Rarity and conservation status do not predict vertebrate population trends

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Abstract

Species' attributes such as rarity and conservation status are often assumed to predict population change which in turn can influence conservation decision-making; however, there are very few empirical tests across taxa and biomes. We use a database of 9284 vertebrate populations from 2084 species in the UK and globally to quantify population change across rarity, Red List status, biomes and taxa. We found that rarity metrics (geographic range, population size and habitat specificity) did not predict population trends in the UK and globally, but greater fluctuations were more likely for smaller populations and species with larger ranges. There was no consistent pattern of net declines with increasing Red List status. We found higher-order taxonomic, but not geographic patterning of population change at global scales, with pronounced declines for amphibians. On a finer taxonomic scale, within amphibian, bird and reptile classes species, for which species-level phylogenies have been especially well resolved, there was no strong phylogenetic or taxonomic signal in the variation in population trends and fluctuations. Our findings suggest that rarity metrics, conservation status and phylogenetic clustering are poor predictors of vertebrate population trends of well monitored species, but that species with smaller populations were nevertheless more likely to fluctuate, potentially increasing their extinction risk. Thus, improved population monitoring across a diverse range of taxa is required, as species rarity and conservation status alone are insufficient to inform conservation prioritization.

Significance statement

Understanding which factors predispose species to population change is essential for conservation decision-making. Species' rarity and conservation status are often assumed to predict population change and thus could inform conservation management. However, empirical tests of this assumption are lacking. We found that rarity and conservation status did not predict population change, but species with smaller populations and larger ranges were more likely to fluctuate. We found taxonomic but not geographic patterning of population change among over 9000 populations from over 2000 vertebrate species, among which only amphibians experienced net declines. Our study suggests that with improved monitoring of diverse taxa and metrics beyond rarity, we can better inform conservation prioritization.

Introduction

Species' attributes such as rarity, conservation status, phylogenetic relatedness, distribution and taxon are often assumed to predict variation in extinction risk and in population change (1–4). Population trends (5) and population fluctuations (6) have both been frequently linked with a higher likelihood of a species' extinction. For decades, conservation efforts have focused on protecting rare species (7–9), those with restricted geographic extents, small population sizes or high habitat specificity, as these species are thought to be more likely to be threatened with extinction. However, there are very few empirical tests of the influence of rarity and conservation status on population change and extinction risk (10–12), and those that exist mostly focus on either specific taxa (13–15) or on population declines alone (10, 15–18), and not population change across taxa and geographic regions. Population change is the fundament process leading to community reassembly (19). And thus, in a period of accelerating human impacts and global change (17, 20), global analyses of population change are required to inform conservation policy and decision-making.

Understanding what factors best explain population change and extinction risk across species has been a key focus in population ecology and conservation biology, with possible measures including species' attributes and traits, such as rarity (10–12, 14, 21, 22). Extinction risk, the likelihood that a species will go extinct within a given time frame (23), is widely assumed to increase when species are rare (i.e., they have small geographic ranges (13), small population sizes (24) and are very specialized in their habitat preferences (16). As per population dynamics theory, species with small populations are more likely to undergo stochastic fluctuations that

could lead to extinction at any given point (6, 25) and local population declines and extinctions can lead to eventual global species extinction (18). Small populations are also more vulnerable to demographic stochasticity and inbreeding (26, 27). Allee effects, the relationship between individual fitness and population density, further increase the likelihood of declines due to lack of potential mates and low reproductive output once populations reach a critically low density (28, 29). Thus, small populations from rare species are thought to be more likely to experience population declines (5, 10, 30).

Investigating population change over time in relation to rarity can provide insights into species' extinction risk. Rabinowitz (31) defined 'seven forms of rarity' based on the combinations of the extremes of three characteristics: geographic range (small vs. large), habitat specificity (generalist vs. specialist), and local population size (small vs. large). Rarity can be either a state in which species naturally occur, or a state to which they are driven following external perturbations (32). However, previous analyses of the influence of rarity on population trends and extinction risk have shown mixed results. Geographic range did not correlate with species' vulnerability to extinction in 45 bird and mammal taxa from all continents except Antarctica (11) and the minimum viable population size did not vary with geographic range and population size in 629 invertebrate, 529 vertebrate and 30 plant species (33). In contrast, in bats, geographic range was found to be the most important predictor of extinction risk (13). Thus, a generalizable relationship between rarity and population declines and increased extinction risk across taxa and geographic regions remains unquantified. However, simplifying the concept of rarity so that it can be

106 modelled as a predictor of population change remains a considerable challenge (19,
107 34).
108
109 Investigations of potential factors that predispose species to population change
110 across geographic and taxonomic scales (e.g., from country to biome level, and from
111 population to taxa level) are particularly valuable for guiding conservation decision-
112 making (11, 17, 19, 20). Conservation actions are predominantly implemented on
113 smaller, country-specific, regional or local scales (35, 36), yet policy may be
114 determined for larger regions or broader taxonomic groups (37, 38). Similarly, overall
115 species' Red List status is determined on a global scale based on multiple criteria
116 (23), but on a local scale, populations may vary in the direction and magnitude of
117 experienced change (16, 20, 39–41). Population time-series data from the Living
118 Planet Database (LPD), complemented by extensive occurrence data from the
119 Global Biodiversity Information Facility (GBIF) and BirdLife (42), and information on
120 species habitat preferences and conservation status from the IUCN Red List, provide
121 a unique opportunity to test which species attributes explain global and country-
122 specific population trends across well-monitored vertebrate species.
123
124 Here, we addressed the research question: Is variation in vertebrate population
125 change (trends and fluctuations) explained by differences in species attributes, such
126 as rarity metrics (geographic range, mean population size and habitat specificity) and
127 conservation status? We tested the following hypotheses: 1) rare species are more
128 likely to be experiencing negative population trends than common species on UK
129 and global scales; 2) declining populations are more likely for species from more
130 threatened Red List categories, 3) there are geographic, taxonomic and phylogenetic

patterns in vertebrate population trends and fluctuations (e.g., hotspots of declines, increases or fluctuations in abundances in specific regions, for specific taxa and among specific clades) and 4) rare species or those with a higher Red List status are more likely to experience greater population fluctuations.

Results

Population trends in the UK and globally across rarity

Across monitored vertebrate populations in the UK and globally, species with smaller ranges, smaller population sizes, or narrower habitat specificity (i.e., rare species) were not more prone to population declines than common species (Figure 1a-f, Table S2).

Population trends in the UK and globally across Red List status

Over the monitoring duration for populations in the UK, species classified as least concern and near threatened had a positive population trend (LC: slope = 0.01, CI = 0.004 to 0.02; NT: slope = 0.03, CI = 0.01 to 0.06), whereas vulnerable, endangered and critically endangered populations did not experience net directional change (Figure 1i and Table S2). Globally, we found increasing, decreasing and stable populations across all Red List categories of conservation status (Figure 1j). For example, a population of the least concern species red deer (*Cervus elaphus*) in Canada declined by 68% over 7 years going from 606 to 194 individuals and a population of the critically endangered Hawksbill sea turtle (*Eretmochelys imbricate*) from Barbados increased by 269% over 7 years going from 89 to 328 individuals. Across all categories, there was no consistent pattern of greater population declines in the UK and globally with increasing Red List status (Figure 2i-j, Table S2).

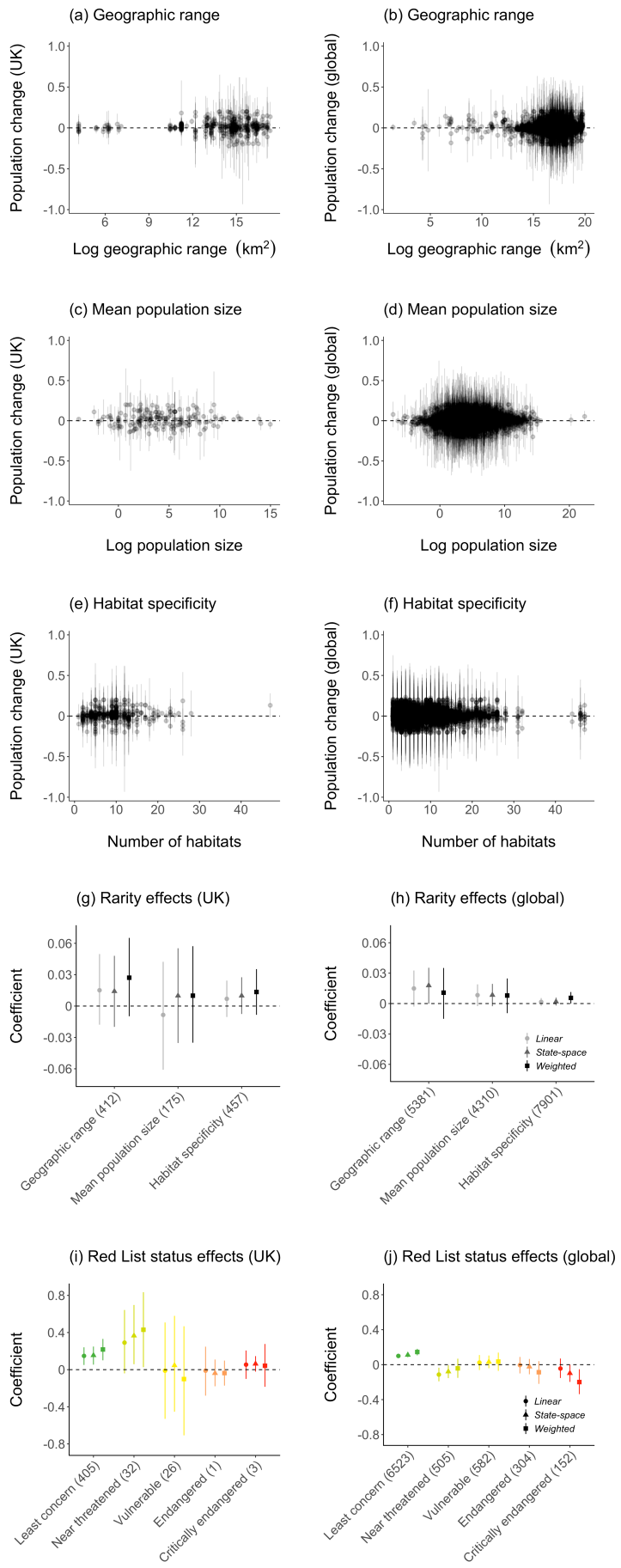

(a) Geographic range
Population change (UK)
Log geographic range (km2)
(b) Geographic range
Population change (global)
Log geographic range (km2)
(c) Mean population size
Population change (UK)
Log population size
(d) Mean population size
Population change (global)
Log population size
(e) Habitat specificity
Population change (UK)
Number of habitats
(f) Habitat specificity
Population change (global)
Number of habitats
(g) Rarity effects (UK)
Coefficient
Geographic range (412)
Mean population size (175)
Habitat specificity (457)
(h) Rarity effects (global)
Coefficient
Linear
State-space
Weighted
Geographic range (5381)
Mean population size (4310)
Habitat specificity (7901)
(i) Red List status effects (UK)
Coefficient
Least concern (405)
Near threatened (32)
Vulnerable (26)
Endangered (1)
Critically endangered (3)
(j) Red List status effects (global)
Coefficient
Linear
State-space
Weighted
Least concern (6523)
Near threatened (505)
Vulnerable (582)
Endangered (304)
Critically endangered (152)

Figure 1. Effects of rarity metrics on vertebrate population trends in the UK (plots a, c, e, g) and globally (b, d, f, h), and vertebrate population trends in the UK (plot i) and globally (plot j) across species' Red List status. The numbers on x axis show sample size for each category. Geographic range refers to the global range of UK species (plot a) and of bird species in the global LPD (plot b). See Figure S11 for geographic distribution of population records based on species' Red List status. The *mu* values of population change (plots a-f) are derived from state-space model fits of changes in abundance over the monitoring duration for each population. Effect sizes (plots g and h) are population trends calculated using linear models (light grey circles), state-space models (*mu*, grey triangles), and population trends (*mu*) weighted by *tau* (black squares), the observation error estimate from the state-space models. Error bars show confidence intervals around population trend (*mu,* plots a-f) and credible intervals for *mu* across rarity metrics (plots g and h). Effect sizes (plots g and h) were standardized by dividing the effect size by the standard deviation of the corresponding input data. See Table S2 for model outputs.

Global population trends across latitude and biomes

Global vertebrate population trends did not show distinct geographic patterning, as increasing, stable and declining populations were present on all continents and across all latitudes (Figure 2a and b). Populations in Mediterranean forests, montane grasslands, polar freshwaters, temperate wetlands, tropical forests and tropical coral biomes were more likely to increase, whereas populations from the remaining studied biomes were not more likely to be increasing versus decreasing (Figure 2c and Table S2). The lack of biogeographic patterning in vertebrate population trends was also apparent on a UK scale (Figure S6 and Table S2).

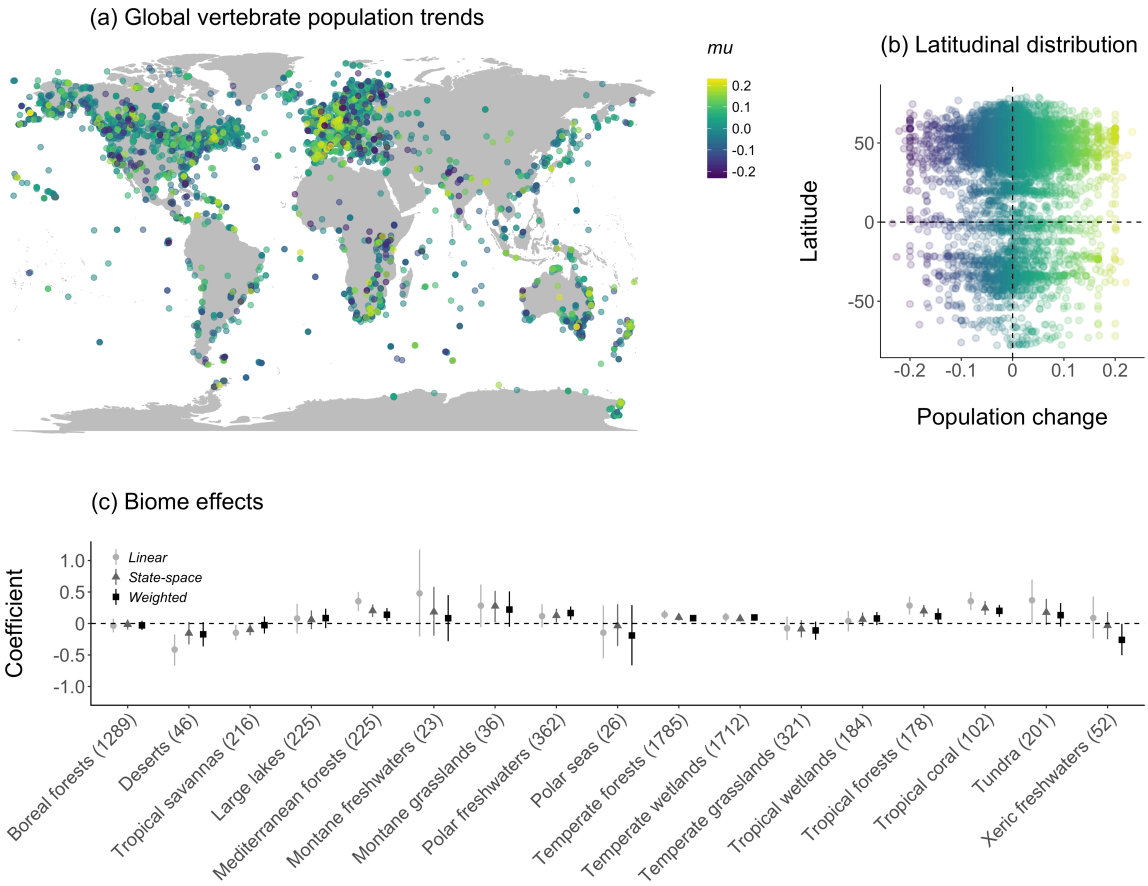


Figure 2. Lack of biogeographic patterning in global vertebrate population trends (plot a), latitudinal distribution of population trends (plot b), and population trends across biomes (plot c). Results include 9284 populations from 2084 species. The numbers on the x axis show the sample size for each biome (plot c). Effect sizes (plot c) include the population trend calculated using linear models (light grey circles), state-space models (*mu*, grey triangles), and population trend (*mu*) weighted by *tau*, the observation error estimate from the state-space models (black squares). Error bars show 95% credible intervals (plot c). Effect sizes (plot c) were standardized by dividing the effect size by the standard deviation of the corresponding input data. See Table S2 for model outputs.

