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Title: Global pattern of nest predation is disrupted by climate change in shorebirds

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Abstract: Ongoing climate change is thought to disrupt trophic relationships with consequences for complex interspecific interactions, yet the effects of climate change on species interactions are poorly understood and such effects have not been documented at a global scale. Using a unique database of 38,191 nests from 237 populations, we found that shorebirds have experienced a worldwide increase in nest predation over the last 70 years. Historically, there existed a latitudinal gradient in nest predation with the highest rates in the tropics, however, this pattern has been recently reversed in the Northern hemisphere, most notably in the Arctic. This increased nest predation is consistent with climate-induced shifts in predator-prey relationships.

One Sentence Summary: Climate change increases offspring mortality in shorebirds globally.

Main Text: Climate change is impacting organisms at a global scale in several ways (*1*–*4*), including directly altering demographic parameters such as adult survival (*5*) and reproduction (*1*), or via altered trophic interactions (*1*, *6*, *7*). Successful recruitment counters mortality and maintains viable populations, thus disruption of reproductive performance can have detrimental effects on wild populations (*8*–*10*). Alterations in demographic parameters have been attributed to recent climate change (*1*, *5*, *11*), especially in the Arctic, where the consequences of warming are expected to be more pronounced (*6*, *12*). However, the evidence for impacts of climate change on species interactions is mixed, and to date there is no evidence that such interactions are changing globally (*1*–*3*).

Offspring mortality due to predation has a pivotal influence on the reproductive performance of wild populations (*8*, *13*–*15*) and extreme rates of predation can quickly lead to population declines or even species extinction (*16*). Thus nest predation is a good indicator of the potential for reproductive recruitment in bird populations (*10*). Disruption to annual productivity through increased nest predation could have a detrimental effect on population dynamics and lead to increased extinction risks (*9*). To explore changes in spatial patterns of reproduction and potential alterations in trophic interactions due to changes in climate, we use nest predation data from shorebirds, a globally distributed group of ground-nesting birds that exhibit high inter-specific similarity in nest appearance to potential predators and are exceptionally well-studied in the wild including ecology, behaviour and demography (*10*, *17*, *18*). We collected data from both published and previously unpublished sources that included 38,191 nests in 237 populations of 111 shorebirds species from 149 locations encompassing all continents across a 70-year time span (fig. S1 and table S1).

Using our comprehensive dataset in a spatio-phylogenetic framework (*19*), we show that rates of nest predation increased over the last 70 years. Daily nest predation, as well as total nest predation (reflecting the full incubation period for a given species), have increased overall worldwide since the 1950s (Fig. 1, Fig. 2A, Fig. 2B, fig. S2A, fig. S2B and table S2). Thus total nest predation was historically (until 1999) on average 43% ± 2% (SEM), and this has increased to 57% ± 2% since 2000. However, the extent of change shows considerable geographical variation. In the tropics and South temperate areas, changes in daily and total nest predation were not statistically significant, whereas in the North temperate zone, and especially the Arctic, the increase was pronounced (Fig. 1, Fig. 2A, Fig. 2B, fig. S2A, fig. S2B and table S2). This pattern holds across major clades of shorebirds (Fig. 2C, Fig. 2D, fig. S2C, fig. S2D and table S3) and is also observed within local populations with daily and total nest predation increasing significantly in well-monitored North temperate and Arctic breeding populations (Fig. 2E and Fig. 2F). Thus the total nest predation was historically 35% ± 6% that increased to 64% ± 5% in recent years for these long-term monitored populations (Fig. 2F, table S4 and table S5).

Life-history theory predicts that species that breed close to the Equator should exhibit higher rates of nest predation than species breeding in temperate and polar latitudes, in part owing to the higher diversity of potential nest predators in the tropics, and there is an empirical support for this prediction (*14*, *15*, *20*, *21*). In line with theoretical expectations, historic rates of nest predation in shorebirds follow the parabolic relationship between both daily and total rates of nest predation and latitude (Fig. 3, fig. S3 and table S6).

However, in recent years, daily nest predation changed only modestly in the tropics and Southern hemisphere (Fig. 3 and fig. S3), although it increased nearly two-fold in the North temperate zone and three-fold in the Arctic compared with historic values (Fig. 2A, Fig. 3). Thus 70% of nests are now being depredated in the Arctic (Fig. 2B). As a consequence of latitude-dependent changes in nest predation, predation rates now increase from the equator to the Arctic, in contrast to the historic parabolic latitudinal pattern (Fig. 3, fig. S3 and table S6). Although data from Southern hemisphere are scanty, they suggest no major changes in nest predation in southern regions (Fig. 1).

It is thought that climate change has influenced trophic interactions (*1*, *6*, *7*, *12*), therefore to investigate whether altered rates of nest predation are driven by climate, we calculated the changes in ambient temperature in each shorebird population and tested whether the temperature changes predict the shifts in nest predation at a global scale (*19*). We used two proxies of climate change: the slope of annual mean temperature regressed against time, and the standard deviation of annual mean temperatures measured over 30 years for each shorebird population. Higher rates of both daily and total nest predation were associated with increased ambient temperatures and temperature variations (Fig. 4). Importantly, these results are robust to the choice of climatic variables over periods of 20, 30 or 40 years (table S7).

Since predation is the most common cause of breeding failure (*13*, *14*), our results imply declining reproductive success in a widely distributed avian taxon. This decline, unless compensated by higher juvenile or adult survival and/or increased production of clutches, will drive global population declines when recruitment is not sufficient to maintain existing population sizes (*9*, *10*). However, adult survival of long-distance migrants are also decreasing due to recent habitat loss at staging areas (*22*, *23*), and declining chick survival has been reported across Europe (*24*). Therefore, high latitude breeders are squeezed by both poor breeding performance and reduced adult survival. Whilst tropical shorebirds may increase the number of breeding attempts and thus compensate for low breeding success, such compensation is limited at higher latitudes by short polar summers (*6*, *12*). Since most shorebirds are already declining (*18*, *23*, *25*), our results suggest that an important correlate of this decline is the elevated nest predation.

Climate change may influence nest predation rates in several ways (*1*, *6*, *12*). First, lemmings (*Lemmus* spp., *Dicrostonyx* spp.), small rodents that represent the key component of the Arctic food web, have experienced a crash in their abundances and population cycling due to unsuitable snow cover resulting from ambient temperature increase and fluctuations (*26–28*). This change was documented over vast Arctic areas around the year 2000 (*26–28*), and the pattern was similar for temperate voles in Europe (*Microtus* spp., *Myodes* spp., *29*, *30*). Changes in rodent abundances may have led to alterations in predator-prey interactions in Northern hemisphere, where predators normally consuming mainly rodents increased predation pressure on alternative prey, including shorebird nests (*12*, *28*). Second, the behavior and/or distribution of nest predators may have changed due to climate-change, for instance the distribution or densities of nest predators such as foxes (*Vulpes* spp.) may have increased, or their behavioral activity have changed making them more successful egg-consumers (*4*, *6*, *12*). Third, vegetation structure may have changed around shorebird nests leading to increased predation (*6*, *12*, *25*).

The demographic changes we report here have two major implications. First, migrating birds have been presumed to benefit from breeding in the Arctic as a consequence of lower predation pressure (*31*). Currently, however, the productivity of Arctic populations is declining due to high rates of nest predation, which suggests that energy demanding long-distance migration to northern breeding grounds is no longer advantageous from a nest predation perspective. Thus the Arctic now represents an extensive ecological trap (*32*) for migrating birds with a predicted negative impact on their global population dynamics. Second, Arctic birds are likely to decline in the future due to the synergistic effects of the climatically-driven increase of predation pressure at their breeding grounds, a trophic mismatch during chick rearing period due to delayed chick hatching relative to the peak of food abundance (*6*, *33*), predicted shrinkage of suitable habitat (*6*, *12*) and reduced adult survival during migration (*22*, *23*). A future scientific challenge with crucial consequences for species conservation lies in disentangling the effects of these drivers on the overall viability of bird species.

