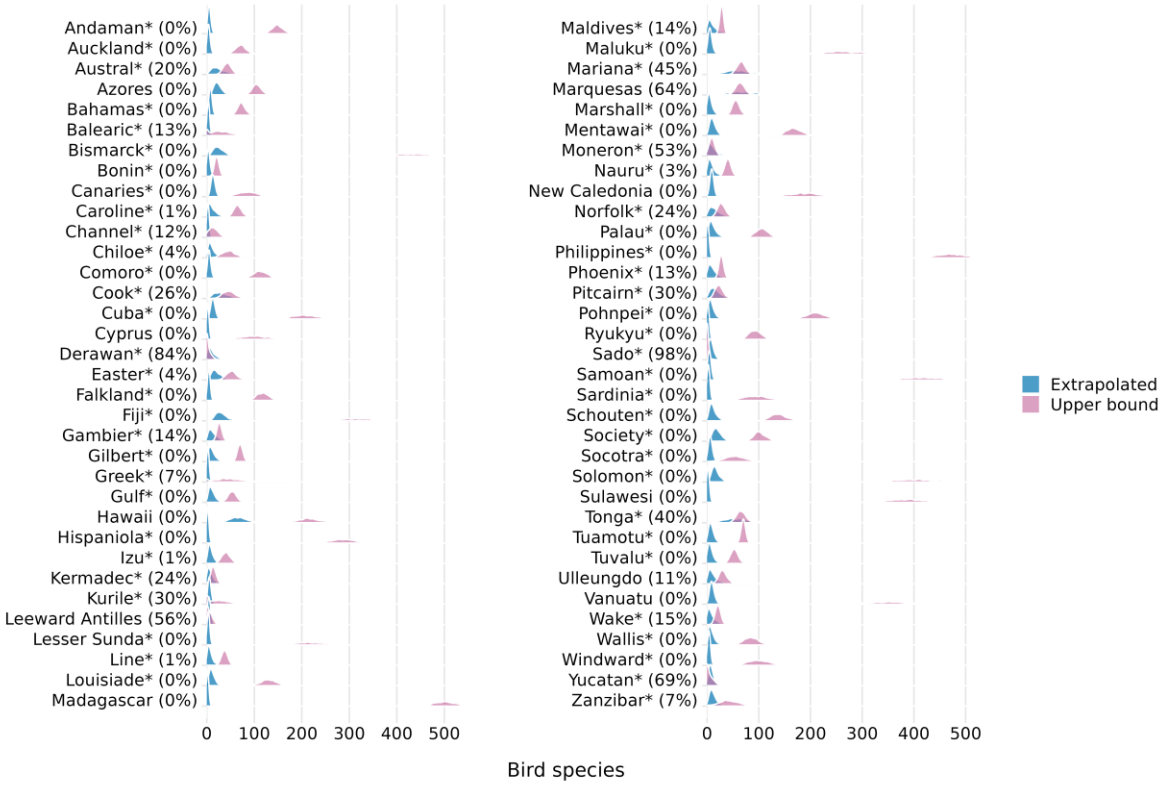
Supplementary Fig. 5: Individual estimates of bird extinction rate. a Bird extinction rate since the Late Pleistocene and **b** over the last ~7,000 years. Ten individual estimates out of 1,000 are displayed. Bird extinction rate is the number of extinctions per species per year (extinctions/species/year), averaged across a 100-year moving window for 10 separate estimates. The number of extinctions (variation in the number of undiscovered extinctions and possibly extinct species) and the timing of extinctions (uncertainty associated with human arrival dates and exponential decay – randomization of exponential extinction sequence) varies per estimate – see Methods. Source data are provided.