Global population trends across systems and taxa

Globally, monitored vertebrate populations experienced net population increases in all three studied systems (freshwater slope = 0.005, CI = 0.002 to 0.01; marine slope = 0.004, CI = 0.002 to 0.01; terrestrial slope = 0.003, CI = 0.001 to 0.005, Figure 3a, c and e, Table S2). In freshwater and terrestrial habitats, there was a bimodal distribution of population change (Hartigans' dip test, D = 0.04, $p < 0.01$, Figure S7a), likely driven by the bimodal distribution for bird populations (Hartigans' dip test, D = 0.04, $p < 0.01$, Figure S7b). Amphibian populations experienced net declines (slope = -0.01, CI = -0.02 to -0.005), whereas birds, mammals and reptiles underwent net increases (slope = 0.004, CI = 0.003 to 0.01; slope = 0.01, CI = 0.01 to 0.01; slope = 0.02, CI = 0.01 to 0.02). Bony fish population trends were centred on zero (slope = -0.001, CI = -0.004 to 0.002, Figure 3b, d and f).

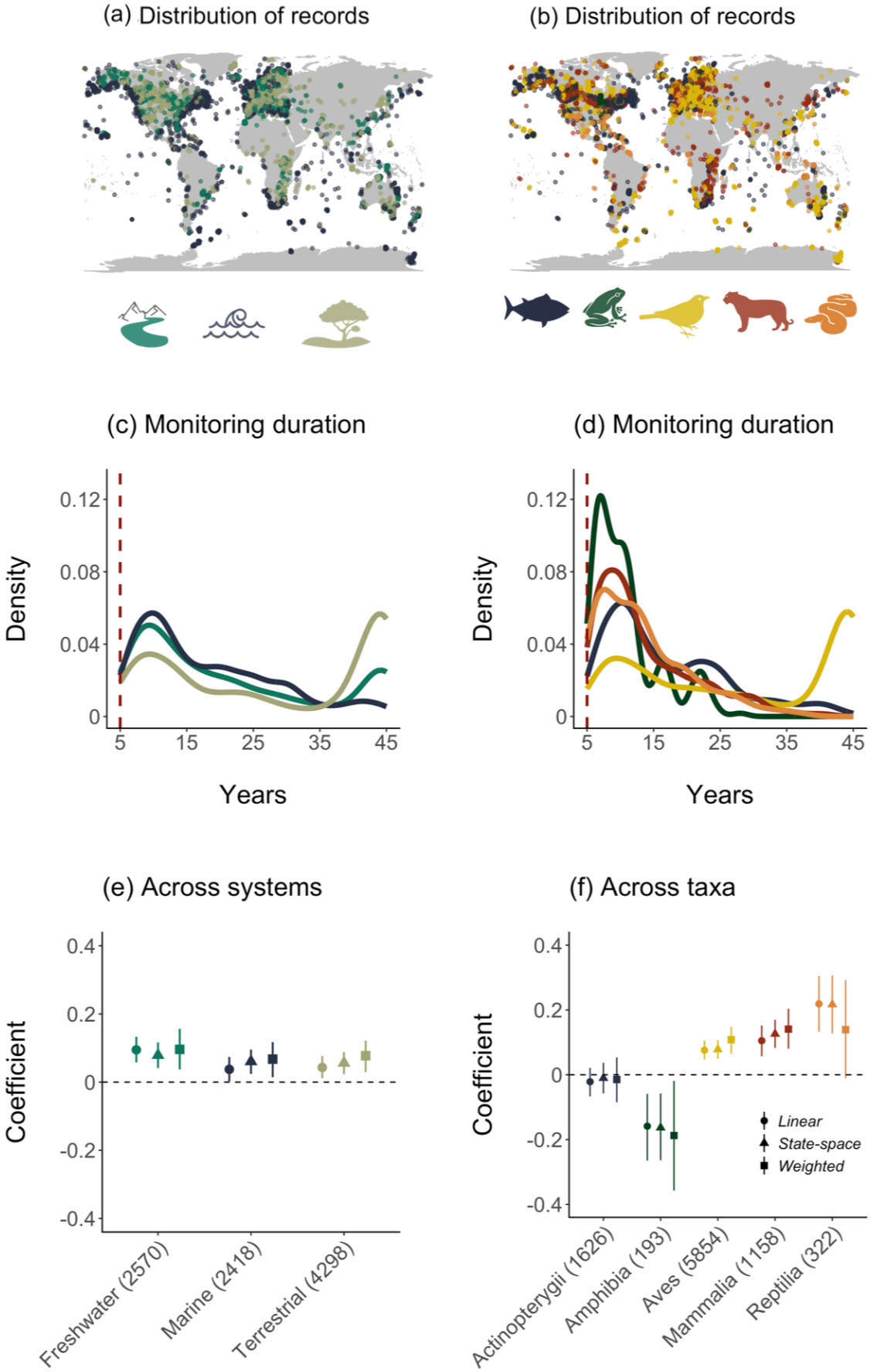

(a) Distribution of records
(b) Distribution of records
(c) Monitoring duration
(d) Monitoring duration
Density
0.12
0.08
0.04
0
5
15
25
35
45
Years
(e) Across systems
(f) Across taxa
Coefficient
0.4
0.2
0
-0.2
-0.4
Freshwater (2570)
Marine (2418)
Terrestrial (4298)
Actinopterygii (1626)
Amphibia (193)
Aves (5854)
Mammalia (1158)
Reptilia (322)
Linear
State-space
Weighted

Figure 3. Distribution of records across (plot a) freshwater, marine and terrestrial systems and (plot b) bony fish, amphibians, birds, mammals and reptiles, monitoring duration (plots c and d) and population trend effect sizes (plots e and f). The numbers on x axis show sample size for each category. Effect sizes are population trends from linear models (circles), from state-space models (*mu*, triangles), and population trend (*mu*) weighted by *tau*, the observation error estimate from the state-space models (squares, plots e and f). Error bars show 95% credible intervals (plots e and f). Effect sizes (plots e and f) were standardized by dividing the effect size by the standard deviation of the corresponding input data. See Table S2 for model outputs.

Population fluctuations across systems, taxa, Red List status and rarity metrics

Global population fluctuations (variation in population abundance over time) did not show distinct geographic patterning (Figure 4a-b). Populations that experienced more fluctuations had smaller mean population sizes (across all taxa, slope = -0.004, CI = -0.01 to -0.002) and for bird species had larger geographic ranges (slope = 0.005, CI = 0.003 to 0.01, Figure 4c). On a global scale, population fluctuations were more common with increasing Red List threat level (LC: slope = 0.11. CI = 0.11 to 0.12; CR: slope = 0.17, CI = 0.15 to 0.19, Figure 4d, Table S2). Across the three studied systems, terrestrial populations experienced less pronounced population fluctuations (slope = 0.10, CI = 0.10 to 0.11, Figure 4e) and were also monitored for the longest duration across systems (average duration – 28 years for terrestrial, 18 years for marine and 21 years for freshwater populations, Table S5). Across taxa, fluctuations were most common for amphibian populations (slope = 0.22, CI = 0.20

to 0.23, Figure 4f), which were monitored for the shortest time period on average (Table S5).

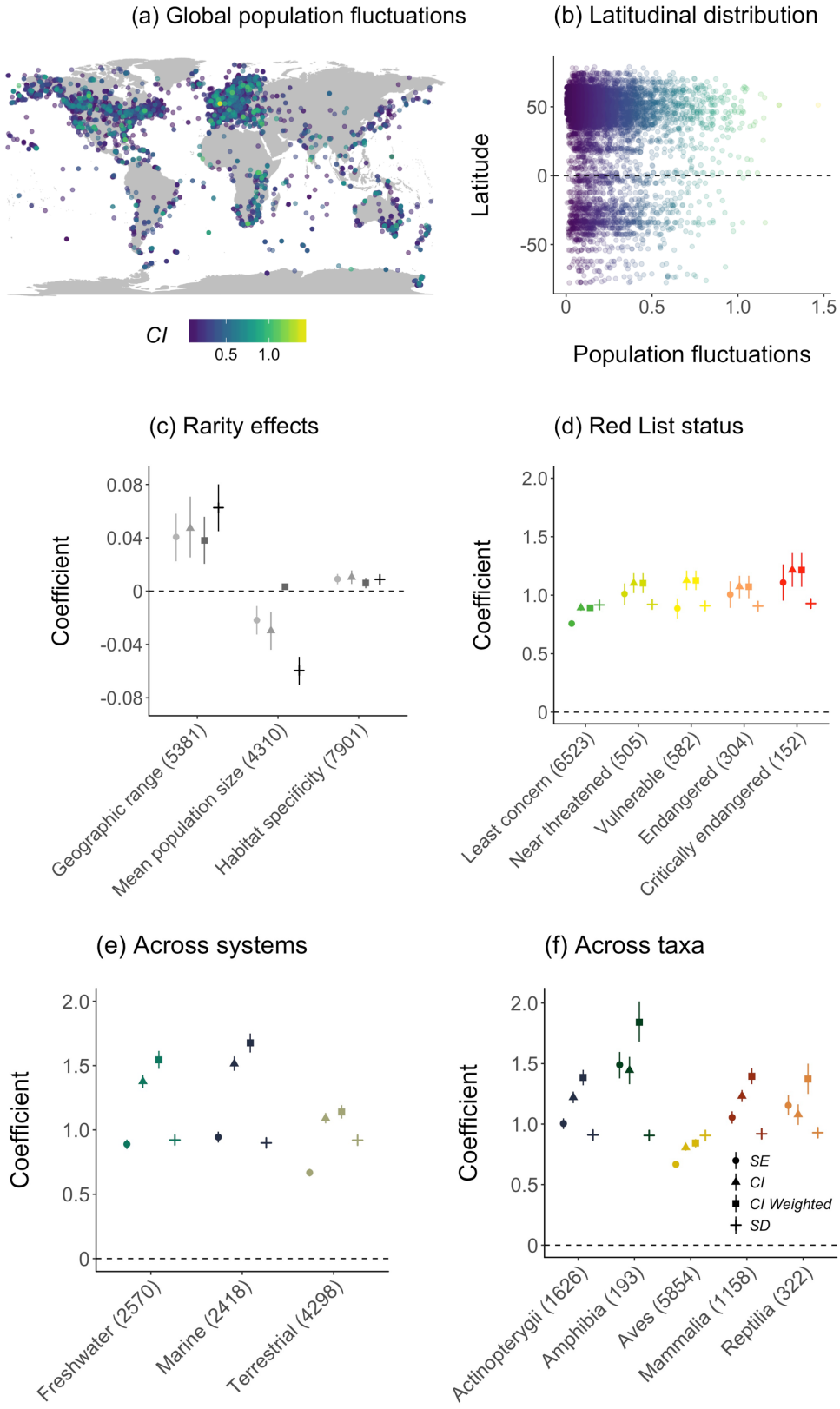
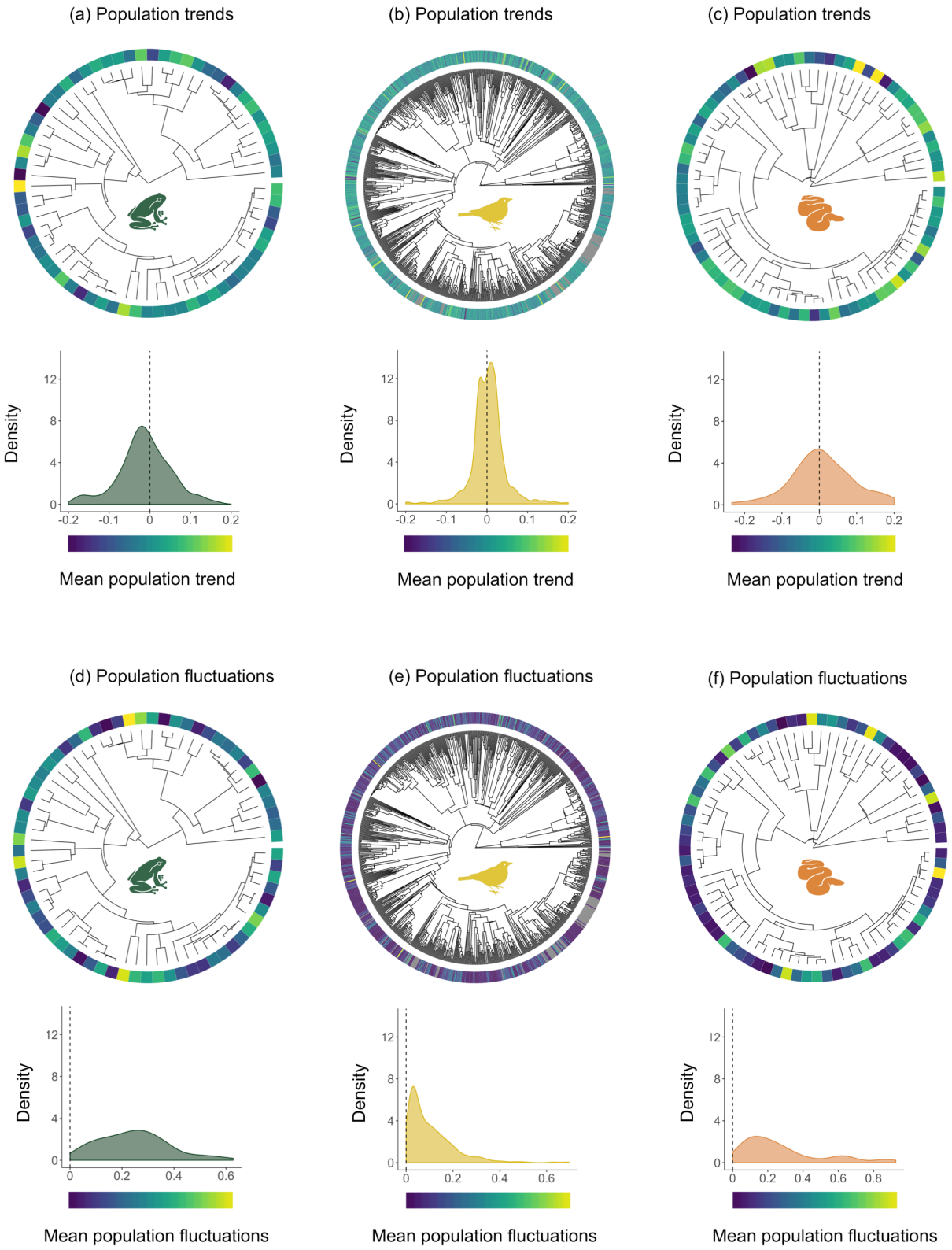


Figure 4. Global population fluctuations in vertebrate species (plot a) across latitude (plot b), rarity metrics (global scale, plot c), Red List status (global scale, plot d), systems (plot e) and taxa (plot f). The numbers on x axis show sample size for each category. The response variables in the models were: 1) the standard error around the slope estimates of the linear model fits of abundance versus year (circles), 2) half of the 95% confidence interval around the *mu* value of population change (triangles), 3) half of the 95% confidence interval around *mu* weighted by *tau*, the observation error estimate from the state-space models (squares), and 4) the standard deviation of the raw data for each population time-series (plus symbols). Larger errors indicate greater population fluctuations. Effect sizes (plots c-f) were standardized by dividing the effect size by the standard deviation of the corresponding input data. Error bars show 95% credible intervals (plots c-f). See Table S2 for model outputs.

Global population trends and fluctuations within amphibian, bird and reptile classes

When we tested for finer scale species-level taxonomic clustering of population change (both overall population trends and population fluctuations) within amphibian, bird and reptile classes, we did not detect a phylogenetic relatedness signal in the patterning of population change for either trends or fluctuations (Figures 5 and S8, Table S2). Similarly, species identity within amphibian, bird and reptile classes also did not explain variation in population trends or fluctuations (Figures 5 and S8, Table S2). There were no distinct clusters of specific clades that were more likely undergo increases, decreases or fluctuations in populations (Figure 5).