We have demonstrated that rapid alterations in species interactions are occurring at a global scale and that these changes are related to altered climate. This underlines the need for understanding the effects of climate change not only for individuals and their populations, but also for interactions in complex ecosystems including prey and predators.

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Supplementary materials:

Materials and Methods

Figures S1 to S3

Tables S1 to S8

References (*34–217*)

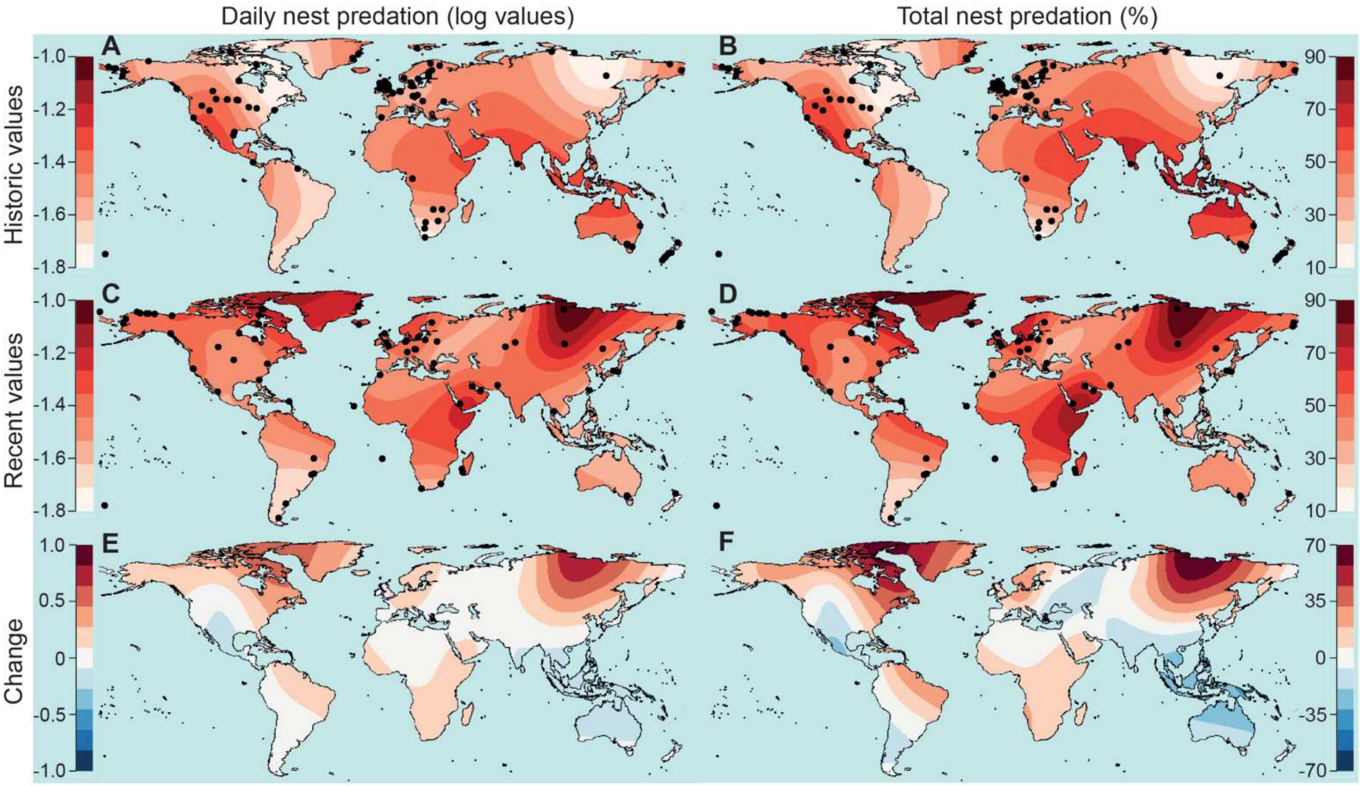

Fig. 1. Nest predation in shorebirds. (**A** and **B**) Historic rates of nest predation (1944–1999, 145 populations). (**C** and **D**) Recent rates of nest predation (2000–2016, 102 populations). (**E** and **F**) Changes between historic and recent nest predation rates. Dots show study locations. (A, C, and E) Daily nest predation; log transformed values after the addition of a small quantity (0.01). (B, D and F) Total nest predation in %, see (*19*) for details and fig. S1 for data distribution.

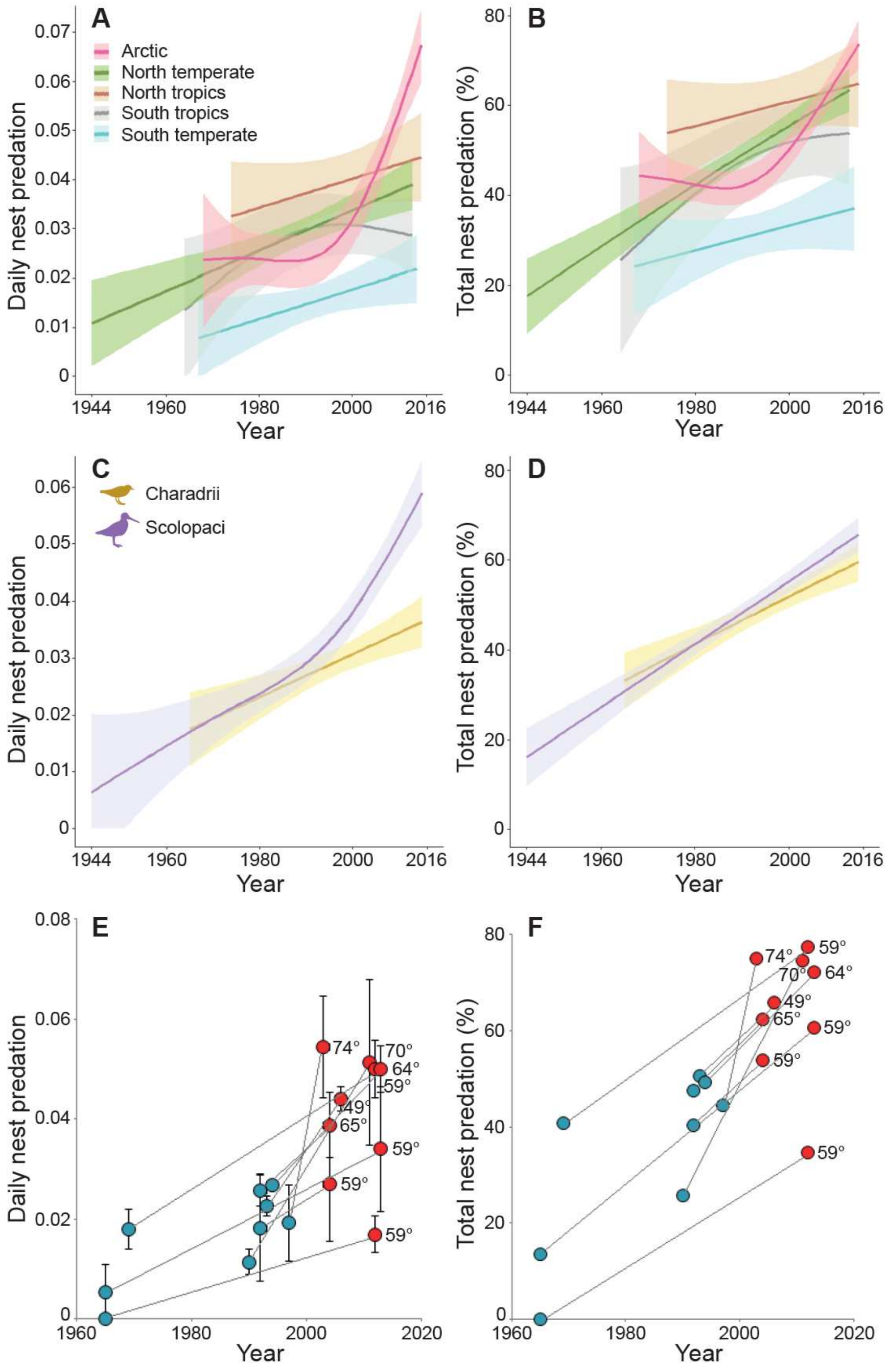

Fig. 2. Temporal changes in nest predation of shorebirds. (**A** and **B**) Nest predation rates for five latitudinal areas (Arctic n = 86 populations, North temperate n = 96 populations, North tropics n = 17 populations, South tropics n = 14 populations, South temperate n = 24 populations), see (*19*) for areas definition and model description in table S2. (**C** and **D**) Nest predation rates for plovers and allies