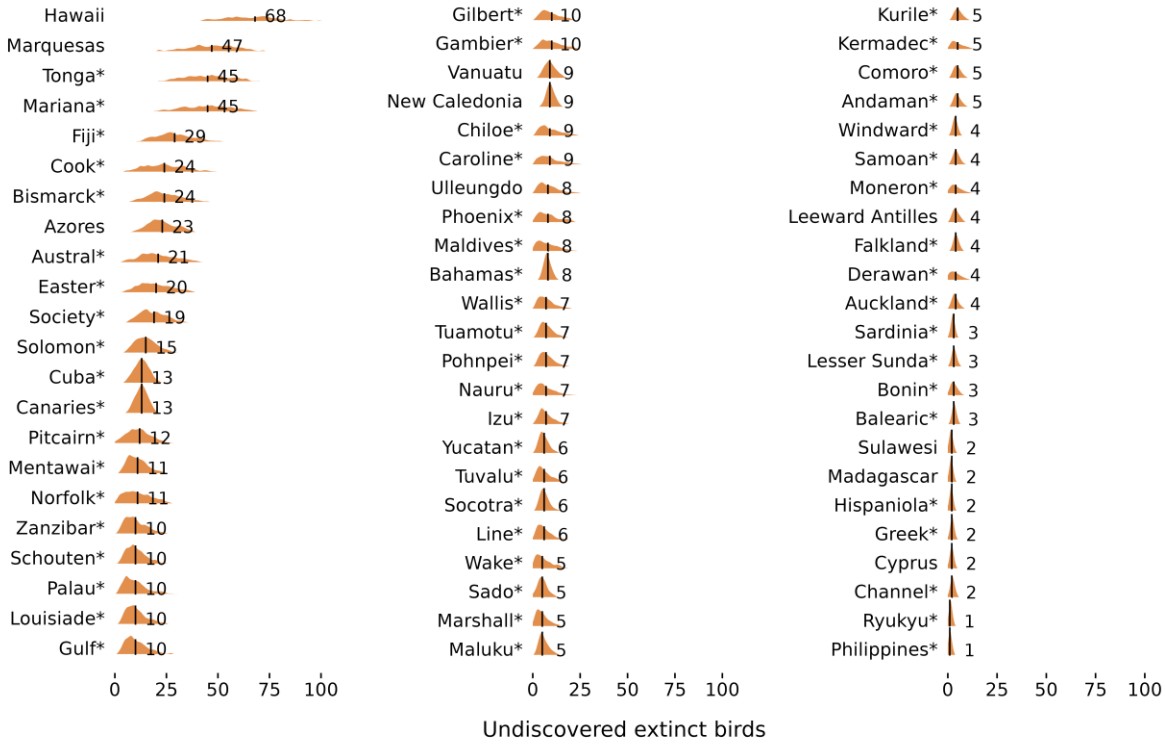
Supplementary Fig. 6: PRISMA flow diagram. Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA)[6] flow diagram for research effort.



Supplementary Fig. 7: Comparison of fossil and extrapolated estimates of extinct birds. The fossil and extrapolated distributions of extinct birds for each predictor included in the model across 69 archipelagos (fossil n = 69, extrapolated n = 69). The extrapolated estimates are the median total of fossil + undiscovered (prior to rejection sampling) extinct birds per archipelago. Convex hulls (black lines) are drawn enclosing the recorded data (black dots). The colour gradient indicates regions of highest (black) to lowest (white) recorded data density. Extrapolated estimates that fall within the convex hulls can be recognized as interpolated, whereas extrapolated estimates outside the convex hulls can be recognized as extrapolated. Source data are provided.



Supplementary Fig. 8: Archipelago upper bounds. Density distributions of extrapolated undiscovered extinct birds (extrapolations from the LM) and the upper bound of potential additional bird species (continental richness minus the number of fossil extinctions, observed extinctions, and extant bird species) across 68 archipelagos (excluding Aotearoa New Zealand) (extrapolated n = 1,000; upper bound n = 1,000 per archipelago). The numbers in brackets are the percent of records that were rejected during the rejection sampling. Source data are provided.



Supplementary Fig. 9: Distributions of undiscovered extinct birds across 68 archipelagos. Plots show the density distributions of undiscovered extinct birds per archipelago after rejection sampling, with a black line and label indicating the median estimate (n = 1,000 per archipelago). The 69 focal archipelagos minus Aotearoa New Zealand which is assumed to have zero undiscovered extinctions. Source data are provided.

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