258

259 **Figure 5. No distinct patterning in population trends (average *mu* across the**

260 **population trends of each species, plots a-c) and in population fluctuations**

(plots d-f) was found across 69 amphibian species, 806 bird species and 79 reptile species. Heat maps around phylogenetic trees indicate population change with darker blue indicating species with declining populations, green indicating species with populations with no change and yellow indicating species with increasing populations. Density plots show mean population change across the sampled species in each class. For model outputs, see Figure S8 and Table S2.

Discussion

Taken together, our findings do not support the application of rarity metrics as generalizable predictors of population trends in well-monitored vertebrate populations. Across monitored vertebrate populations in the UK and globally, rarity metrics (geographic range, population size and habitat specificity) and species' Red List status did not explain variation in population trends (Figure 1). There was no consistent pattern of greater population declines with increasing Red List status in either the UK or globally (Figure 1g-j). There was no biogeographic patterning of population trends and fluctuations, as populations increased, remained stable and declined across different biomes on all continents (Figure 2). Among higher-order taxonomic units (class), birds, mammals and reptiles increased, bony fish did not experience net directional change and amphibians were the only taxon with overall declines, as well as the taxon that experienced the most population fluctuations (Figures 3-4). On a finer taxonomic scale, across amphibian, bird and reptile species, there were no distinct phylogenetic clustering of closely-related species experiencing similar population trends or fluctuations (Figure 5). Fluctuations were more likely for species with smaller population sizes and broader habitat preferences (Figure 4). Thus, although we did not find evidence that rarity metrics explain

variation in population trends, rare species were nevertheless more likely to fluctuate, potentially increasing their extinction risk.

Population change across rarity metrics

The power of rarity metrics to explain population trends could be mediated by the type of threats to which populations are exposed (43), as well as whether species are naturally rare, or have become rare due to external drivers in recent time (44–46). Geographic range, population size and habitat specificity may be of lesser importance in human-dominated landscapes where threats such as habitat change, pollution and exploitation are more prevalent (11, 33, 47). For UK and global vertebrate populations, the lack of rarity effects on population trends (Figure 1) could be related to urbanization, intensive land management and/or high investment in conservation (48), which may be contributing to the observed increases in species classified as near threatened by the IUCN (Figure 1i). Species with larger geographic ranges and small populations were most likely to fluctuate (Figure 4). A higher likelihood of fluctuations for populations with smaller mean population size (Figure 4c) is in line with population dynamics theory, suggesting that even though rarity metrics did not predict population trends, they might still be good indicators of extinction risk, as greater fluctuations could lead to a higher probability of extinction (6, 25).

Population change across Red List status

Across all Red List status categories, there was no consistent pattern of net declines in the UK and globally with increasing threat level (Figure 1g-j). Populations from vulnerable and endangered species did not experience net directional change,

311 possibly indicating that local scale conservation actions might have stabilized
312 populations for species which are declining on a global scale (49–52). However, the
313 threats and mitigation actions to which populations with more threatened Red List
314 statuses are exposed on a local scale are likely heterogeneous across different
315 biomes (53, 54). The finding that populations from species with higher Red List
316 status were more likely to fluctuate (Figure 4d) might relate to the shorter monitoring
317 duration of threatened populations versus populations from Least Concern species
318 (on average 8 years shorter duration, Table S5), or to one of the Red List criteria –
319 number of breeding individuals (23). Extinction risk is higher when there are very few
320 breeding individuals due to Allee effects and demographic stochasticity (28, 29).
321 Thus, although we did not find evidence to support the hypothesis that species with a
322 higher Red List status are more likely to be declining, those populations did
323 experience higher population fluctuations, suggesting that species of concern could
324 have a higher extinction risk.
325
326 *Global population change across latitude, biomes and systems*
327 Global vertebrate population trends varied among taxa but did not show distinct
328 geographic patterning (Figures 2-3). Some biomes like Mediterranean forests were
329 more likely to include increasing populations, whilst populations in other biomes did
330 not experience net directional population change (Figure 2 and Table S2). Similar
331 heterogeneity in the patterns of population trends across habitats has been
332 documented in the Netherlands (40) and in temperate North America and Europe
333 (41) also using the LPD, suggesting that local scale environmental factors or
334 proximity to anthropogenic drivers of change may be better predictors of population
335 trends (15, 33). The lack of distinct geographic patterning of population trends and

336 fluctuations around the world (Figures 2 and 4) might be attributable to either
337 stochastic (random events) and deterministic (e.g., anthropogenic threats) processes
338 influencing inter-annual population change (26, 55). Thus, to attribute population
339 trends and fluctuations to anthropogenic drivers, we need to go beyond previous
340 studies (18, 56) and quantify the full spectrum of population change including
341 positive, negative and stable trends and fluctuations. Thus, quantifying the drivers of
342 population change is a critical first step towards disentangling the pathways from
343 population change to biodiversity change in the Anthropocene (41, 57).
344
345 *Global population change across taxa*
346 Taxon-specific factors including reproductive strategy, trophic level, generation time,
347 life history traits (10, 14), or sampling effects (58) could explain why some taxa were
348 more likely to increase (birds, mammals and reptiles), whereas others were more
349 likely to decline (amphibians) or remain stable (bony fish), (Figure 3 and Table S2).
350 Amphibians were the only taxa to experience net population declines as well as
351 greater population fluctuations among monitored vertebrate species in the LPD,
352 which could in part be due to shorter on average amphibian monitoring duration
353 across taxa (11 years average duration for amphibians, 3 years less than for
354 mammals and reptiles, Figure 3f and 4f, Table S5). The global amphibian decline
355 (59), also demonstrated with this dataset at the temperate North American and
356 European scales (41), has been linked to the spread of a fungal disease (chytrid
357 fungus, *Batrachochytrium dendrobatidis*), facilitated by global warming (60), as well
358 as habitat loss and Allee effects in small populations (24). Within the classes
359 *Amphibia*, *Aves* and *Reptilia*, phylogenetic relatedness and species-level taxanomic
360 classification did not predict variation in population trends and fluctuations. Similar

361 lack of phylogenetic dependencies has been detected for the population growth rates
362 of migratory birds (61). Among seabirds, however, breeding phenology varied based
363 on phylogeny and taxonomy (62). Among squamates and amphibians, there is
364 evidence that phylogenetic relatedness predicts extinction (3, 4), a process that
365 occurs over much longer time-scales than the population change we studied here.
366
367 *Conclusion*
368 In summary, rarity metrics did not explain vertebrate population trends and
369 we did not find a consistent pattern of net declines with increasing Red List status in
370 the UK and globally. We found higher-order taxonomic but not geographic patterning
371 of population change around the world, yet within-classes, phylogeny and species
372 identity did not explain variation in population trends and fluctuations among
373 amphibian, bird and reptile species. Vertebrate populations experienced different
374 magnitudes of change and population fluctuations, which in the future may lead to
375 shifts in community composition as some species become locally extinct and others
376 expand into new habitats. Our findings caution the use of rarity metrics for the
377 prediction of future global population trends, but suggest that such metrics, in
378 particular population size, are nevertheless indicators of population fluctuations,
379 which might ultimately link to increased species extinction risk. It is only with
380 improved monitoring of diverse taxa that we can test the drivers of global population
381 change to inform wildlife conservation in the Anthropocene.
382
383 **Methods**
384 See SI for detailed methods.
385 *Population data*

386 To quantify vertebrate population change, we extracted the abundance data for 9284
387 populations from 2084 species from the LPD (48, Table S1). Monitoring duration
388 differed among populations (Figures S1 and S2, see SI and Figures S5 and S9 for
389 effects of monitoring duration on detected trends); however, in our analysis, we
390 retained only populations that had at least five time points of monitoring data. Before
391 analysis, we scaled the abundance of each population to a common magnitude
392 between zero and one, because the populations were monitored using different
393 metrics of abundance (e.g., population indices vs. number of individuals). This
394 allowed us to explore trends among populations relative to the variation experienced
395 across each time series.
396
397 Phylogenetic data
398 We obtained phylogenies for amphibian species from https://vertlife.org (4), for bird
399 species from https://birdtree.org (64), and for reptile species from https://vertlife.org
400 (3). For each of the three classes (*Amphibia*, *Aves* and *Reptilia*), we downloaded 100
401 trees and randomly chose 10 for analysis (30 trees in total). Species-level
402 phylogenies for the classes *Actinopterygii* and *Mammalia* have not yet been resolved
403 with high confidence (65, 66).
404
405 *Rarity metrics data*
406 We defined rarity following a simplified version of the 'seven forms of rarity' model
407 (31), and thus consider rarity to be the state in which species exist when they have a
408 small geographic range, low population size, or narrow habitat specificity. We
409 combined publicly available data from three sources: 1) population records for
410 vertebrate species from the LPD (63) to calculate mean population size, 2)

occurrence data from the Global Biodiversity Information Facility (67) and range data from BirdLife (42) to estimate geographic range size, and 3) habitat specificity and Red List classification data for each species from the International Union for Conservation (68). See SI methods for details on the calculation of rarity metrics and study limitations.

Population change modelling

As the first stage of our analysis, we used state-space models that model abundance over time (freely-varying intercept) to calculate the amount of overall population change experienced by each population (*mu*, 59, 60). State-space models account for process noise and observation error and thus deliver robust estimates of population change when working with large datasets where records were collected using different approaches (41, 71, 72). Not accounting for process and measurement error could lead to over-estimation of population declines (73). Positive *mu* values indicate population increase and negative *mu* values indicate population decline. We calculated the error around *mu* for each population (half of the difference between the upper 95% confidence limit and the lower 95% confidence limit), with larger errors indicating populations that have experienced more fluctuations (variance in abundance) over time. For comparisons of different approaches to modelling population change, see SI.

Population trends across rarity metrics

To test the influence of rarity metrics (geographic range, mean population size and habitat specificity) on variation in population trends, we conducted a second stage analysis using six Bayesian linear models (one per metric in the UK and globally)

436 based on Markov Chain Monte Carlo Bayesian inference (74). The response variable
437 was population trend (*mu* values from state-space models), and the fixed effects
438 were geographic range (log transformed), mean population size (log transformed)
439 and habitat specificity (number of distinct habitats occupied). We used weakly
440 informative priors for all coefficients (an inverse Wishart prior for the variances and a
441 normal prior for the fixed effects), and we refer to predictors as 'significant' when the
442 95% credible interval for the corresponding model parameter did not overlap zero.
443 We did not include random effects in the Bayesian models (e.g., a species or region
444 random intercept), because only 28% of the studied species had more than four
445 monitored populations and spatial replication was low (Table S1).
446
447 *Population trends across species' Red List status*
448 To investigate the relationship between population trends, and species' Red List
449 status, we modelled population trends from the first stage of the analysis (state-
450 space models) as a function of Red List status (categorical variable) using two
451 Bayesian linear models (for the UK and global databases).
452
453 *Global population trends across latitude, biomes, systems and taxa*
454 To investigate the geographic and taxonomic patterns of population trends, we
455 estimated population trend from the first stage of the analysis (state-space models)
456 as a function of (1) latitude and biome (as defined by the 'biome' category in the
457 LPD, e.g., 'temperate broadleaf forest' (75), (2) system (freshwater, marine,
458 terrestrial), and (3) taxon (*Actinopterygii*, bony fish; *Amphibia*, amphibians; *Aves*,
459 birds; *Mammalia*, mammals; *Reptilia*, reptiles). Each categorical model from this
460 second stage of our analyses was fitted with a zero intercept to allow us to determine

461 if net population trends differed from zero for each of the categories under
462 investigation.
463
464 *Global population trends within amphibian, bird and reptile classes*
465 To determine if there is a phylogenetic signal in the patterning of population change
466 within amphibian, bird and reptile taxa, we modelled population change to test the
467 phylogenetic and species-level taxonomic relatedness, which were both included as
468 random effects in three (one per class) Bayesian linear mixed effects models using
469 the package *MCMCglmm* (74). The models did not include fixed effects. We
470 assessed significance of the random effects (phylogeny and species) by inspecting
471 their posterior distributions, with a distribution pushed up against zero indicating lack
472 of effect significance, since these distributions are always bounded by zero and have
473 only positive values. For details and methods for accounting for phylogenetic
474 uncertainty, see SI Methods.
475
476 *Population fluctuations across systems, taxa, Red List status and rarity metrics*
477 To test whether rare species fluctuate more than common species and whether there
478 is geographic and taxonomic patterning in population fluctuations, we modelled the
479 error around *mu* (half of the 95% confidence interval) as a response variable across
480 systems, taxa, Red List status and rarity metrics.
481
482 All statistical analyses were conducted using R version 3.4.3 (76). Code and data
483 are publicly available on GitHub (link to be added at time of publication).
484
485 **Statement of authorship**

GND and IMS conceived the idea and conducted the statistical analyses. JLG contributed to the calculation of geographic range estimates. All authors contributed to the integration of the LPI, GBIF and IUCN databases. GND wrote the first draft of the manuscript and all authors contributed to revisions. The authors declare no conflicts of interest.

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Supplementary Information for "Rarity and conservation status do not predict vertebrate population trends"

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This PDF file includes:

- Supplementary methods
- References for supplementary methods
- Tables S1 to S5
- Figures S1 to S11

Methods

Calculating rarity metrics

To estimate geographic range for species monitored in the UK, we calculated a km^2 occurrence area extent using a minimal convex hull approach based on occurrence data for each species from GBIF (1). We filtered the GBIF data to remove invalid records and outliers using the *CoordinateCleaner* package (2). We excluded records with no decimal places in the decimal latitude or longitude values, with equal latitude or longitude, within a one degree radius of the GBIF headquarters in Copenhagen, within 0.0001 degrees of various biodiversity institutions and within 0.1 degrees of capital cities. For each species, we excluded the lower 0.02 and upper 0.98 quantile intervals of the latitude and longitude records to account for outlier points that are records from zoos or other non-wild populations. We drew a convex hull to most parsimoniously encompass all remaining occurrence records using the *chull* function, and we calculated the area of the resulting polygon using *areaPolygon* from the *geosphere* package (3).

We did not use IUCN range maps, as they were not available for all of our study species, and previous studies using GBIF occurrences to estimate range have found a positive correlation between GBIF-derived and IUCN-derived geographic range (4). Extracting and filtering GBIF data and calculating range was computationally-intensive and occurrence data availability was lower for certain species; thus, we did not estimate geographic range for all species globally. Instead, we focused on analyzing range effects for species monitored in the UK, a country with intensive and detailed biodiversity monitoring of vertebrate species, and for birds globally, as they are a very well-studied taxon. To estimate geographic range for bird species

731 monitored globally, we extracted the area of occurrence in km^2 for all bird species in
732 the LPD that had records in the BirdLife Data Zone (5).
733
734 We calculated mean population size across the monitoring duration for each
735 population using the raw population data. To create an index of habitat specificity,
736 we extracted the number of distinct habitats a species occupies based on the IUCN
737 habitat category for each species, accessed through the package *rredlist* (6). We
738 also quantified habitat specificity by surveying the number of breeding and non-
739 breeding habitats for each species from its online IUCN profile (the 'habitat and
740 ecology' section, IUCN 2017). The two approaches yielded similar results (Figure
741 S3, Table S2, key for the profiling method is presented in Table S4). We obtained
742 global conservation status data for all study species through the IUCN Red List
743 classification (7).
744
745 *Phylogenetic analyses*
746 We used parameter-expanded priors, with a variance-covariance structure that
747 allows the slopes of population trend (the *mu* values from the first stage analysis
748 using state-space models) to covary for each random effect. To account for
749 phylogenetic uncertainty, for each class, we ran ten models with identical structures
750 but based on different randomly selected phylogenetic trees. We report the mean
751 estimates and their range for each class. The phylogeny and taxonomy models were
752 ran for 120 000 iterations with a thining factor of ten and a burn-in period of 20 000
753 iterations.
754
755 *Monitoring duration and units*

To assess the influence of monitoring duration on population trends, we used a Bayesian linear model (Figures S1 and S2). We modelled population trend (*mu*) as a function of monitoring duration (years) for each population, fitted with a zero intercept, as when duration is zero, no population change has occurred. Variation in population trends was not explained by sampling method across the five most commonly used units (Figure S5). Monitoring duration was weakly positively related to vertebrate population trends, with slightly more increasing populations found for longer duration studies (Figure S9, Table S2).