(Charadrii = 110 populations) and sandpipers and allies (Scolopaci = 127 populations), see (*19*) for clades definition and models description in table S3. (**E** and **F**) Local changes in nest predation rates for nine populations, each dot represents mean ± SEM (E) over 2–19 breeding seasons for historic data (blue) and recent data (red), latitude of the population is given next to the recent data, see table S4 and models description in table S5. (A–D) Generalized additive model fits with 95% confidence intervals. (A, C and E) Daily nest predation. (B, D and F) Total nest predation.

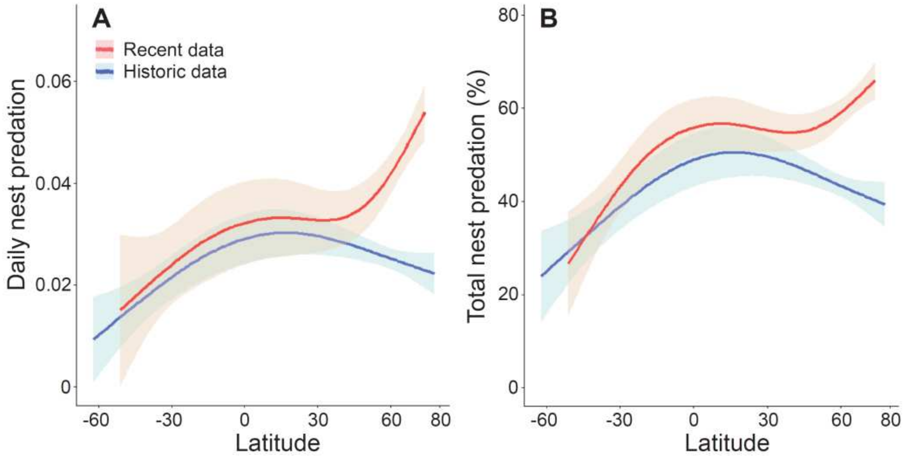

Fig. 3. Latitudinal gradient in historic versus recent nest predation of shorebirds. Daily (**A**) and total (**B**) nest predation rates (historic data 1944–1999, n = 145 populations; recent data 2000–2016, n = 102 populations), generalized additive model fits with 95% confidence intervals, see (*19*) for details and models description in table S6.

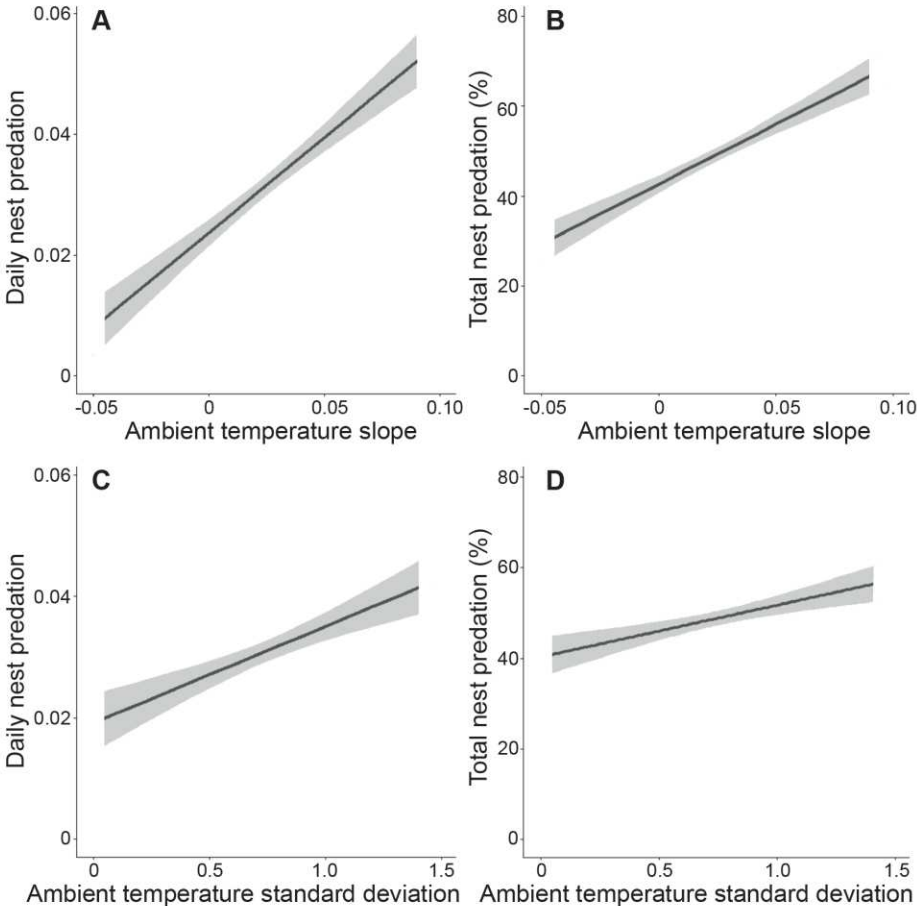

Fig. 4. Climate change predicts nest predation rates in shorebirds. (**A** and **B**) Relationship between daily (A) or total (B) nest predation rates and the slope of mean year temperatures. **(C** and **D**) Relationship between daily (C) or total (D) nest predation rates and the standard deviation of mean year temperatures. (A–D) Climatic data over 30 years prior to the last year of data collection, n = 247 values, generalized additive model fits with 95% confidence intervals, see (*19*) for details and table S7 for models description.

Supplementary Materials for

Global pattern of nest predation is disrupted by climate change in shorebirds

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This PDF file includes:

- Materials and Methods
- Figs. S1 to S3
- Tables S1 to S8

Materials and methods

Data collection

We targeted our search for data on nest predation in 245 shorebird species (*17*, *34*, *35*). We searched articles using keywords (species Latin name + „breeding" or „breeding success" or „nest predation") in electronic databases including Web of Science, Searchable Ornithological Research Archive and Google Scholar, reference books (*36–42*), and reviews (*24*, *43*). We either downloaded articles from electronic databases or photocopied the printed version in the ornithological Alexander Library in Oxford (UK). Additionally, we asked members of International Wader Study Group for published grey literature and previously unpublished datasets concerning shorebirds nest predation. In total, these searches provided over 12,000 articles. From these, we chose more than 900 papers for closer investigation and out of them, 143 publications held information on nest predation or additional variables used in this study. Altogether, the final dataset contains nest predation for 38,191 nests (with continuous exposure of 503,120 days) in 237 populations of 111 shorebird species at 149 localities worldwide (fig. S1 and table S1).

For each shorebird population, we extracted 12 additional variables. We estimated latitude and longitude at the centre of the study area via a GPS coordinates converter (www.gps-coordinates.net/gps-coordinates-converter) in decimal degrees format (three decimal spaces) with use of World Geodetic System 84 (WGS 84). We also recorded the year of the study (if the research was carried over more seasons, we used the mean) and the number of nests. The last eight variables represent a set of climatic factors addressing the climate change impact on species demographic parameters (*1*, *6*, *12*). Although it is possible that there is a small short-term advantage of warmer temperatures for the breeding productivity of birds at northern locations during particular breeding season (*12*, *44*), the larger the climate change over the years at a given location, the bigger negative impact on species and biotic interactions is expected (*3*, *6*, *45*).