Comparison of modelling approaches

We conducted the following supplementary analyses: in the second-stage Bayesian models estimating population trends across systems, biomes, taxa and rarity metrics, 1) we weighed *mu* values by the square of *tau*, the observation error estimate derived from the state-space models, 2) we used slopes of linear model fits of abundance (scaled at the population level, centered on zero and with a standard deviation of one) instead of the *mu* estimates from state-space models, 3) we modelled the standard error around the slope values of the linear models and the standard deviation of the raw population data for each time-series as additional metrics of population fluctuations. All different analytical approaches yielded very similar results (see main text and Figures S6, S7 and S10, Table S2).

Study limitations

Our study is limited by three main factors: 1) gaps in global monitoring of populations, 2) challenges in estimating geographic range, and 3) overrepresentation of common species. The LPD under-represents populations outside of Europe and

North America (8–10). The GBIF database includes sub-optimal representation of some species and there might be confusion between sub-species and occurrence outliers (11, 12). We used a static measure of geographic range, which does not account for changes in species distributions over time. Species could naturally have a small range or the small range size could be due to historic habitat loss (13, 14). The UK populations included in the LPD are predominantly from species with wide geographic ranges (Table S3). The relationship between population change and geographic range could differ for highly endemic species that are not monitored or included in the LPD dataset.

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824 **Table S1. Number of species and populations included in analyses.**

Scale	Analysis	Number of species	Number of populations	Number of species with >3 populations
UK	Geographic range	167	381	32
	Population size	112	253	19
	Habitat specificity	144	289	29
	Red List status	153	364	31
Global	System	2074	9284	834
	Biome	2074	9284	834
	Taxa			
	- *Actinopterygii*	544	1626	151
	- *Amphibia*	78	193	21
	- *Aves*	968	5852	538
	- *Mammalia*	306	1158	94
	- *Reptilia*	110	322	16
	Red List status	1702	8064	708
	Latitude	2074	9284	834
	Duration	2074	9284	834

825

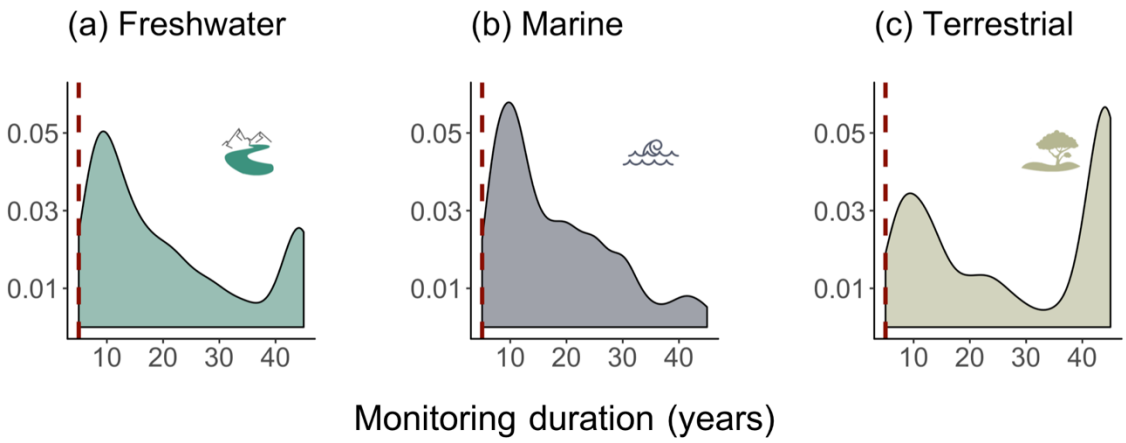


Figure S1. Distribution of monitoring duration across (a) freshwater, (b) marine and (c) terrestrial systems. Results include 9284 populations from 2084 species.

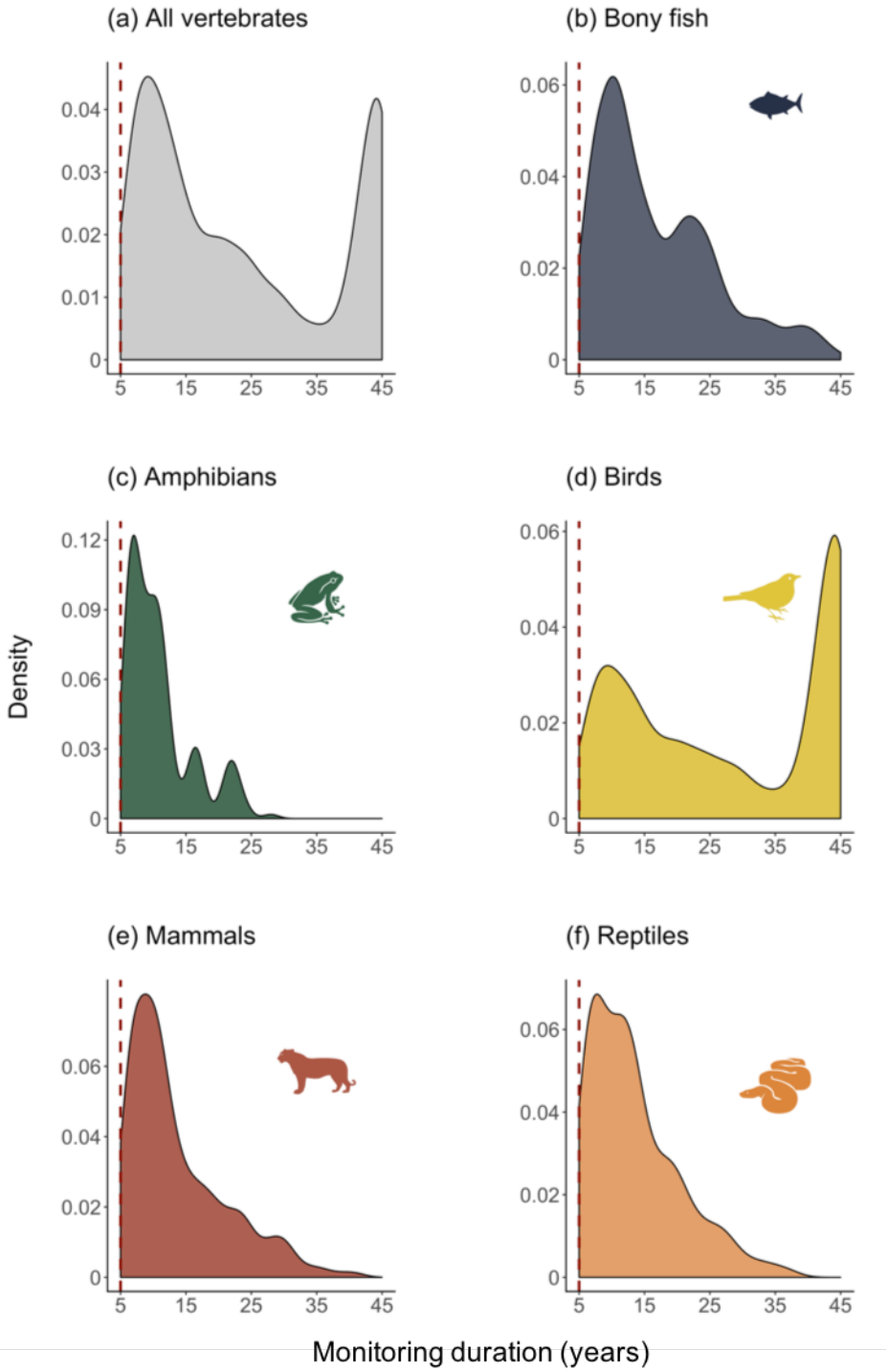


Figure S2. Distribution of monitoring duration across all monitored vertebrate populations (plot a), bony fish (plot b), amphibians (plot c), birds (plot d), mammals (plot e) and reptiles (plot f). See Table S1 for sample sizes of each group.

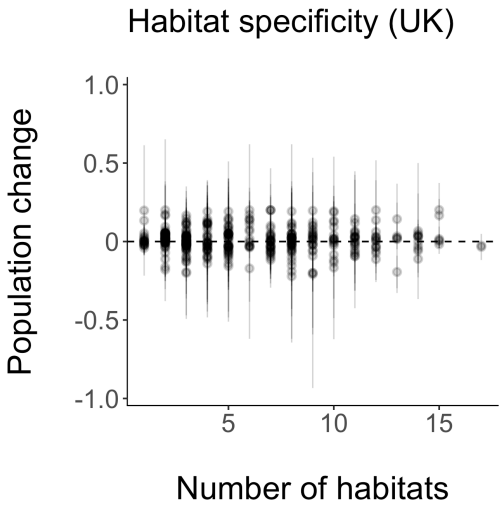


Figure S3. Effect of habitat specificity (calculated by surveying the 'Habitat and Ecology' profile for each species on the IUCN Red List website) on vertebrate population trends in the UK. The *mu* values of population change are derived from state-space model fits of changes in abundance over the monitoring duration for each population. Error bars show confidence intervals around population trend (mu). See Table S2 for full model outputs.

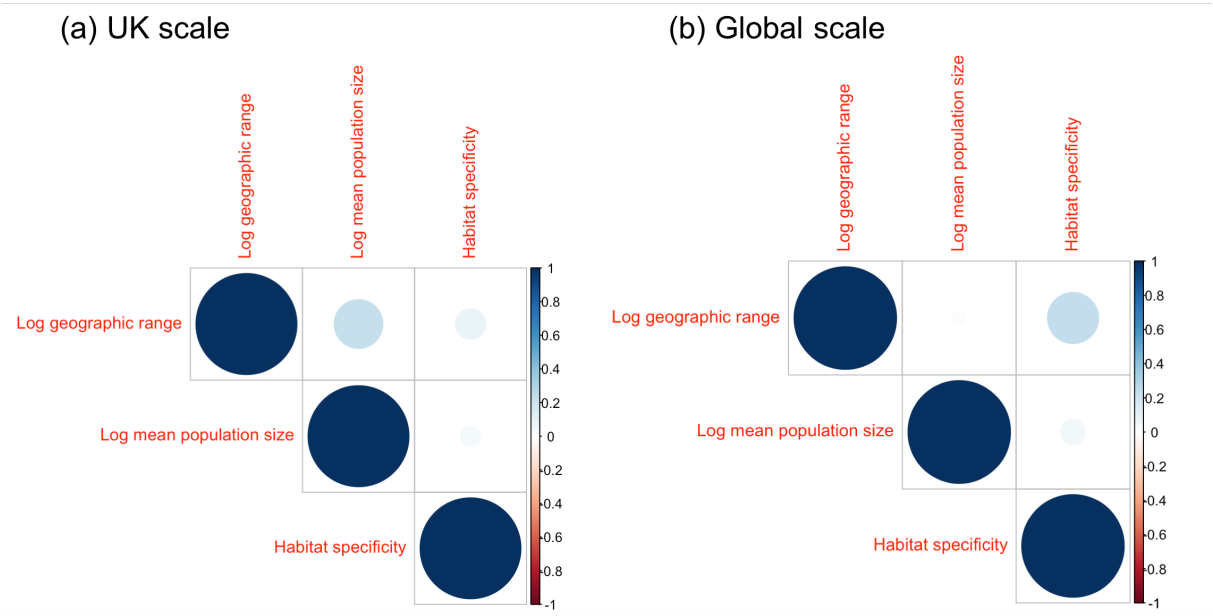


Figure S4. Correlation matrix between rarity metrix on (a) UK and (b) global scales. The three rarity metrics were weakly correlated at both study scales.

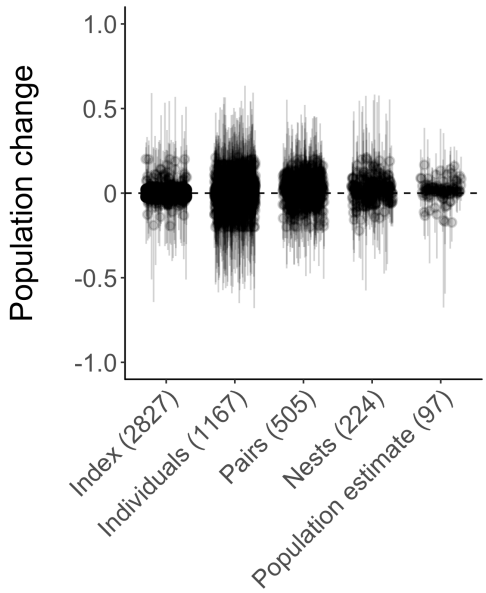


Figure S5. Population change (*mu* values from state-space models) across the five most commonly used units in the subset of the LPD we analyzed. Numbers on the x axis correspond to sample size in each category.

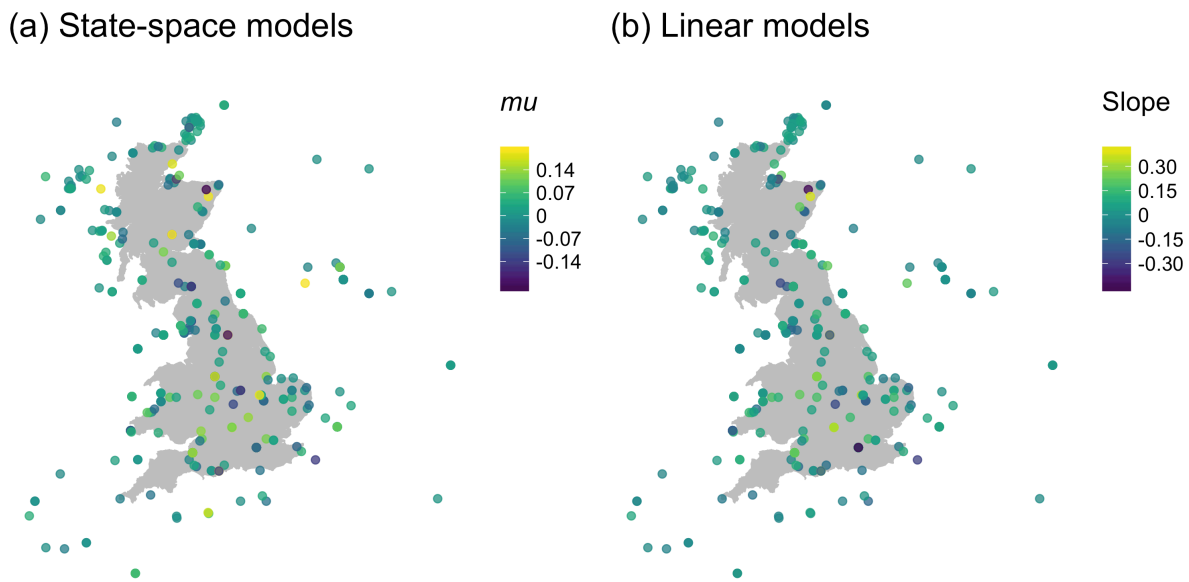


Figure S6. Geographic distribution of vertebrate population change in the UK, from state-space models (plot a) and linear models (plot b). Results include 508 populations from 237 species in the UK.

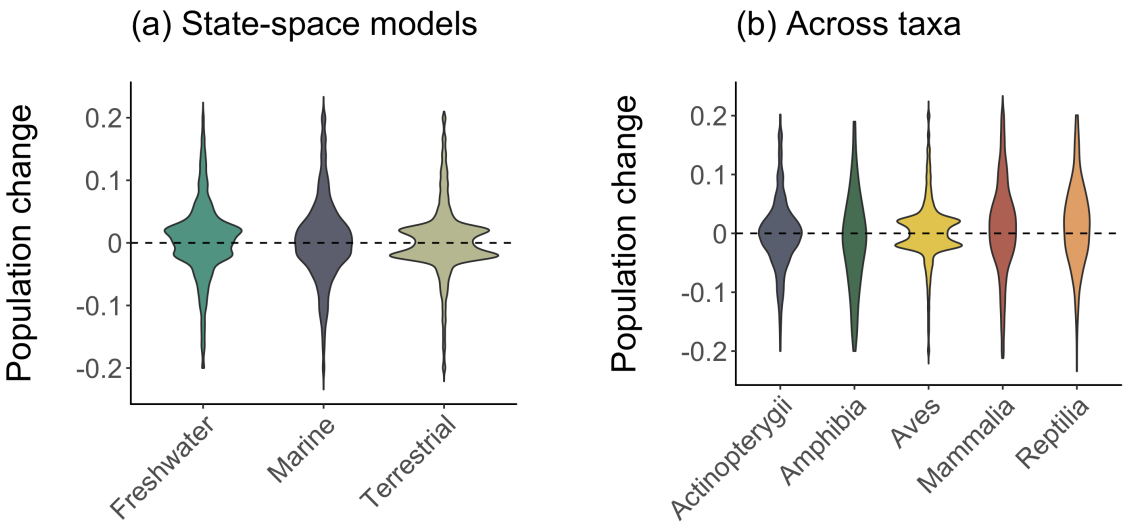
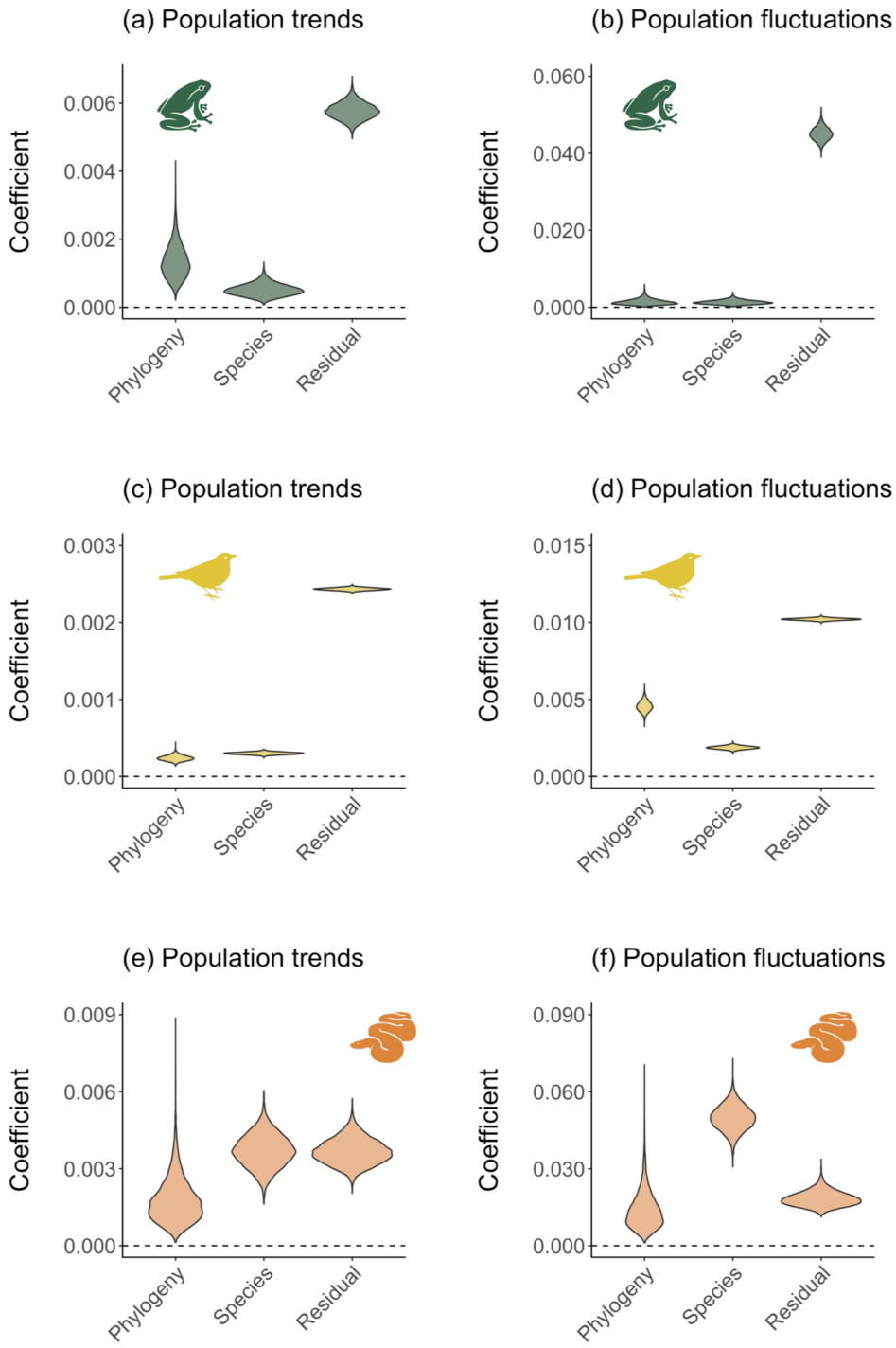


Figure. S7. Distribution of population change (*mu*) values from state-space models of vertebrate abundance over time across systems (plot a) and across taxa (plot b). See Table S1 for sample sizes.



857

858 **Figure. S8. Distribution of posterior means (mean distributions across ten**
859 **models for each taxa for each type of population change using 10 random**
860 **trees to account for phylogenetic uncertainty) for phylogenetic, species and**
861 **residual variance across taxa.** Phylogeny effects were calculated based on a
862 branch length covariance matrix. See Table S2 for full model outputs.

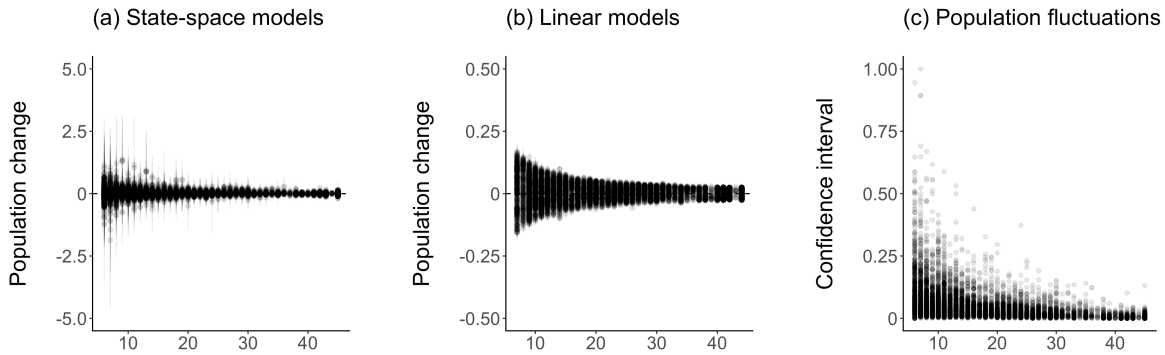


Figure S9. Vertebrate population trends across monitoring duration. Results are for 9284 populations from 2084 species. Population trends (*mu*) were estimated for all populations monitored for more than five time points using state-space models (plot a) and linear models (plot b). Population fluctuations (plot c) were estimated using the confidence interval (half of the 95% confidence interval) of the *mu* values (see also Figure 5). Error bars show 95% confidence intervals.

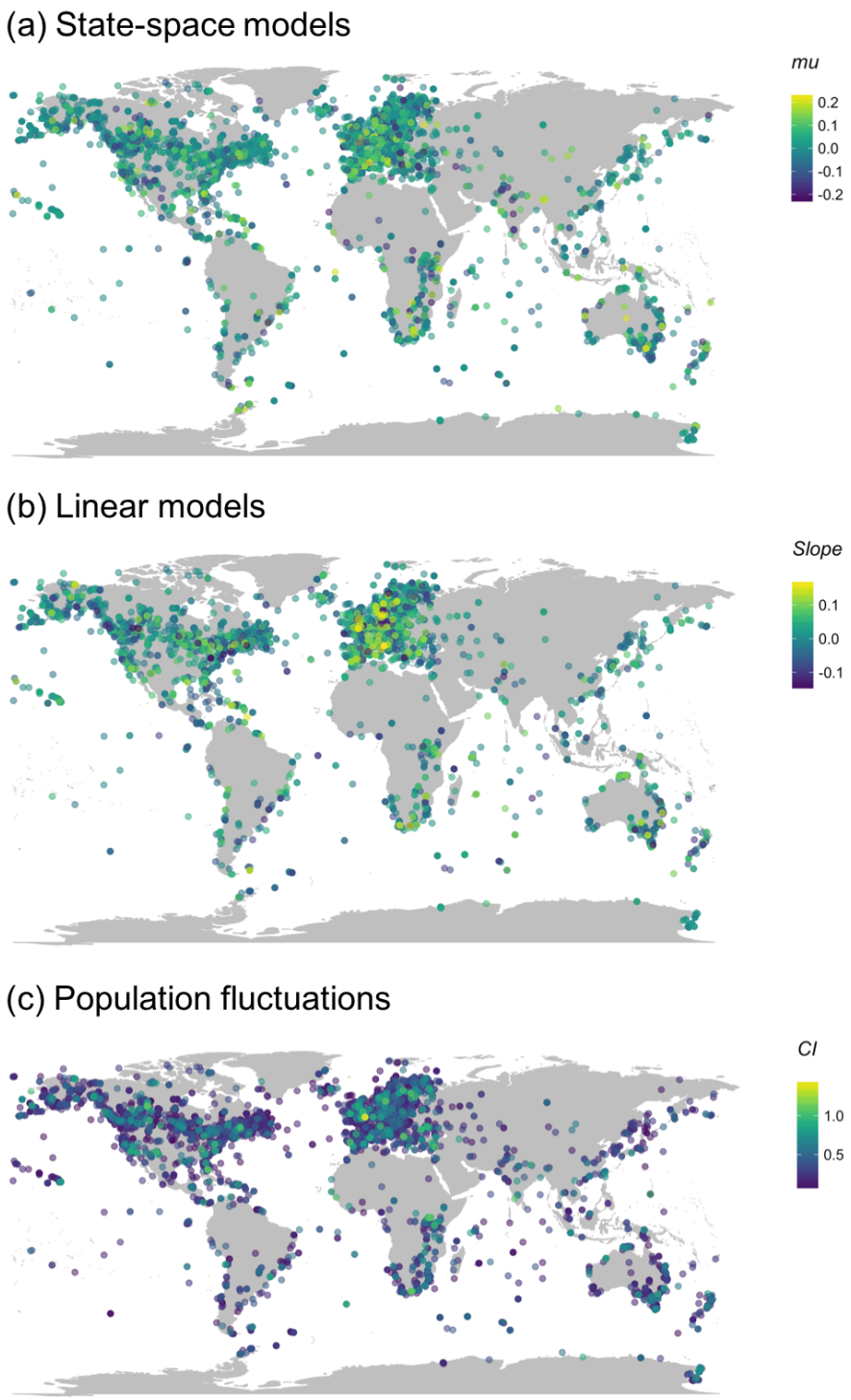


Figure S10. Geographic distribution of population change, calculated using state-space models (plot a), linear models (plot b), and using the confidence interval (half of the 95% confidence interval) of the *mu* values (plot c). Results include 9284 populations from 2084 species. Larger confidence intervals on (c) correspond to populations that have experienced more fluctuations.

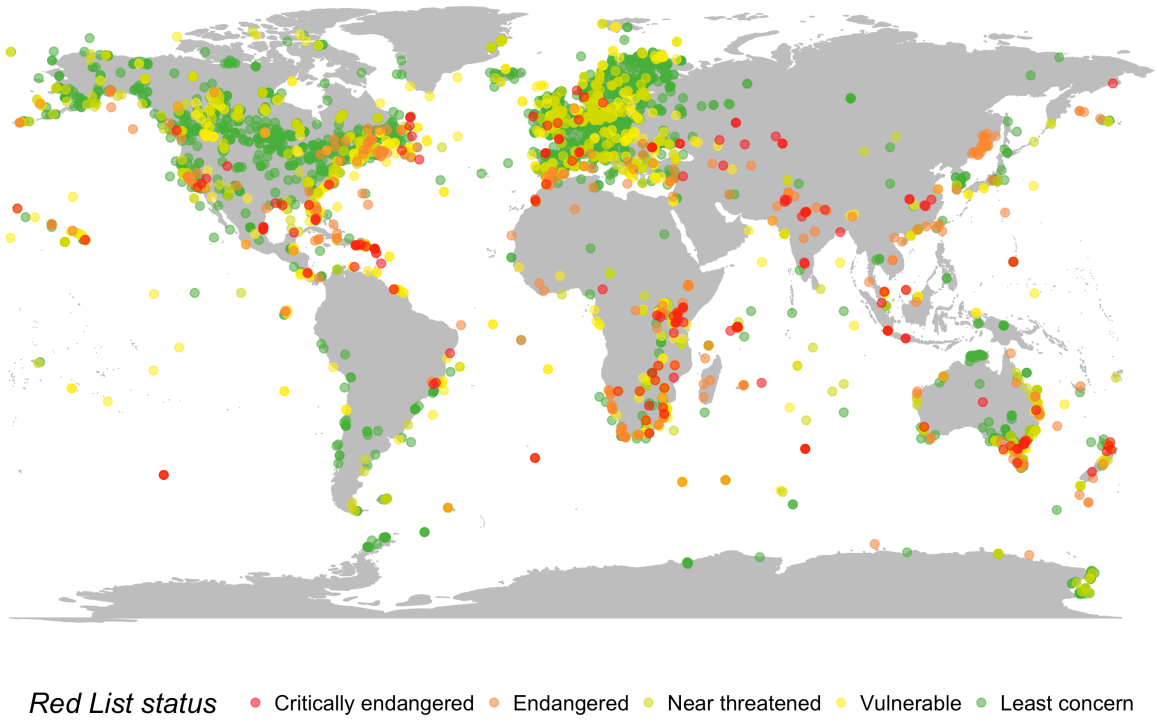


Figure S11. Geographic distribution of population records, colour coded by species' Red List status.

Table S2. Model outputs from UK and global analyses. Sigma is the overall model residual variance. Net population change is estimated using *mu* values derived from state-space models of population abundance versus time and slopes of linear models of population abundance versus time. The weighted *mu* models included *mu* as a response variable, weighted by *tau*, the observation error estimate derived from the state-space models. The fluctuation models included half of the 95% confidence interval around the *mu* value of population change, the standard error around the slopes of linear models of population abundance versus time, and the standard deviation of the raw time-series data for each population. Larger confidence intervals correspond to populations that experienced more fluctuations. The weighted fluctuation models were weighted by *tau*, the observation error estimate derived from the state-space models. To account for phylogenetic uncertainty, we ran the phylogenetic models for amphibian, bird and reptile species using 10 different trees for each class, and here we present the mean, min and max values from the different model runs.