Climatic variables

We extracted ambient temperature data from the University of East Anglia Climate Research Unit database (CRU; http://www.cru.uea.ac.uk/,version3.10.01) (*46*). The CRU database is a freely available global dataset containing interpolated monthly average temperatures from 1901 onward in a grid of spatial coordinates (0.5° × 0.5°). For each population, we selected temperatures from 40 years prior to the last year of data collection, inclusive and calculated mean year temperatures. We computed two main indices of climate change from those data: 1) the slope of the regression of mean year temperatures over 30 years prior to the last year of data collection, the higher positive slope, the more pronounced effect of climate change (global warming) was supposed; 2) the standard deviation of mean year temperatures over 30 years prior to the last year of data collection, the higher standard deviation, the more pronounced effect of climate change (climatic instability) was supposed. For the sensitivity control of the chosen period of 30 years, we prepared the same temperature slope and temperature standard deviation variables also for 40, 20 and 10 years prior to the last year of data collection, resulting in eight climatic variables for each population in total (table S7).

Data processing

We used two response variables in the study. Daily nest predation rate of nests, according to Mayfield defined as the number of depredated nests divided by the exposure of all nests in days (*47*, *48*) or follow-up methods (*49–51*), was the target variable for the nest predation rate, standardized among species and locations (*14*). We calculated the standard error (SEM) for each data point following Johnson (*51*). We computed total nest predation rate of the nests as 1-((1-daily nest predation rate)$^{\text{incubation period}}$), where incubation period means the egg-laying and incubation period in days together for particular species (*47*, *48*). Because the egg-laying and incubation periods represent the interval for which the successful nest with eggs is exposed to potential predators, the total nest predation rate provides a species-specific nest predation rate (mean percentage of nests being depredated in particular population) with respect to species life-history strategies (*20*, *52*). Total nest predation rate can be well used for inspecting spatial patterns because species are geographically restricted and their incubation period is also connected with the particular location. However, we must interpret temporal patterns in total nest predation rate with increased caution, because changes in species composition in our dataset (with various incubation periods among species) over the years has no ecologically relevant nature. Albeit having probably only limited influence, species composition could affect average total nest predation rate for a particular period. Egg-laying and incubation period was the same for every population of a particular species, data obtained from Myhrvold (*53*) or from primary articles. Where not available (six cases), we assumed egg-laying periods to be identical with those of closely related species. We refer to these variables through the article as daily nest predation and total nest predation, the later expressed between 0–100%.

For 97 populations (41%), daily nest predation or exposure in days and number of depredated nests were given in the source data. In any given article, daily nest predation may have been: 1) directly given; 2) computed from the given exposure and number of predated nests; 3) computed as a mean weighted by sample size (number of nests) from daily nest predation values available for particular habitats or other data subsets; 4) back-calculated from total nest predation provided by authors with the period for which the total nest predation was extrapolated; or 5) obtained by combination of aforementioned approaches. Options 1–4 are equivalent to each other and reflect several ways in which authors may present the same data. Therefore when used to calculate daily nest predation, obtained values were directly comparable.

The procedure for computing the exposure for daily nest predation was as follows. The exposure for hatched nests is from a day of finding until known or predicted hatching (e.g. 11 April and 28 April means 28-11 = 17 days of exposure). The exposure of depredated nests is from day of finding until midpoint assumption between last positive and first negative visits of the particular nest, the exposure of failed nests due to any other reason than predation (agriculture machinery, flooding, trampling etc.) or for nest with an unidentified fate is from day of finding until the last positive visits (not midpoint assumption between last positive and first negative visits of the nest).

For 140 populations (59%), daily nest predation and the total exposure were not provided but numbers of nests hatched, predated or failed for other reasons were reported instead for "apparent predation" or "apparent survival" computation (*47*, *48*, *54*). Therefore we used the Beintema's method (*55*) for estimating the exposure for these nests to subsequently convert "apparent predation" to daily nest predation values. The logic of the method is that a successful nest is on average found halfway from laying to hatching (e.g. 15 days in case of 30 days incubation period) and a depredated nest is on average lost halfway from this 15-days period. However, if most nests were found earlier after egg-laying, mean observation time set up on 0.5 of egg-laying and incubation period needs to be adjusted (*55*). We applied two additional options of mean observation time (0.9 and 0.6) to account for this. The first option was used for studies, where authors were checking the study plot for new nests every day and where most nests were found during the egg-laying period. The second option was applied for the majority of cases, where study plots were checked for new nests once or twice per week and most of the nests were found before reaching the half of incubation stage. The default 0.5 option was employed when data from nest card schemes were analysed or visits of the locality were very scarce and thus the incubation stage of found nest was random.

To check the accuracy of our approach, we compared computed daily nest predation rates with given values in 56 shorebird populations for which both approaches were available. The computed daily nest predation highly correlated with given values: Pearson's correlation coefficient, $r_s = 0.96$, $P < 0.001$, mean daily nest predation computed value = 0.042 ± 0.004(SEM), given value = 0.046 ± 0.005(SEM), pairs of values did not differ (paired t-test, $t = 1.70$, $df = 55$, $P = 0.094$) and temporal trends were consistent between groups of data with directly given daily nest predation and data where daily nest predation was derived from "apparent predation" (table S3), therefore all data were treated together. We excluded all studies which violated the aforementioned consistent methodologies from all comparative analyses.

Every nest where at least one chick hatched was regarded as successful. Only complete nest depredations were included in the predated nests category (partial egg loss were omitted). Clutches with infertile eggs with present parents which had not been depredated over expected egg-laying and incubation period were regarded as successful ones for the purpose of predation analyses. Nests with unclear fate (without any certainly survived period between two visits) were totally excluded from further computations and they are not included in sample sizes. In two cases, a single study from Antarctica (*56*) and a single study from Alaska (*57*), we presumed all failed nests to be depredated, although it was not explicitly stated in the article. Potential small overestimation of predation in these cases should not present an issue because it is contrary to our expectation of lower nest predation in polar regions (*14*, *20*, *58*).

Different populations of one species were defined as localities at least 40 km from each other. Southern hemisphere breeding season over two calendar years was attributed only to one year (the first one) to be comparable with the Northern hemisphere. When data were available for more seasons in particular population, the sum of depredated nests and overall exposure were pooled over years to obtain mean predation values with presenting the mean year of data collection.

The number of seasons involved in each data point ($n = 237$) varied from one to 44 years, mean = 5.3 ± 5.8 (SD), median = 3 years. Total exposure per data point varied between 77–70,000 days, mean = 2,123 ±6,508 (SD), median = 631 days. Number of nests varied between 12–5,000 nests, mean = 161 ± 479 (SD), median = 51 nests. Studies with fewer than 12 nests with known fate were omitted from all analyses as well as nests covered with cages in predator control management. We accounted for the number of nests per population in modelling (see Statistical analyses for details). The variation for daily nest predation values was as follows: 0–0.209, mean = 0.031 ± 0.028 (SD), median = 0.025 and for total nest predation values was 0–99.77%, mean = 48.91% ± 25.23 (SD), median = 50.89%.

Where the fate was given for individual eggs only but not for whole nests and authors were not able to provide us with additional information, we omitted these data because such data are not possible to use for correct calculation of daily nest predation values for nests as the unit.

Data division

For the purpose of more detailed analyses of temporal trend in nest predation, we divided the whole data set into 1) five latitudinal areas: South temperate (from -62° to -30°) – 24 populations, South tropics (from -30° to 0°) – 14 populations, North tropics (from 0° to 30°) – 17 populations, North temperate (from 30° to 60°) – 96 populations and the Arctic (from 60° to 78°) – 86 populations; 2) two clades of shorebirds i) Charadrii – 110 populations (families: Charadriidae, Haematopodiae, Recurvirostridae, Burhinidae, Chionidae) and ii) Scolopaci and allies – 127 populations (families: Scolopacidae, Jacanidae, Glareolidae, Rostratulidae). Generally, there is an obvious lack of available demographic data for shorebirds from the tropics and South America (*59*), even after 20 years of research and therefore we encourage further targeted investigation of shorebirds in these regions.