Model name	Variable	Posterior mean	Lower 95% CI	Upper 95% CI	Effective sample size	pMCMC	Effect
Geographic range (UK) - mu	(Intercept)	-0.001	-0.04	0.03	18,000	0.94	fixed
	log(km2_range)	0.001	-0.001	0.004	18,000	0.41	fixed
	sigma	0.01	0.005	0.01	18,000		residual
Geographic range (UK) - weighted	(Intercept)	-0.01	-0.05	0.03	17,509	0.58	fixed
	log.range	0.002	-0.001	0.005	17,525	0.16	fixed
	sigma	0.005	0.004	0.01	18,435		residual
Geographic range (UK) - slope	(Intercept)	-0.01	-0.07	0.06	18,000	0.85	fixed
	log.range	0.002	-0.002	0.01	17,583	0.38	fixed
	sigma	0.02	0.02	0.02	18,000		residual
Geographic range (UK) - fluctuations CI	(Intercept)	0.03	-0.04	0.10	18,000	0.41	fixed
	log.range	0.01	0.003	0.01	18,000	0.002	fixed
	sigma	0.02	0.02	0.02	18,000		residual
Geographic range (UK) - fluctuations CI weighted	(Intercept)	0.02	-0.06	0.10	18,000	0.59	fixed
	log.range	0.01	0.003	0.01	18,000	0.002	fixed
	sigma	0.02	0.02	0.03	18,000		residual

Geographic range (UK) - fluctuations SE	(Intercept)	-0.02	-0.09	0.06	18,000	0.67	fixed
	log.range	0.01	0.005	0.02	18,000	0.0002	fixed
	sigma	0.02	0.02	0.03	18,000		residual
Geographic range (UK) - fluctuations SD	(Intercept)	0.15	0.08	0.23	17,410	0.0002	fixed
	log.range	0.02	0.01	0.02	18,056	0.0001	fixed
	sigma	0.03	0.02	0.03	18,000		residual
Mean population size (UK) - mu	(Intercept)	0.003	-0.02	0.03	18,710	0.79	fixed
	log.meanpop	0.001	-0.003	0.005	21,192	0.67	fixed
	sigma	0.005	0.004	0.01	18,000		residual
Mean population size (UK) - weighted	(Intercept)	0.003	-0.02	0.02	18,000	0.80	fixed
	log.meanpop	0.001	-0.003	0.005	18,000	0.67	fixed
	sigma	0.005	0.004	0.01	18,000		residual
Mean population size (UK) - slope	(Intercept)	0.04	-0.01	0.08	18,581	0.11	fixed
	log(meanpop)	-0.001	-0.01	0.01	18,717	0.74	fixed
	sigma	0.02	0.02	0.03	18,000		residual
Mean population size (UK) - fluctuations CI	(Intercept)	0.30	0.24	0.36	17,427	0.0001	fixed
	log.meanpop	-0.01	-0.02	0.0004	18,000	0.05	fixed
	sigma	0.03	0.03	0.04	18,000		residual
Mean population size (UK) - fluctuations CI weighted	(Intercept)	0.30	0.24	0.36	17,570	0.0001	fixed
	log.meanpop	-0.01	-0.02	0.0001	18,000	0.05	fixed
	sigma	0.03	0.03	0.04	18,000		residual
Mean population size (UK) - fluctuations SE	(Intercept)	0.21	0.17	0.25	18,000	0.0001	fixed
	log.meanpop	-0.01	-0.02	-0.01	18,000	0.0001	fixed
	sigma	0.02	0.01	0.02	18,000		residual
Mean population size (UK) - fluctuations SD	(Intercept)	0.50	0.44	0.56	18,000	0.0001	fixed
	log.meanpop	-0.01	-0.03	-0.005	18,000	0.01	fixed
	sigma	0.03	0.02	0.04	18,403		residual
Habitat specificity (UK) - mu	(Intercept)	0.01	-0.01	0.02	18,000	0.38	fixed
	hab_spec	0.001	-0.001	0.002	18,000	0.28	fixed
	sigma	0.01	0.005	0.01	16,892		residual
Habitat specificity (UK) - weighted	(Intercept)	0.01	-0.01	0.02	18,000	0.40	fixed
	hab_spec	0.001	-0.001	0.003	18,000	0.23	fixed
	sigma	0.005	0.004	0.01	18,727		residual
Habitat specificity (UK) - slope	(Intercept)	0.01	-0.01	0.04	20,246	0.33	fixed
	hab_spec	0.001	-0.001	0.003	18,000	0.44	fixed
	sigma	0.02	0.02	0.02	18,436		residual
Habita specificity (UK) - profiling method	(Intercept)	0.01	-0.003	0.03	18,000	0.11	fixed
	hab_spec	-0.0003	-0.002	0.002	18,000	0.76	fixed
	sigma	0.01	0.01	0.01	18,000		residual
Habitat specificity (UK) - fluctuations CI	(Intercept)	0.11	0.09	0.14	18,000	0.0001	fixed
	hab_spec	0.003	0.0003	0.01	18,000	0.03	fixed
	sigma	0.02	0.02	0.02	18,000		residual

Habitat specificity (UK) - fluctuations CI weighted	(Intercept)	0.11	0.08	0.15	18,000	0.0001	fixed
	hab_spec	0.004	0.0005	0.01	18,000	0.02	fixed
	sigma	0.02	0.02	0.03	18,000		residual
Habitat specificity (UK) - fluctuations SE	(Intercept)	0.11	0.08	0.14	18,000	0.0001	fixed
	hab_spec	0.002	-0.001	0.004	18,000	0.28	fixed
	sigma	0.02	0.02	0.03	18,000		residual
Habitat specificity (UK) - fluctuations SD	(Intercept)	0.37	0.34	0.40	18,000	0.0001	fixed
	hab_spec	0.001	-0.001	0.004	18,000	0.32	fixed
	sigma	0.03	0.02	0.03	18,000		residual
Red List status (UK) - mu	Least concern	0.01	0.004	0.02	18,000	0.001	fixed
	Near threatened	0.03	0.005	0.06	16,876	0.02	fixed
	Vulnerable	0.002	-0.02	0.03	18,000	0.86	fixed
	Endangered	-0.04	-0.18	0.11	18,000	0.60	fixed
	Critically endangered	0.06	-0.02	0.15	18,000	0.15	fixed
	sigma	0.01	0.005	0.01	18,000		residual
Red List status (UK) - weighted	Least concern	0.02	0.01	0.02	18,000	0.0001	fixed
	Near threatened	0.03	0.002	0.07	18,416	0.04	fixed
	Vulnerable	-0.01	-0.04	0.03	18,000	0.73	fixed
	Endangered	-0.04	-0.17	0.10	18,000	0.59	fixed
	Critically endangered	0.04	-0.18	0.28	18,000	0.72	fixed
	sigma	0.005	0.004	0.01	18,398		residual
Red List status (UK) - slope	Least concern	0.02	0.01	0.03	18,827	0.002	fixed
	Near threatened	0.04	-0.01	0.09	18,000	0.10	fixed
	Vulnerable	-0.001	-0.05	0.05	18,000	0.96	fixed
	Endangered	-0.01	-0.28	0.25	18,000	0.93	fixed
	Critically endangered	0.05	-0.10	0.21	18,000	0.48	fixed
	sigma	0.02	0.02	0.02	18,000		residual
Red List status (UK) - fluctuations CI	Least concern	0.14	0.13	0.16	18,000	0.0001	fixed
	Near threatened	0.14	0.09	0.19	18,000	0.0001	fixed
	Vulnerable	0.10	0.05	0.16	18,000	0.0002	fixed
	Endangered	0.24	-0.05	0.52	18,000	0.10	fixed
	Critically endangered	0.09	-0.07	0.26	17,435	0.30	fixed
	sigma	0.02	0.02	0.02	18,000		residual
Red List status (UK) - fluctuations CI weighted	Least concern	0.15	0.13	0.17	17,566	0.0001	fixed
	Near threatened	0.16	0.09	0.22	18,000	0.0001	fixed
	Vulnerable	0.11	0.04	0.17	17,582	0.001	fixed
	Endangered	0.24	-0.06	0.54	18,000	0.11	fixed
	Critically endangered	0.06	-0.23	0.34	18,000	0.68	fixed
	sigma	0.02	0.02	0.03	17,700		residual
Red List status (UK) - fluctuations SE	Least concern	0.13	0.11	0.14	18,000	0.0001	fixed
	Near threatened	0.13	0.08	0.18	18,600	0.0001	fixed
	Vulnerable	0.07	0.01	0.13	18,809	0.02	fixed
	Endangered	0.07	-0.23	0.37	19,204	0.65	fixed
	Critically endangered	0.07	-0.11	0.24	18,000	0.45	fixed
	sigma	0.02	0.02	0.03	18,000		residual

Red List status (UK) - fluctuations SD	Least concern	0.33	0.33	0.34	18,000	0.0001	fixed
	Near threatened	0.40	0.37	0.43	20,507	0.0001	fixed
	Vulnerable	0.23	0.21	0.25	18,000	0.0001	fixed
	Endangered	0.24	-0.02	0.52	18,000	0.08	fixed
	Critically endangered	0.28	0.16	0.40	18,000	0.0001	fixed
	sigma	0.02	0.02	0.02	18,000		residual
System (UK) - mu	Freshwater	0.02	0.001	0.03	18,000	0.04	fixed
	Marine	0.01	-0.001	0.02	18,905	0.07	fixed
	Terrestrial	0.02	0.004	0.03	18,135	0.01	fixed
	sigma	0.01	0.004	0.01	18,000		residual
System (UK) - weighted	Freshwater	0.02	-0.004	0.03	21,467	0.10	fixed
	Marine	0.01	0.0004	0.02	17,586	0.04	fixed
	Terrestrial	0.02	0.01	0.03	18,424	0.005	fixed
	sigma	0.005	0.004	0.01	18,000		residual
System (UK) - slope	Freshwater	0.03	0.004	0.06	18,000	0.02	fixed
	Marine	0.01	-0.005	0.03	18,064	0.20	fixed
	Terrestrial	0.03	0.01	0.05	18,705	0.01	fixed
	sigma	0.02	0.01	0.02	18,000		residual
Taxa (UK) - mu	Actinopterygii	-0.004	-0.02	0.01	18,000	0.51	fixed
	Amphibia	-0.002	-0.04	0.03	18,000	0.90	fixed
	Aves	0.01	0.002	0.02	18,000	0.02	fixed
	Mammalia	0.03	0.02	0.05	18,000	0.0001	fixed
	Reptilia	0.04	-0.02	0.10	18,000	0.16	fixed
	sigma	0.005	0.004	0.01	18,000		residual
Taxa (UK) - weighted	Actinopterygii	-0.01	-0.02	0.01	18,000	0.29	fixed
	Amphibia	-0.002	-0.05	0.04	17,451	0.92	fixed
	Aves	0.02	0.01	0.03	18,000	0.003	fixed
	Mammalia	0.04	0.02	0.05	18,000	0.0001	fixed
	Reptilia	0.03	-0.04	0.10	17,161	0.41	fixed
	sigma	0.004	0.004	0.01	18,000		residual
Taxa (UK) - slope	Actinopterygii	-0.01	-0.04	0.01	18,000	0.41	fixed
	Amphibia	-0.003	-0.07	0.06	18,000	0.92	fixed
	Aves	0.02	0.0001	0.03	18,468	0.05	fixed
	Mammalia	0.06	0.04	0.09	18,000	0.0001	fixed
	Reptilia	0.07	-0.05	0.18	18,000	0.23	fixed
	sigma	0.02	0.01	0.02	18,000		residual
System (global) - mu	Freshwater	0.005	0.002	0.01	19,286	0.0001	fixed
	Marine	0.004	0.002	0.01	18,820	0.0003	fixed
	Terrestrial	0.003	0.001	0.005	18,000	0.001	fixed
	sigma	0.003	0.003	0.004	18,000		residual
System (global) - weighted	Freshwater	0.01	0.002	0.01	18,000	0.001	fixed
	Marine	0.004	0.001	0.01	18,000	0.01	fixed
	Terrestrial	0.004	0.002	0.01	17,492	0.001	fixed
	sigma	0.004	0.004	0.004	19,112		residual
System (global) - slope	Freshwater	0.01	0.01	0.01	18,000	0.0001	fixed
	Marine	0.004	0.0002	0.01	18,000	0.04	fixed
	Terrestrial	0.004	0.001	0.01	18,000	0.01	fixed
	sigma	0.01	0.01	0.01	18,000		residual
System (global) - fluctuations CI	Freshwater	0.13	0.13	0.14	18,000	0.0001	fixed
	Marine	0.13	0.13	0.14	18,000	0.0001	fixed

	Terrestrial	0.10	0.10	0.10	18,000	0.0001	fixed
	sigma	0.02	0.02	0.02	18,000		residual
System (global) - fluctuations CI weighted	Freshwater	0.15	0.14	0.16	18,000	0.0001	fixed
	Marine	0.15	0.14	0.16	18,000	0.0001	fixed
	Terrestrial	0.11	0.10	0.11	18,000	0.0001	fixed
	sigma	0.02	0.02	0.02	18,000		residual
System (global) - fluctuations SE	Freshwater	0.12	0.12	0.13	18,000	0.0001	fixed
	Marine	0.12	0.11	0.12	18,000	0.0001	fixed
	Terrestrial	0.09	0.09	0.09	18,000	0.0001	fixed
	sigma	0.02	0.02	0.02	16,149		residual
System (global) - fluctuations SD	Freshwater	0.55	0.55	0.56	18,943	0.0001	fixed
	Marine	0.56	0.56	0.56	18,000	0.0001	fixed
	Terrestrial	0.54	0.54	0.54	18,000	0.0001	fixed
	sigma	0.01	0.01	0.01	18,000		residual
Biome (global) - mu	Boreal forests/taiga	-0.001	-0.004	0.002	17,462	0.70	fixed
	Deserts and xeric shrublands	-0.01	-0.03	0.002	18,000	0.09	fixed
	Trop. and subtrop. grasslands savannas and shrublands	-0.01	-0.02	-0.001	18,000	0.03	fixed
	Large lakes	0.003	-0.004	0.01	18,000	0.42	fixed
	Mediterranean forests woodlands and scrub	0.02	0.01	0.02	18,000	0.0002	fixed
	Montane freshwaters	0.01	-0.01	0.04	18,000	0.34	fixed
	Montane grasslands and shrublands	0.02	0.001	0.04	18,000	0.03	fixed
	Polar freshwaters	0.01	0.001	0.01	18,000	0.02	fixed
	Polar seas	-0.002	-0.02	0.02	18,000	0.83	fixed
	Temperate forests	0.005	0.002	0.01	18,000	0.0001	fixed
	Temperate wetlands and rivers	0.005	0.002	0.01	18,000	0.001	fixed
	Temperate grasslands savannas and shrublands	-0.004	-0.01	0.002	18,000	0.22	fixed
	Tropical wetlands and rivers	0.01	-0.003	0.01	18,000	0.21	fixed
	Tropical and subtropical forests	0.02	0.01	0.03	18,000	0.0001	fixed
	Tropical coral	0.02	0.01	0.04	18,000	0.0001	fixed
	Tundra	0.01	-0.001	0.01	18,000	0.09	fixed
	Xeric freshwaters and endorheic basins	-0.002	-0.02	0.01	15,937	0.77	fixed
	sigma	0.003	0.003	0.003	17,444		residual
Biome (global) - slope	Boreal forests/taiga	-0.001	-0.01	0.003	18,000	0.55	fixed
	Deserts and xeric shrublands	-0.04	-0.06	-0.02	17,811	0.001	fixed
	Trop. and subtrop. grasslands savannas and shrublands	-0.01	-0.02	-0.002	18,000	0.02	fixed
	Large lakes	0.004	-0.01	0.02	18,000	0.50	fixed
	Mediterranean forests woodlands and scrub	0.03	0.01	0.04	18,000	0.0001	fixed
	Montane freshwaters	0.03	-0.01	0.07	18,000	0.18	fixed
	Montane grasslands and shrublands	0.02	-0.004	0.05	18,000	0.10	fixed

	Polar freshwaters	0.01	-0.004	0.02	18,000	0.22	fixed
	Polar seas	-0.01	-0.04	0.02	18,000	0.50	fixed
	Temperate forests	0.01	0.004	0.01	18,000	0.0001	fixed
	Temperate wetlands and rivers	0.01	0.002	0.01	18,000	0.004	fixed
	Temperate grasslands savannas and shrublands	-0.004	-0.01	0.01	18,000	0.42	fixed
	Tropical wetlands and rivers	0.003	-0.01	0.02	18,000	0.64	fixed
	Tropical and subtropical forests	0.02	0.01	0.04	17,621	0.0001	fixed
	Tropical coral	0.04	0.02	0.05	18,960	0.0001	fixed
	Tundra	0.01	0.0001	0.03	18,000	0.04	fixed
	Xeric freshwaters and endorheic basins	0.01	-0.02	0.03	18,000	0.60	fixed
	sigma	0.004	0.003	0.004	18,000		residual
Biome (global) - weighted	Boreal forests/taiga	-0.002	-0.01	0.003	17,517	0.42	fixed
	Deserts and xeric shrublands	-0.03	-0.05	0.003	18,000	0.08	fixed
	Trop. and subtrop. grasslands savannas and shrublands	-0.002	-0.02	0.01	18,000	0.71	fixed
	Large lakes	0.01	-0.01	0.02	18,000	0.29	fixed
	Mediterranean forests woodlands and scrub	0.02	0.005	0.03	19,064	0.01	fixed
	Montane freshwaters	0.01	-0.03	0.05	18,469	0.65	fixed
	Montane grasslands and shrublands	0.02	-0.01	0.06	18,000	0.12	fixed
	Polar freshwaters	0.02	0.01	0.03	18,630	0.002	fixed
	Polar seas	-0.01	-0.05	0.02	17,320	0.44	fixed
	Temperate forests	0.01	0.004	0.01	17,516	0.0002	fixed
	Temperate wetlands and rivers	0.01	0.01	0.01	17,324	0.0001	fixed
	Temperate grasslands savannas and shrublands	-0.01	-0.02	0.002	17,573	0.14	fixed
	Tropical wetlands and rivers	0.01	-0.004	0.02	18,000	0.13	fixed
	Tropical and subtropical forests	0.01	-0.001	0.03	18,000	0.07	fixed
	Tropical coral	0.04	0.02	0.06	17,511.66	0.0001	fixed
	Tundra	0.01	-0.004	0.02	18,000	0.16	fixed
	Xeric freshwaters and endorheic basins	-0.03	-0.05	-0.0004	18,000	0.04	fixed
	sigma	0.01	0.01	0.01	18,000		residual
Biome (global) - fluctuations CI	Boreal forests/taiga	0.07	0.07	0.08	18,000	0.0001	fixed
	Deserts and xeric shrublands	0.22	0.18	0.26	18,658	0.0001	fixed
	Trop. and subtrop. grasslands savannas and shrublands	0.21	0.19	0.23	18,000	0.0001	fixed
	Large lakes	0.11	0.09	0.12	18,000	0.0001	fixed
	Mediterranean forests woodlands and scrub	0.15	0.13	0.16	17,403	0.0001	fixed
	Montane freshwaters	0.14	0.09	0.19	18,000	0.0001	fixed
	Montane grasslands and shrublands	0.17	0.13	0.21	18,000	0.0001	fixed