Apart from possible latitudinal variations in the impact of climate change (*1*, *6*), nest predation rates could be affected by different predator communities in different geographical areas as it was hypothesized that higher diversity of nest predators in the tropics (*14*), particularly snakes (*15*, *60*, *61*) or small mammals (*62*), is primarily responsible for higher nest predation rate near the Equator (*14*, *20*, *58*, *63*, *64*). Indeed, communities of shorebirds nest predators vary latitudinally (*17*, *21*). The Arctic Fox (*Vulpes lagopus*), four species of skuas (Stercorariidae) and gulls (*Larus* spp.) are the main predators in the Arctic (*10*, *12*, *17*). Red Fox (*Vulpes vulpes*), several mustelids species (Mustelidae), hedgehogs (*Erinaceus* spp.) and gulls are perceived as predominant predators of shorebird nests in temperate regions (*17*, *21*, *37*, *43*, *65*). Members of the family Corvidae, especially *Corvus* spp., are effective avian predators of shorebird nests from the Arctic to temperate and tropical regions (*17*, *21*, *37*, *43*). Our knowledge of predators on shorebird clutches in the tropics is based mainly on accidental observations or assumptions (*17*) which is in line with the general lack of studies from tropical regions (Fig S1). Despite this data deficiency, highly diverse taxa such as coyotes and jackals (*Canis* spp.), domestic cats and dogs, mongooses and suricates (Herpestidae), rats (*Rattus* spp.), various raptor species, coots and gallinules (Rallidae), monitor lizards (Varanidae), several species of snakes, Atlantic Ghost Crab (*Ocypode quadrata*) but also foxes, mustelids and gulls have been repeatedly reported as shorebird nest predators in the tropics (*17*, *66*, *67*). Despite recent improvement with camera monitoring technology (*68*), our better understanding of tropical predator communities and their relative relevance as ground nesting birds predators still remains an obvious challenge for next decades of research.

For more detailed investigation of spatial pattern in nest predation, we divided our dataset into the two subsets of historic and recent data (before and after the year 2000 – the year 2000 is in the latter period). The extensive change of Arctic and North temperate ecosystem food-webs, the crash of small rodent, the lemmings (*Lemmus* spp., *Dicrostonyx* spp.) and voles (*Microtus* spp., *Myodes* spp.) population cycles and abundances dated around the year 2000 (*26*–*30*) led us to the assumption that this change could cause the increase in shorebirds nest predation via altered trophic interactions (*1*, *6*), because shorebirds nests are known as alternative prey instead rodents (*12*, *69*). Furthermore, climate-induced changes in the Arctic nest predation rates could account also for spreading of new predators to the North (*4*, *6*, *12*), namely Red Fox (*70*) or alterations in vegetation structures changing the nest visibility for potential predators (*6*, *12*, *25*).

Ten populations with long surveillance over decades and over the year 2000 were divided into two subsets. Nine of them with data from two and more seasons in a given period are described in table S4 and were used for pairwise comparison of historic and recent nest predation values at same localities for the same species (Fig. 2E, Fig. 2F, table S5). Otherwise, every population was classified into the historic (1944–1999) or recent (2000–2016) period according to the mean year of data collection, altogether accounting for 145 populations before 2000 and 102 populations after 2000 (Fig. 3). Further division according to shorebirds clades was not possible due to insufficient samples in some latitudinal areas and the total lack of Scolopaci clade nest predation values from Southern hemisphere after the year 2000.

Maps and figures preparation

Values of daily nest predation which were log transformed after the addition of a small quantity (0.01) and original total nest predation values were used for extrapolation of nest predation over the globe (Fig. 1). A single data point from Antarctica (*56*) from the mean year 1988, daily nest predation = 0.0098, total nest predation = 27%, although included in all analyses, was not included in all maps (Fig. 1), to avoid non-appropriate extrapolation of nest predation over the whole continent of Antarctica. For all populations and their localities see fig. S1. Mapped nest predation rates were generated by generalized additive models (maximum dimension of the basis k = 50), with Gaussian error family (*71*–*73*) in R (ver. 3.3.3) (*74*) for each point on the globe using latitude/longitude and known daily and total nest predation values separately. Daily nest predation values, as well as total nest predation values in maps, were presented in nine colour categories. The scale was the same for historic and recent values. Differences between historic and recent values were plotted for the figures of change in daily and total nest predation at the scale of 11 colour categories (Fig. 1E and Fig. 1F) with use of R (ver. 3.3.3) (*74*). Note that nest predation extrapolation over the globe is more precise in North temperate and the Arctic with more data points (Fig. 1). Figures 2A–D, 3A, 3B and 4A–4D were generated by the generalized additive model of the given relationship with 95% confidence intervals, the dimension of the basis (k) = 5, Gaussian error family (*71*). Figures were plotted with 'ggplot' function in 'ggplot2' R package (*75*). Original daily nest predation values and total nest predation values (in %) were plotted in figures 2, 3, 4, S2 and S3.

Statistical analysis

All statistical analyses were performed with R (ver. 3.3.3) (*74*). To assure normality of response variables, all daily nest predation values were adjusted to original value + 0.01 and log-transformed before entering analyses; total nest predation values were left in their original form. We used phylogenetically and spatially controlled generalized linear models. Specifically, we control for 1) phylogeny – we obtained species level of phylogeny from current avian tree (*76*) with manual addition of two recently recognized species: Snowy Plover (*Charadrius nivosus*) (*77*) and Wilson's Snipe (*Gallinago delicata*) (*17*, *35*). We created a variance–covariance matrix (**V**) to model the expected similarity among species that is defined by the phylogeny (*78–80*), and incorporated it into each model. Because data were analysed at the population level, we accounted for this by incorporating the random effect of the species into each model; 2) spatial autocorrelation – we created a spatial matrix (**D**) from GPS coordinates of each locality for each population following an established approach (*80*, *81*) and incorporated it into each model; 3) number of nests – due to the fact that nest predation values obtained from smaller sample of nests could be less precise (*55*), we accounted for this in two ways: i) incorporating a control variable, the logarithm of number of nests into each model and ii) creating a diagonal matrix from reciprocal of the number of nests (**H**) (*71*) and incorporating it into each model.

Overall, the model for the predation rate of population i in species j (p_{ij}), transformed by the addition of a small amount in the case of DPR, included: an intercept term estimated as a random effect, grouped by species (α_j with variance σ_α^2); an effect of time (the mean year of study y_i for the population); the number of nests measured in population i (N_i) as well as additional modelled covariates measured at the population level (x_{ik}):

$$\log(p_{ij}) = \alpha_j + b_y y_i + b_N \log(N_i) + \sum_{k=1}^{n} b_k x_{ik} + \varepsilon_i;\ \alpha_j \sim \mathcal{N}(0, \sigma_\alpha^2)\ \varepsilon_i \sim \mathcal{N}(0, \mathbf{J} \otimes \mathbf{W})$$

$$\mathbf{W} = \phi\mathbf{D} + \lambda(1-\phi)\mathbf{V} + (1-\phi)(1-\lambda)\mathbf{H}$$

The errors (ε_i) are distributed accroding to a multivariate normal distribution with covariance matrix $\mathbf{J}\otimes\mathbf{W}$ where **J** indicates which species each population belongs to, and the matrix **W** is a species-level matrix that combines the matrices of geographic distances (**D**), phylogenetic similarity (**V**) and variation resulting from measured numbers of nests (**H**), with estimated variance components (ϕ, λ) weighting the contribution of each, see (*81*). ϕ, λ are estimated by restricted maximum likelihood along with the rest of the model parameters. To address the issue of uncertainty resulting from phylogenetic error, we ran the analyses described above for 1000 randomly sampled trees. We found that the variance in parameters and model outputs was low (see supplementary code for an example) therefore we did not explore this further.

Because explanatory variables were potentially inter-correlated (see correlation matrix in table S8), we performed the climatic modelling in the sequence of simple linear mixed-effects models (table S7) with control for phylogeny, spatial autocorrelation and sample size (see above). Only for within-population temporal variation in predation (table S5), we used linear mixed-effect models (*71*) with random effects of species and locality. We ran individual models including all predictors (table S2, table S3, table S5 and table S7). Additionally separate models for possible interaction effects were fitted, then non-significant interactions deleted (table S6). Phylo-spatial models were fitted using the package ‘coxme’ (*82*). Linear mixed-effects models were fitted with the ‘lme4’ package (*83*). Residuals from all tests were checked for normality in quantile-quantile plot (*71*). All statistical tests were two-tailed.

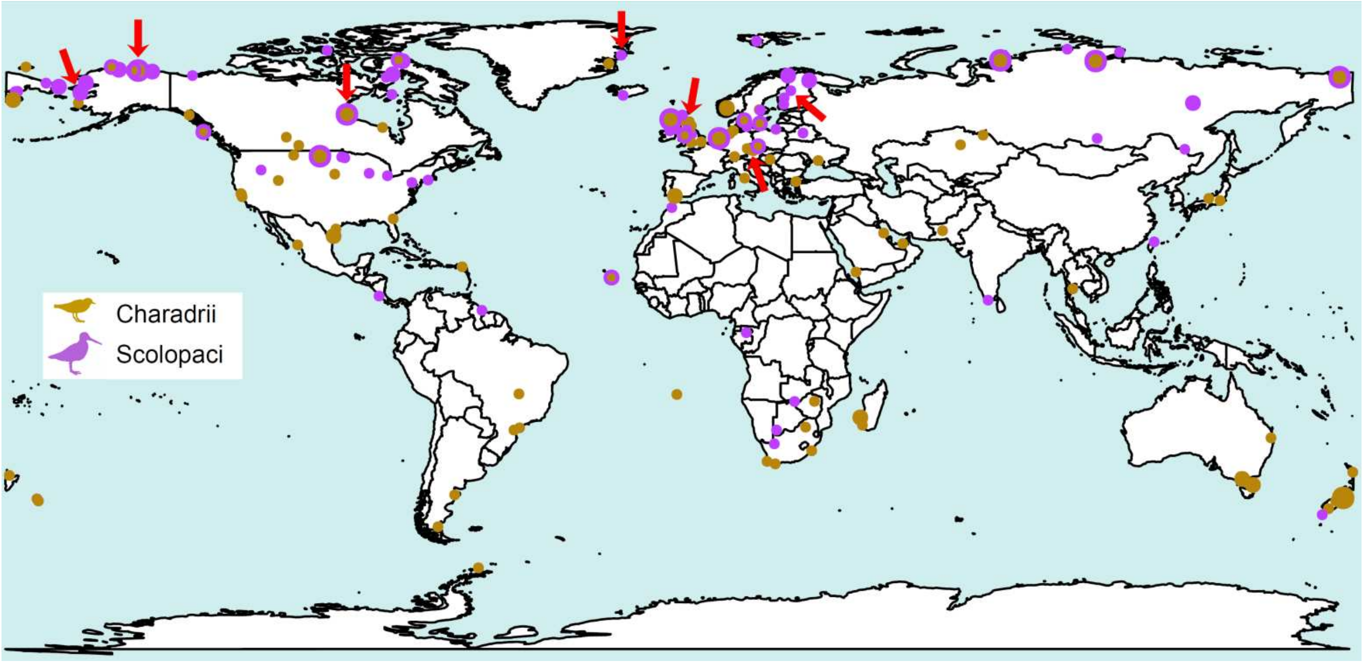

Fig. S1. Geographical distribution of the analysed data on nest predation in shorebirds. Altogether, 237 populations of 111 shorebirds species at 149 localities were used in analyses. Dots of locations are divided into three size categories (small = 1 population only, medium = 2–3 populations, big = 4 and more populations per locality). Where shorebirds from both clades were studied, dots are presented in both colours. Red arrows denote seven locations with long-term monitoring of nine shorebird populations presented in the Fig. 2E, Fig. 2F and table S4.

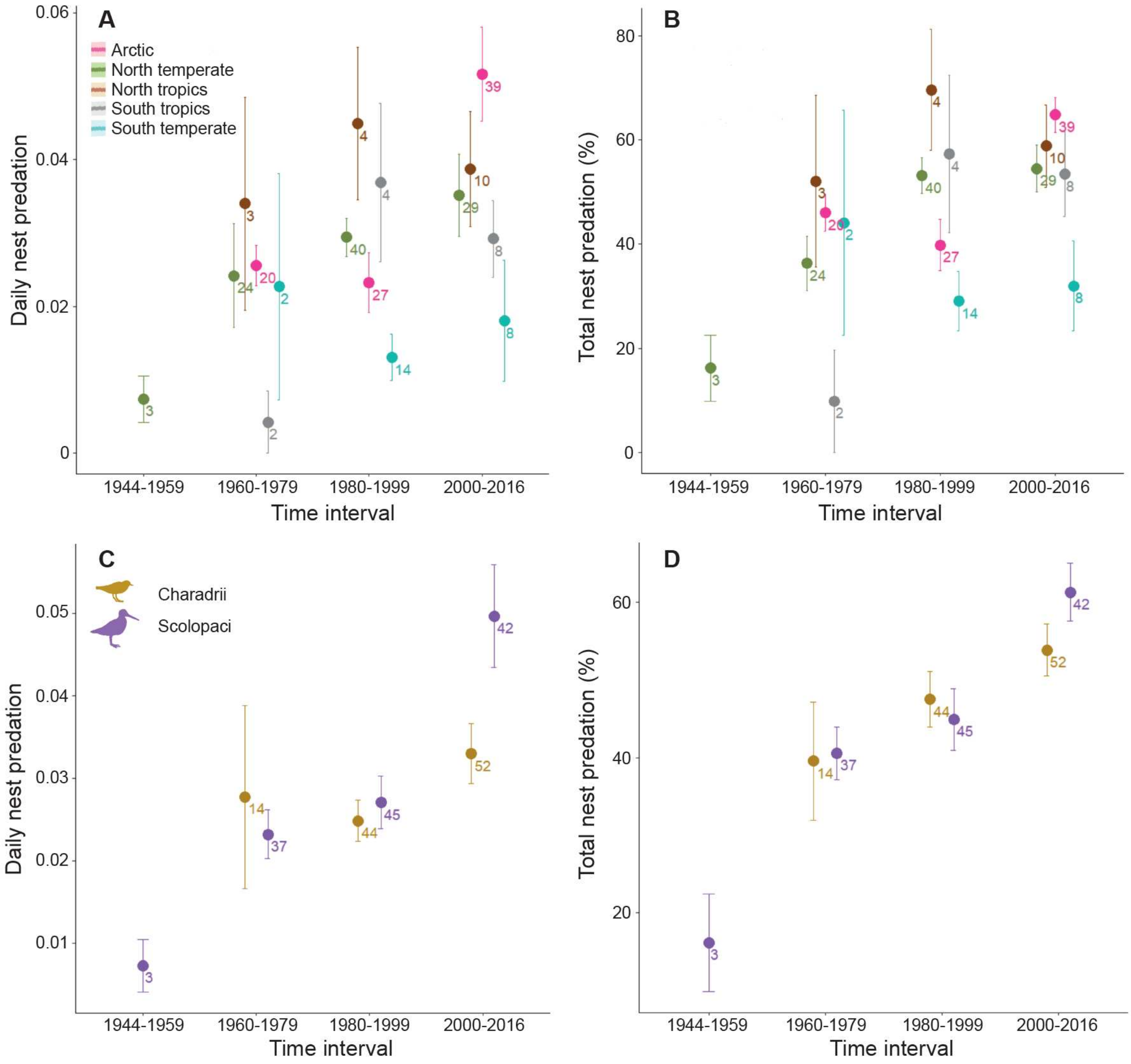

Fig. S2. Temporal changes in nest predation of shorebirds in 20 years intervals. (**A** and **B**) Nest predation rates for five latitudinal areas, see (*19*) for areas definition. (**C** and **D**) Nest predation rates for plovers and allies (Charadrii) and sandpipers and allies (Scolopaci), see (*19*) for clades definition. (A–D) Mean ± SEM, number of populations is given next to the relevant data point. (A and C) Daily nest predation. (B and D) Total nest predation.