	Polar freshwaters	0.14	0.13	0.15	18,000	0.0001	fixed
	Polar seas	0.16	0.11	0.21	18,148	0.0001	fixed
	Temperate forests	0.09	0.09	0.10	18,000	0.0001	fixed
	Temperate wetlands and rivers	0.13	0.12	0.13	18,000	0.0001	fixed
	Temperate grasslands savannas and shrublands	0.08	0.07	0.09	18,000	0.0001	fixed
	Tropical wetlands and rivers	0.20	0.19	0.22	18,440	0.0001	fixed
	Tropical and subtropical forests	0.20	0.18	0.21	18,000	0.0001	fixed
	Tropical coral	0.16	0.14	0.19	17,964	0.0001	fixed
	Tundra	0.11	0.09	0.13	18,000	0.0001	fixed
	Xeric freshwaters and endorheic basins	0.18	0.14	0.21	18,000	0.0001	fixed
	sigma	0.02	0.01	0.02	18,000		residual
Biome (global) - fluctuations CI weighted	Boreal forests/taiga	0.08	0.07	0.08	18,000	0.0001	fixed
	Deserts and xeric shrublands	0.26	0.21	0.30	18,000	0.0001	fixed
	Trop. and subtrop. grasslands savannas and shrublands	0.25	0.23	0.27	17,477	0.0001	fixed
	Large lakes	0.12	0.09	0.14	18,000	0.0001	fixed
	Mediterranean forests woodlands and scrub	0.16	0.14	0.19	18,000	0.0001	fixed
	Montane freshwaters	0.23	0.15	0.31	17,217	0.0001	fixed
	Montane grasslands and shrublands	0.18	0.12	0.23	18,681	0.0001	fixed
	Polar freshwaters	0.17	0.15	0.19	17,751	0.0001	fixed
	Polar seas	0.18	0.12	0.23	18,000	0.0001	fixed
	Temperate forests	0.09	0.09	0.10	18,000	0.0001	fixed
	Temperate wetlands and rivers	0.14	0.13	0.15	18,000	0.0001	fixed
	Temperate grasslands savannas and shrublands	0.08	0.06	0.10	18,000	0.0001	fixed
	Tropical wetlands and rivers	0.22	0.20	0.25	18,000	0.0001	fixed
	Tropical and subtropical forests	0.21	0.19	0.24	18,000	0.0001	fixed
	Tropical coral	0.18	0.15	0.21	18,000	0.0001	fixed
	Tundra	0.11	0.09	0.14	18,000	0.0001	fixed
	Xeric freshwaters and endorheic basins	0.23	0.18	0.27	18,000	0.0001	fixed
	sigma	0.02	0.02	0.02	18,000		residual
Biome (global) - fluctuations SE	Boreal forests/taiga	0.06	0.06	0.07	18,000	0.0001	fixed
	Deserts and xeric shrublands	0.21	0.17	0.25	18,000	0.0001	fixed
	Trop. and subtrop. grasslands savannas and shrublands	0.11	0.09	0.13	17,497	0.0001	fixed
	Large lakes	0.09	0.07	0.11	18,000	0.0001	fixed
	Mediterranean forests woodlands and scrub	0.16	0.14	0.18	18,000	0.0001	fixed
	Montane freshwaters	0.15	0.10	0.21	16,658	0.0001	fixed
	Montane grasslands and shrublands	0.11	0.07	0.15	18,000	0.0001	fixed

	Polar freshwaters	0.14	0.13	0.15	18,000	0.0001	fixed
	Polar seas	0.08	0.03	0.13	18,000	0.002	fixed
	Temperate forests	0.09	0.08	0.09	18,000	0.0001	fixed
	Temperate wetlands and rivers	0.11	0.11	0.12	18,000	0.0001	fixed
	Temperate grasslands savannas and shrublands	0.07	0.06	0.09	18,000	0.0001	fixed
	Tropical wetlands and rivers	0.21	0.19	0.23	18,000	0.0001	fixed
	Tropical and subtropical forests	0.15	0.13	0.17	18,000	0.0001	fixed
	Tropical coral	0.18	0.16	0.21	18,000	0.0001	fixed
	Tundra	0.13	0.11	0.14	17,343	0.0001	fixed
	Xeric freshwaters and endorheic basins	0.13	0.09	0.17	18,000	0.0001	fixed
	sigma	0.02	0.02	0.02	18,000		residual
Biome (global) - fluctuations SD	Boreal forests/taiga	0.51	0.51	0.52	18,000	0.0001	fixed
	Deserts and xeric shrublands	0.60	0.57	0.62	17,053.04	0.0001	fixed
	Trop. and subtrop. grasslands savannas and shrublands	0.61	0.60	0.62	18,000	0.0001	fixed
	Large lakes	0.54	0.52	0.55	18,000	0.0001	fixed
	Mediterranean forests woodlands and scrub	0.59	0.58	0.61	17,567	0.0001	fixed
	Montane freshwaters	0.58	0.54	0.62	18,000	0.0001	fixed
	Montane grasslands and shrublands	0.59	0.56	0.62	18,000	0.0001	fixed
	Polar freshwaters	0.55	0.54	0.56	18,000	0.0001	fixed
	Polar seas	0.55	0.52	0.59	18,000	0.0001	fixed
	Temperate forests	0.53	0.53	0.54	18,056	0.0001	fixed
	Temperate wetlands and rivers	0.55	0.55	0.56	18,000	0.0001	fixed
	Temperate grasslands savannas and shrublands	0.52	0.51	0.53	17,393	0.0001	fixed
	Tropical wetlands and rivers	0.60	0.59	0.62	18,000	0.0001	fixed
	Tropical and subtropical forests	0.62	0.60	0.63	18,000	0.0001	fixed
	Tropical coral	0.61	0.59	0.63	18,000	0.0001	fixed
	Tundra	0.54	0.53	0.56	18,000	0.0001	fixed
	Xeric freshwaters and endorheic basins	0.56	0.53	0.58	18,000	0.0001	fixed
	sigma	0.01	0.01	0.01	18,000		residual
Taxa (global) - mu	Actinopterygii	-0.001	-0.003	0.002	18,000	0.67	fixed
	Amphibia	-0.01	-0.02	-0.005	18,000	0.003	fixed
	Aves	0.004	0.003	0.01	18,000	0.0001	fixed
	Mammalia	0.01	0.01	0.01	18,000	0.0001	fixed
	Reptilia	0.02	0.01	0.02	18,000	0.0001	fixed
	sigma	0.003	0.003	0.004	18,000		residual
Taxa (global) - weighted	Actinopterygii	-0.001	-0.01	0.003	18,000	0.68	fixed
	Amphibia	-0.01	-0.03	-0.002	18,000	0.03	fixed
	Aves	0.01	0.003	0.01	18,000	0.0001	fixed
	Mammalia	0.01	0.01	0.02	18,000	0.0001	fixed
	Reptilia	0.01	-0.001	0.02	18,000	0.07	fixed

	sigma	0.004	0.004	0.004	18,000		residual
Taxa (global) - slope	Actinopterygii	-0.002	-0.01	0.002	18,000	0.34	fixed
	Amphibia	-0.02	-0.04	-0.01	18,000	0.002	fixed
	Aves	0.01	0.004	0.01	17,484	0.0001	fixed
	Mammalia	0.01	0.01	0.02	16,803	0.0001	fixed
	Reptilia	0.03	0.02	0.04	17,631	0.0001	fixed
	sigma	0.01	0.01	0.01	18,000		residual
Taxa (global) - fluctuations CI	Actinopterygii	0.15	0.14	0.16	18,000	0.0001	fixed
	Amphibia	0.22	0.20	0.24	17,663	0.0001	fixed
	Aves	0.09	0.09	0.10	18,000	0.0001	fixed
	Mammalia	0.17	0.17	0.18	18,000	0.0001	fixed
	Reptilia	0.17	0.15	0.18	18,410	0.0001	fixed
	sigma	0.01	0.01	0.02	18,000		residual
Taxa (global) - fluctuations CI weighted	Actinopterygii	0.17	0.16	0.18	18,000	0.0001	fixed
	Amphibia	0.28	0.26	0.31	18,000	0.0001	fixed
	Aves	0.10	0.09	0.10	18,000	0.0001	fixed
	Mammalia	0.20	0.19	0.21	18,000	0.0001	fixed
	Reptilia	0.21	0.19	0.23	18,000	0.0001	fixed
	sigma	0.02	0.02	0.02	18,000		residual
Taxa (global) - fluctuations SE	Actinopterygii	0.14	0.13	0.14	18,000	0.0001	fixed
	Amphibia	0.24	0.23	0.26	18,539	0.0001	fixed
	Aves	0.08	0.07	0.08	18,000	0.0001	fixed
	Mammalia	0.15	0.14	0.16	16,776	0.0001	fixed
	Reptilia	0.19	0.18	0.20	18,576	0.0001	fixed
	sigma	0.02	0.02	0.02	18,836		residual
Taxa (global) - fluctuations SD	Actinopterygii	0.56	0.56	0.57	18,000	0.0001	fixed
	Amphibia	0.62	0.60	0.63	17,434	0.0001	fixed
	Aves	0.53	0.53	0.53	18,000	0.0001	fixed
	Mammalia	0.60	0.59	0.60	18,000	0.0001	fixed
	Reptilia	0.59	0.58	0.60	18,000	0.0001	fixed
	sigma	0.01	0.01	0.01	18,000		residual
Amphibian population trends – mu and phylogeny	(Intercept)	-0.009 (-0.009 – -0.008)	-0.005 (-0.005 – -0.005)	0.031 (0.027 – 0.035)	10,047 (10,713 – 9350)	0.59 (0.55 – 0.62)	fixed
	phylo	0.001 (0.001 – 0.002)	0.001 (0.001 – 0.001)	0.004(0.004 – 0.005)	7,037 (6,171 – 7,602)		random
	species	0.001 (0.001 – 0.001)	0.001 (0.001 – 0.001)	0.002 (0.002 – 0.002)	7,912 (6,541 – 8,500)		random
	sigma	0.006 (0.006 – 0.006)	0.004 (0.004 – 0.004)	0.007 (0.007 – 0.007)	9,855 (9,280 – 10,041)		residual
Bird population trends – mu and phylogeny	(Intercept)	0.005 (0.004 – 0.005)	-0.009 (-0.014 – -0.005)	0.017 (0.02 – 0.02)	10,304 (9,515 – 12,560)	0.45 (0.31 – 0.63)	fixed
	phylo	0.001 (0.001 – 0.003)	0.001 (0.001 – 0.001)	0.001 (0.001 – 0.001)	3,850 (3,305 – 4,144)		random
	species	0.001 (0.001 – 0.001)	0.001 (0.001 – 0.001)	0.001 (0.001 – 0.001)	6,799 (6,358 – 7,260)		random
	sigma	0.002 (0.002 – 0.002)	0.002 (0.002 – 0.002)	0.003 (0.003 – 0.003)	9,991 (9,713 – 10,345)		residual

Reptile population trends – mu and phylogeny	(Intercept)	0.004 (0.003 – 0.005)	-0.004 (-0.005 – -0.003)	0.047 (0.043 – 0.056)	10,030 (9,679 – 10,595)	0.83 (0.81 – 0.85)	fixed
	phylo	0.002 (0.001 – 0.003)	0.001 (0.001 – 0.001)	0.007 (0.005 – 0.010)	3,971 (2,850 – 4,823)		random
	species	0.004 (0.004 – 0.004)	0.001 (0.001 – 0.001)	0.007 (0.007 – 0.007)	3,418 (3,058 – 3,701)		random
	sigma	0.004 (0.004 – 0.004)	0.001 (0.001 – 0.001)	0.007 (0.007 – 0.007)	3,562 (3,133 – 3,765)		residual
Amphibian population fluctuations – CI and phylogeny	(Intercept)	0.271 (0.269 – 0.271)	0.217 (0.215 – 0.219)	0.323 (0.321 – 0.327)	9,905 (8,988 – 10,066)	0.001 (0.001 – 0.001)	fixed
	phylo	0.001 (0.001 - 0.002)	0.001 (0.001 - 0.001)	0.006 (0.005 – 0.006)	9,754 (8,283 – 10,000)		random
	species	0.001 (0.001 – 0.001)	0.001 (0.001 - 0.001)	0.005 (0.005 – 0.005)	9,822 (8,557 – 10,000)		random
	sigma	0.045 (0.0349 – 0.045)	0.035 (0.035 – 0.035)	0.056 (0.055 – 0.056)	10,076 (10,000 – 10,413)		residual
Bird population fluctuations – CI and phylogeny	(Intercept)	0.114 (0.109 – 0.119)	0.059 (0.048 – 0.070)	0.169 (0.153 – 0.188)	10,000 (10, 000 – 10,000)	0.001 (0.001 – 0.001)	fixed
	phylo	0.005 (0.004 – 0.006)	0.003 (0.0.002 – 0.003)	0.007 (0.005 – 0.009)	4,017 (3,779 – 4,336)		random
	species	0.002 (0.002 – 0.002)	0.001 (0.001 – 0.001)	0.003 (0.002 – 0.003)	5,706 (4,991 – 6,092)		random
	sigma	0.010 (0.010 – 0.010)	0.010 (0.010 – 0.010)	0.011 (0.011 – 0.011)	9,936 (9,223 – 11,161)		residual
Reptile population fluctuations – CI and phylogeny	(Intercept)	0.302 (0.301 – 0.306)	0.180 (0.1625 – 0.190)	0.424 (0.410 – 0.434)	9,837 (9,242 – 10,009)	0.001 (0.001 – 0.001)	fixed
	phylo	0.014 (0.012 – 0.014)	0.001 (0.001 – 0.001)	0.056 (0.050 – 0.060)	2,779 (2,256 – 3,213)		random
	species	0.050 (0.049 – 0.050)	0.019 (0.016 – 0.022)	0.082 (0.081 – 0.084)	4,407 (3,544 – 4,730)		random
	sigma	0.018 (0.018 – 0.018)	0.006 (0.006 – 0.007)	0.036 (0.035 – 0.036)	3,985 (3,817 – 4,536)		residual
Geographic range (birds) - mu	(Intercept)	-0.01	-0.03	0.004	18,000	0.15	fixed
	log(range)	0.001	-0.0000	0.002	18,000	0.05	fixed
	sigma	0.003	0.003	0.003	18,000		residual
Geographic range (birds) - weighted	(Intercept)	-0.003	-0.03	0.02	18,000	0.77	fixed
	log(range)	0.001	-0.001	0.002	17,620	0.41	fixed
	sigma	0.003	0.003	0.003	18,000		residual
Geographic range (birds) - slope	(Intercept)	-0.02	-0.04	0.01	18,000	0.26	fixed
	log.range	0.001	-0.0003	0.003	18,000	0.10	fixed
	sigma	0.01	0.01	0.01	18,881		residual
Geographic range (birds) - fluctuations CI	(Intercept)	0.02	-0.02	0.05	18,000	0.37	fixed
	log(range)	0.005	0.003	0.01	18,000	0.0001	fixed
	sigma	0.01	0.01	0.01	18,000		residual