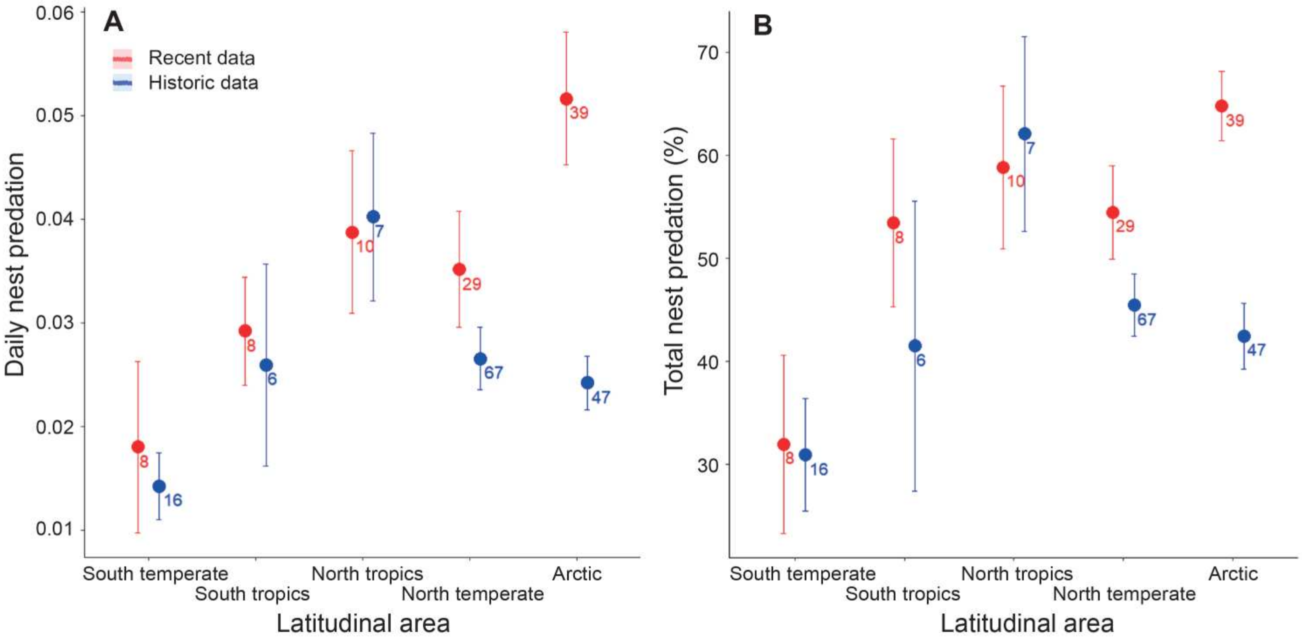

Fig. S3. Latitudinal gradient in historic versus recent nest predation of shorebirds. Daily (**A**) and total (**B**) nest predation rates (historic data 1944–1999; recent data 2000–2016), Mean ± SEM for five latitudinal areas separately, see (*19*) for areas definition. Number of populations is given next to the relevant data point.

Table S1. Shorebird species used in the study with number of populations and relevant data sources.

Species order	Species	N populations	Data sources
1	Eurasian Thick-knee (*Burhinus oedicnemus*)	2	(Taylor 2006) (*84*), (Nadeem *et al.* 2014) (*85*), Nadeem in litt.
2	Water Thick-knee (*Burhinus vermiculatus*)	1	(Dobson 2004) (*86*)
3	Snowy Sheatbill (*Chionis albus*)	1	(Favero 1993) (*56*)
4	Magellanic Plover (*Pluvianellus socialis*)	1	(Lishman & Nol 2012) (*87*), C. Lishman in litt.
5	American Black Oystercatcher (*Haematopus bachmani*)	1	(Tessler & Garding 2006) (*88*)
6	American Oystercatcher (*Haematopus palliatus*)	2	(Sabine *et al.* 2005) (*89*), (Barbieri & Delchiaro 2009) (*90*)
7	African Oystercatcher (*Haematopus moquini*)	2	(Calf & Underhill 2002) (*91*), (Scott *et al.* 2011) (*92*)
8	Eurasian Oystercatcher (*Haematopus ostralegus*)	5	(Hughey 1985) (*93*), (Beintema & Müskens 1987) (*94*), (Rudenko 1998) (*95*), (Jackson & Green 2000) (*96*), (Otwall 2005) (*97*)
9	Pied Oystercatcher (*Haematopus longirostris*)	1	(Lauro & Nol 1995) (*98*)
10	Variable Oystercatcher (*Haematopus unicolor*)	1	(Michaux 2013) (*99*)
11	Chatham Oystercatcher (*Haematopus chathamensis*)	1	(Moore & Reid 2009) (*100*)
12	Sooty Oystercatcher (*Haematopus fuliginosus*)	1	(Lauro & Nol 1995) (*98*)
13	Black-winged Stilt (*Himantopus himantopus*)	2	(Hughey 1985) (*93*), (Cuervo 2003) (*101*)
14	Black Stilt (*Himantopus novaezelandiae*)	1	(Pierce 1986) (*102*)
15	Pied Avocet (*Recurvirostra avosetta*)	2	(Beintema & Müskens 1987) (*94*), (Cuervo 2003) (*101*)
16	American Avocet (*Recurvirostra americana*)	1	(Herring *et al.* 2011) (*103*)
17	Northern Lapwing (*Vanellus vanellus*)	16	(Bain 1987) (*104*), (Beintema & Müskens 1987) (*94*), (Galbraith 1988) (*105*), (Baines 1990) (*106*), (Berg *et al.* 1992) (*107*), (Blomqvist & Johansson 1995) (*108*), (Flodin *et al.* 1995) (*109*), (Jackson & Green 2000) (*96*), (Hart *et al.* 2002) (*110*), (Schröpfer 2002) (*111*), (Šálek & Šmilauer 2002) (*112*), (Köster & Bruns 2003) (*113*), (Otwall 2005) (*97*), (Junker *et al.* 2006) (*114*), (Sharpe 2006) (*115*), (Kragten & De Snoo 2007) (*116*), (Pucha *et al.* 2009) (*117*), (Zámečník *et al.* 2017) (*118*), V. Kubelka unpublished data, M. Šálek unpublished data, V. Štorek in litt.
18	Spur-winged Lapwing (*Vanellus spinosus*)	1	(Makrigianni *et al.* 2008) (*119*), E. Makrigianni in litt.
19	Crowned Lapwing (*Vanellus coronatus*)	1	(Ade 1979) (*120*)
20	Grey-headed Lapwing (*Vanellus cinereus*)	1	(Takahashi & Ohkawara 2007) (*121*)
21	Black-shouldered Lapwing (*Vanellus novaehollandie*)	3	(Barlow *et al.* 1972) (*122*), (Giese & Jones 1996) (*123*), (Cardilini *et al.* 2013) (*124*)
22	Sociable Lapwing (*Vanellus gregarius*)	2	(Watson *et al.* 2006)(*125*), (Shedon *et al.* 2013) (*126*), P. Donald & I. Fisher in litt.
23	Southern Lapwing (*Vanellus chilensis*)	2	(Cerboncini *et al.* 2015) (*127*), (Santos & Macedo 2017) (*128*), R. A. Cerboncini in litt., E. S. A. Santos & R. H. Macedo in litt.
24	Wrybill (*Anarhynchus frontalis*)	1	(Hughey 1985) (*93*)
25	Golden Plover (*Pluvialis apricaria*)	1	(Byrkjedal 1987) (*129*)
26	Pacific Golden Plover (*Pluvialis fulva*)	3	(Schekkerman *et al.* 2004) (*130*), (Arctic Shorebird Demographics Network 2016) (*131*), P. Tomkovich unpublished data
27	American Golden Plover (*Pluvialis dominica*)	3	(Moitoret *et al.* 1996) (*57*), (Arctic Shorebird Demographics Network 2016) (*131*)
28	Grey Plover (*Pluvialis squatarola*)	4	(Kondratyev 1982) (*132*), (Moitoret *et al.* 1996) (*57*), (Tomkovich & Dondua 2011) (*133*), (Arctic Shorebird Demographics Network 2016) (*131*)
29	Northern Red-breasted Plover (*Charadrius aquilonius*)	1	(Wills *et al.* 2003) (*134*)
30	Common Ringed Plover (*Charadrius hiaticula*)	5	(Kondratyev 1982) (*132*), (Pienkowski 1984) (*135*), (Jackson & Green 2000) (*96*)
31	Semipalmated Plover (*Charadrius semipalmatus*)	2	(Jehl 1971) (*136*), (Cooper & Miller 1997) (*137*)
32	Long-billed Plover (*Charadrius placidus*)	1	(Katayama *et al.* 2010) (*138*)
33	Little Ringed Plover (*Charadrius dubius*)	2	(Dolanský & Žďárek 2001) (*139*), (Cepáková *et al.* 2007) (*140*), Cepáková *et al.* in litt.
34	Wilson's Plover (*Charadrius wilsonia*)	3	(Bergstrom 1982) (*141*), (Brown & Brindock 2011) (*142*)
35	Killdeer (*Charadrius vociferus*)	1	(Kantrud & Higgins 1992) (*143*)
36	Piping Plover (*Charadrius melodus*)	3	(Catlin *et al.* 2011) (*144*), (Richardson 1999) (*145*), (White 2005) (*146*)
37	Black-banded Plover (*Charadrius thoracicus*)	2	(Zefania *et al.* 2008) (*147*), C. Carmona *et al.* in litt., L. Eberhart-Phillips *et al.* in litt.
38	Kittlitz's Plover (*Charadrius pecuarius*)	1	C. Carmona *et al.* in litt., L. Eberhart-Phillips *et al.* in litt.
39	St Helena Plover (*Charadrius sanctaehelenae*)	1	(Burns et al. 2013) (*148*)
40	White-fronted Plover (*Charadrius marginatus*)	1	C. Carmona *et al.* in litt., L. Eberhart-Phillips *et al.* in litt.