Geographic range (birds) - fluctuations CI weighted	(Intercept)	0.01	-0.04	0.05	18,000	0.72	fixed
	log(range)	0.01	0.003	0.01	18,000	0.0001	fixed
	sigma	0.02	0.01	0.02	18,657		residual
Geographic range (birds) - fluctuations SE	(Intercept)	-0.04	-0.08	-0.01	18,000	0.01	fixed
	log(range)	0.01	0.01	0.01	18,000	0.0001	fixed
	sigma	0.01	0.01	0.01	18,000		residual
Geographic range (birds) - fluctuations SD	(Intercept)	0.47	0.44	0.50	18,000	0.0001	fixed
	log(range)	0.004	0.002	0.01	18,000	0.0001	fixed
	sigma	0.01	0.01	0.01	18,000		residual
Mean population size (global) - mu	(Intercept)	0.01	0.001	0.01	18,000	0.03	fixed
	log.meanpop	0.001	-0.0002	0.001	18,000	0.14	fixed
	sigma	0.005	0.005	0.01	17,393		residual
Mean population size (global) - weighted	(Intercept)	0.01	0.0004	0.01	17,924	0.04	fixed
	log.meanpop	0.001	-0.001	0.002	18,000	0.37	fixed
	sigma	0.01	0.01	0.01	18,000		residual
Mean population size (global) - slope	(Intercept)	0.01	0.0004	0.02	17,382	0.04	fixed
	log.meanpop	0.001	-0.0003	0.002	17,360	0.14	fixed
	sigma	0.01	0.01	0.01	18,000		residual
Mean population size (global) - fluctuations CI	(Intercept)	0.21	0.20	0.23	18,000	0.0001	fixed
	log.meanpop	-0.004	-0.01	-0.002	18,000	0.0001	fixed
	sigma	0.03	0.03	0.03	18,000		residual
Mean population size (global) - fluctuations CI weighted	(Intercept)	0.25	0.23	0.26	18,000	0.0001	fixed
	log.meanpop	-0.01	-0.01	-0.003	18,000	0.0001	fixed
	sigma	0.03	0.03	0.03	18,000		residual
Mean population size (global) - fluctuations SE	(Intercept)	0.22	0.21	0.23	18,000	0.0001	fixed
	log.meanpop	-0.01	-0.01	-0.01	18,000	0.0001	fixed
	sigma	0.03	0.03	0.03	17,622		residual
Mean population size (global) - fluctuations SD	(Intercept)	-0.002	-0.002	-0.001	18,000	0.0001	fixed
	log.meanpop	0.0003	0.0002	0.0004	18,000	0.0001	fixed
	sigma	0.0002	0.0001	0.0002	18,000		residual
Habitat specificity (global) - mu	(Intercept)	0.004	0.001	0.01	18,000	0.002	fixed
	hab_spec	0.0001	-0.0001	0.0004	18,000	0.36	fixed
	sigma	0.004	0.004	0.004	18,000		residual
Habitat specificity (global) - weighted	(Intercept)	0.003	-0.0002	0.01	18,000	0.06	fixed
	hab_spec	0.0003	0.0000	0.001	18,000	0.05	fixed
	sigma	0.004	0.004	0.004	18,000		residual
Habitat specificity (global) - slope	(Intercept)	0.01	0.002	0.01	17,426	0.004	fixed
	hab_spec	0.0002	-0.0002	0.001	17,536	0.41	fixed
	sigma	0.01	0.01	0.01	18,000		residual

Habitat specificity (global) - fluctuations CI	(Intercept)	0.11	0.10	0.11	17,358	0.0001	fixed
	hab_spec	0.001	0.001	0.002	18,000	0.0001	fixed
	sigma	0.02	0.02	0.02	18,000		residual
Habitat specificity (global) - fluctuations CI weighted	(Intercept)	0.12	0.11	0.12	18,000	0.0001	fixed
	hab_spec	0.001	0.001	0.002	18,000	0.0001	fixed
	sigma	0.02	0.02	0.02	18,000		residual
Habitat specificity (global) - fluctuations SE	(Intercept)	0.10	0.09	0.10	18,000	0.0001	fixed
	hab_spec	0.001	0.001	0.002	18,000	0.0001	fixed
	sigma	0.02	0.02	0.02	18,000		residual
Habitat specificity (global) - fluctuations SD	(Intercept)	0.54	0.54	0.55	18,000	0.0001	fixed
	hab_spec	0.001	0.0002	0.001	18,563	0.002	fixed
	sigma	0.01	0.01	0.01	18,000		residual
Red List status (global) - mu	Least concern	0.01	0.005	0.01	18,000	0.0001	fixed
	Near threatened	-0.01	-0.01	-0.0005	18,000	0.04	fixed
	Vulnerable	0.002	-0.003	0.01	18,294	0.40	fixed
	Endangered	-0.002	-0.01	0.01	18,000	0.60	fixed
	Critically endangered	-0.01	-0.02	0.0001	18,000	0.05	fixed
	sigma	0.004	0.003	0.004	18,000		residual
Red List status (global) - weighted	Least concern	0.01	0.01	0.01	19,846	0.0001	fixed
	Near threatened	-0.003	-0.01	0.005	18,000	0.45	fixed
	Vulnerable	0.002	-0.005	0.01	18,000	0.52	fixed
	Endangered	-0.01	-0.02	0.003	18,000	0.19	fixed
	Critically endangered	-0.02	-0.03	-0.01	18,000	0.01	fixed
	sigma	0.004	0.004	0.004	18,000		residual
Red List status (global) - slope	Least concern	0.01	0.01	0.01	18,000	0.0001	fixed
	Near threatened	-0.01	-0.02	-0.004	18,000	0.01	fixed
	Vulnerable	0.002	-0.01	0.01	17,507	0.58	fixed
	Endangered	-0.001	-0.01	0.01	18,000	0.91	fixed
	Critically endangered	-0.01	-0.02	0.01	17,564	0.44	fixed
	sigma	0.01	0.01	0.01	18,000		residual
Red List status (global) - fluctuations CI	Least concern	0.11	0.11	0.12	18,000	0.0001	fixed
	Near threatened	0.14	0.13	0.15	18,000	0.0001	fixed
	Vulnerable	0.14	0.13	0.15	19,536	0.0001	fixed
	Endangered	0.16	0.15	0.17	18,000	0.0001	fixed
	Critically endangered	0.17	0.15	0.19	18,000	0.0001	fixed
	sigma	0.02	0.02	0.02	18,000		residual
Red List status (global) - fluctuations CI weighted	Least concern	0.12	0.12	0.12	18,432	0.0001	fixed
	Near threatened	0.16	0.15	0.18	18,812	0.0001	fixed
	Vulnerable	0.15	0.14	0.17	18,832	0.0001	fixed
	Endangered	0.19	0.17	0.21	17,714	0.0001	fixed
	Critically endangered	0.19	0.16	0.22	18,469	0.0001	fixed
	sigma	0.02	0.02	0.02	18,000		residual

Red List status (global) - fluctuations SE	Least concern	0.10	0.10	0.10	18,000	0.0001	fixed
	Near threatened	0.13	0.12	0.14	19,308	0.0001	fixed
	Vulnerable	0.11	0.10	0.12	18,645	0.0001	fixed
	Endangered	0.13	0.12	0.15	18,000	0.0001	fixed
	Critically endangered	0.15	0.13	0.17	18,000	0.0001	fixed
	sigma	0.02	0.02	0.02	18,555		residual
Red List status (global) - fluctuations SD	Least concern	0.54	0.54	0.55	18,390	0.0001	fixed
	Near threatened	0.57	0.56	0.58	18,000	0.0001	fixed
	Vulnerable	0.56	0.55	0.57	18,214	0.0001	fixed
	Endangered	0.59	0.58	0.60	18,000	0.0001	fixed
	Critically endangered	0.61	0.59	0.62	17,295	0.0001	fixed
	sigma	0.01	0.01	0.01	18,000		residual
Latitude (global) - mu	(Intercept)	0.004	0.002	0.01	18,254	0.0001	fixed
	Decimal.Latitude	-0.0000	-0.0000	0.0000	18,670	0.90	fixed
	sigma	0.003	0.003	0.004	18,000		residual
Duration (global) - mu	End	0.0000	0.0000	0.0001	18,561	0.03	fixed
	sigma	0.003	0.003	0.004	18,000		residual

895 **Table S3. List of species included in the UK scale analysis of population**

896 **change across rarity metrics.**

897

Species name	Number of populations
Acrocephalus schoenobaenus	1
Acrocephalus scirpaceus	1
Agonus cataphractus	1
Alca torda	4
Anarhichas lupus	1
Anas acuta	1
Anas crecca	1
Anas platyrhynchos	2
Anser albifrons	4
Anser fabalis	1
Anthus pratensis	2
Ardea cinerea	1
Arenaria interpres	1
Argentina silus	1
Argentina sphyraena	1
Arnoglossus laterna	1
Asio flammeus	1
Aythya ferina	4
Aythya fuligula	2
Botaurus stellaris	14
Branta bernicla	54
Branta canadensis	1
Branta leucopsis	3
Brosme brosme	1
Bucephala clangula	1
Bufo bufo	1
Burhinus oedicnemus	1
Buteo buteo	1
Calidris alba	1
Calidris alpina	1
Calidris canutus	2
Calidris maritima	2
Callionymus maculatus	1

Capreolus capreolus	3
Carduelis cannabina	2
Cepphus grylle	2
Cervus elaphus	2
Cetorhinus maximus	1
Cettia cetti	1
Charadrius hiaticula	1
Chelidonichthys lucerna	2
Circus aeruginosus	1
Circus cyaneus	1
Clupea harengus	2
Columba oenas	1
Coronella austriaca	1
Corvus corax	1
Corvus corone	1
Corvus monedula	1
Crex crex	1
Cyclopterus lumpus	1
Cygnus columbianus	3
Cygnus cygnus	1
Cygnus olor	1
Delphinus delphis	2
Echiichthys vipera	1
Egretta garzetta	1
Emberiza cirlus	1
Emberiza citrinella	1
Emberiza schoeniclus	3
Eptesicus serotinus	1
Esox lucius	2
Falco peregrinus	1
Falco tinnunculus	1
Fulica atra	1
Fulmarus glacialis	7
Gadus morhua	7
Glyptocephalus cynoglossus	1
Haematopus ostralegus	2
Haliaeetus albicilla	1
Halichoerus grypus	52

Hippoglossus hippoglossus	1
Lagopus lagopus	3
Larus argentatus	1
Larus canus	1
Larus fuscus	1
Larus melanocephalus	1
Lepidorhombus whiffiagonis	2
Lepus timidus	1
Limosa lapponica	2
Limosa limosa	2
Lissotriton vulgaris	5
Lophius budegassa	1
Lophius piscatorius	2
Lullula arborea	1
Melanogrammus aeglefinus	9
Meles meles	1
Mergus serrator	1
Merlangius merlangus	8
Merluccius merluccius	2
Micromesistius poutassou	1
Milvus milvus	3
Molva molva	1
Morus bassanus	4
Muscicapa striata	1
Myotis nattereri	1
Natrix natrix	1
Netta rufina	1
Numenius arquata	2
Nyctalus noctula	1
Oenanthe oenanthe	1
Orcinus orca	1
Oriolus oriolus	1
Oryctolagus cuniculus	6
Oxyura jamaicensis	2
Pandion haliaetus	1
Parus major	2
Passer domesticus	1
Passer montanus	1

Perca fluviatilis	3
Perdix perdix	1
Phalacrocorax aristotelis	8
Phoca vitulina	28
Phrynorhombus norvegicus	1
Pipistrellus pipistrellus	1
Pipistrellus pygmaeus	1
Platichthys flesus	1
Plecotus auritus	1
Plectrophenax nivalis	2
Pleuronectes platessa	6
Pluvialis apricaria	2
Pluvialis squatarola	1
Podiceps cristatus	1
Pollachius pollachius	1
Pollachius virens	3
Prunella modularis	1
Puffinus mauretanicus	2
Pyrrhula pyrrhula	1
Raja brachyura	1
Raja clavata	1
Raja microocellata	1
Raja montagui	1
Rhinolophus ferrumequinum	2
Rhinolophus hipposideros	4
Rissa tridactyla	9
Salmo salar	1
Salmo trutta	1
Scomber scombrus	2
Scyliorhinus canicula	1
Sitta europaea	1
Sprattus sprattus	1
Stenella coeruleoalba	1
Stercorarius parasiticus	3
Sterna dougallii	5
Sterna hirundo	1
Sterna paradisaea	1
Sternula albifrons	1

Streptopelia turtur	1
Strix aluco	1
Sturnus vulgaris	1
Sylvia communis	1
Syngnathus rostellatus	1
Tachybaptus ruficollis	1
Tadorna tadorna	1
Thalasseus sandvicensis	2
Trachurus trachurus	2
Tringa nebularia	1
Tringa totanus	1
Trisopterus esmarkii	2
Trisopterus luscus	1
Trisopterus minutus	1
Triturus cristatus	5
Turdus philomelos	1
Tursiops truncatus	4
Uria aalge	10
Vanellus vanellus	3
Xiphias gladius	1

899 **Table S4. Profiling method for estimating habitat specificity for 144 species**
900 **with populations in the UK in the LPD.** We extracted the habitats in which each
901 species occurs from their IUCN profiles (http://www.iucnredlist.org/) and we followed
902 this key for consistency.

Habitat	Considered to be the same as:	Considered to be different to:
Rural park	Suburban park, urban park, rural garden, suburban garden, urban garden	
Lake	Big lake, small lake, pond, pool, dam, oxbow lake, reservoir	
Bog	Swamp, bogland	Lagoon
Coastal cliff	Island cliff	
Shingle beach	Pebble beach, rock beach	Sandy beach
Stream	River	Weir
Fruit Tree Plantation	Fruit Garden, orchard	
Thicket	Copse, grove, small stand	
Forest		Woodland
Glade	Forest Clearing	
Broadleaf	Deciduous	
Urban	Suburban	
River margin	Various types of river margins	
Tidal Creek		Estuary
Harbour	Dock, jetty, pier	
Bush lands	Shrublands	
Irrigation channel	Ditch	
Heath	Moorland	
Sandy beach	Spit, dune	Shingle beach, pebble beach, rock beach
Crag	Rocky outcrop, cliff, rocky slope	

Marsh	Wet meadow
Islet	Island

Table S5. Model outputs from analyses testing variation in duration across systems, taxa and Red List status. Sigma is the overall model residual variance. The intercepts in the models were as follows: system model – Terrestrial; taxa model – Amphibia; Red List status model – Least concern.

Model name	Variable	Posterior mean	Lower 95% CI	Upper 95% CI	Effective sample size	pMCMC	Effect
Duration - system	(Intercept)	27.74	27.35	28.15	18,000	0.0001	fixed
	Marine	-9.74	-10.41	-9.07	18,000	0.0001	fixed
	Freshwater	-6.87	-7.50	-6.17	18,000	0.0001	fixed
	sigma	186.61	181.15	191.95	18,577.71		residual
Duration - taxa	(Intercept)	10.82	9.05	12.69	18,000	0.0001	fixed
	Actinopterygii	6.14	4.18	8.00	18,000	0.0001	fixed
	Aves	17.24	15.41	19.09	18,000	0.0001	fixed
	Mammalia	2.90	0.93	4.86	18,294.71	0.004	fixed
	Reptilia	2.64	0.31	4.88	18,000	0.02	fixed
	sigma	165.98	161.25	170.85	18,000		residual
Duration - Red List status	(Intercept)	24.51	24.15	24.84	17,109.46	0.0001	fixed
	Near threatened	-6.52	-7.78	-5.24	18,408.08	0.0001	fixed
	Vulnerable	-5.84	-7.01	-4.64	18,000	0.0001	fixed
	Endangered	-9.35	-10.95	-7.72	17,500.06	0.0001	fixed
	Critically endangered	-11.82	-14.05	-9.58	18,939.23	0.0001	fixed
	sigma	195.22	189.29	201.33	17,822.52		residual