Table continued on next page. Species are taxonomically ordered according to IOC Word Bird List (ver. 6.3, 2016) (*35*). Complete references from this table are presented in the list of references.

Table S1. Shorebird species used in the study with number of populations and relevant data sources. – table continued from the previous page.

Species order	Species	N populations	Data sources
41	Kentish Plover (*Charadrius alexandrinus*)	6	(Székely *et al.* 1994) (*149*), (Pietrelli *et al.* 2001) (*150*), (Kozstolány *et al.* 2009) (*151*), (Al Rashidi *et al.* 2011) (*152*), (Carmona-Isunza *et al.* 2015) (*153*), (Al Rashidi 2016) (*154*), M. C. Carmona-Isunza *et al.* in litt.
42	Snowy Plover (*Charadrius nivosus*)	5	(Paton 1994) (*155*), (Rupert 1997) (*156*), (Neuman 2003) (*157*), (Demers & Robinson-Nilsen 2012) (*158*), M. C. López in litt.
43	Red-capped Plover (*Charadrius ruficapillus*)	1	(Tan *et al.* 2015) (*159*)
44	Malay Plover (*Charadrius peronii*)	1	(Yasué *et al.* 2007) (*160*)
45	Two-banded Plover (*Charadrius falklandicus*)	1	G. D. Hevia & V. L. D’Amico in litt.
46	Double-banded Plover (*Charadrius bicinctus*)	2	(Hughey 1985) (*93*), (Keedwell & Sanders 2002) (*161*)
47	Lesser Sandplover (*Charadrius mongolus*)	1	P. Tomkovich unpublished data
48	Eurasian Dotterel (*Eudromias morinellus*)	1	(Byrkjedal 1987) (*129*)
49	Mountain Plover (*Charadrius montanus*)	1	(Dinsmore *et al.* 2002) (*49*)
50	Hooded Plover (*Thinornis cucullatus*)	2	(Dowling & Weston 1999) (*162*), (Baird & Daan 2003) (*163*)
51	Shore Plover (*Thinornis novaeseelandiae*)	1	(Davis 1994) (*164*)
52	Greater Painted-snipe (*Rostratula benghalensis*)	1	(Hsu & Severinghaus 2011) (*165*)
53	African Jacana (*Actophilornis africanus*)	1	(Tarboton 1992) (*166*)
54	Bronze-winged Jacana (*Metopidius indicus*)	1	(Butchart 2000) (*167*)
55	Northern Jacana (*Jacana spinosa*)	1	(Stephens 1984) (*67*), M. L. Stephens in litt.
56	Wattled Jacana (*Jacana jacana*)	1	(Osborne 1982) (*168*)
57	Eurasian Woodcock (*Scolopax rusticola*)	1	(Hoodles & Coulson 1998) (*169*)
58	American Woodcock (*Scolopax minor*)	1	(Miller & Jordan 2011) (*170*)
59	Auckland Snipe (*Coenocorypha aucklandica*)	1	(Miskelly 1990) (*171*)
60	Common Snipe (*Gallinago gallinago*)	3	(Beintema & Müskens 1987) (*94*), (Mongin 2002) (*172*), (Yarovikova 2003) (*173*)
61	Wilson's Snipe (*Gallinago delicata*)	1	(Kantrud & Higgins 1992) (*143*)
62	Short-billed Dowitcher (*Limnodromus griseus*)	1	(Arctic Shorebird Demographics Network 2016) (*131*)
63	Long-billed Dowitcher (*Limnodromus scolopaceus*)	4	(Kondratyev 1982) (*132*), (Moitoret *et al.* 1996) (*57*), (Arctic Shorebird Demographics Network 2016) (*131*)
64	Black-tailed Godwit (*Limosa limosa*)	3	(Beintema & Müskens 1987) (*94*), (Groen & Hemerik 2002) (*174*), (Groen *et al.* 2006) (*175*)
65	Hudsonian Godwit (*Limosa haemastica*)	1	(Jehl 1971) (*136*), (Arctic Shorebird Demographics Network 2016) (*131*)
66	Bar-tailed Godwit (*Limosa lapponica*)	1	(Larsen & Moldsvor 1992) (*176*)
67	Marbled Godwit (*Limosa fedoa*)	1	(Kantrud & Higgins 1992) (*143*)
68	Whimbrel (*Numenius phaeopus*)	5	(Jehl 1971) (*136*), (Skeel 1983) (*177*), (Larsen & Moldsvor 1992) (*176*), (Pulliainen & Saari 1993) (*178*), (Katrínardóttir *et al.* 2015) (*179*), (Arctic Shorebird Demographics Network 2016) (*131*), B. Katrínardóttir in litt.
69	Eurasian Curlew (*Numenius arquata*)	6	(Bain 1987) (*104*), (Berg 1992) (*180*), (Grant *et al.* 1999) (*181*), (Valkama *et al.* 1999) (*182*)
70	Far Eastern Curlew (*Numenius madagascariensis*)	1	(Antonov 2010) (*183*), A. I. Antonov in litt.
71	Long-billed Curlew (*Numenius americanus*)	1	(Redmond & Jenni 1986) (*184*)
72	Upland Sandpiper (*Bartramia longicauda*)	1	(Kantrud & Higgins 1992) (*143*)
73	Spotted Redshank (*Tringa erythropus*)	1	(Kondratyev 1982) (*132*)
74	Common Redshank (*Tringa totanus*)	4	(Beintema & Müskens 1987) (*94*), (Flodin *et al.* 1995) (*109*), (Jackson & Green 2000) (*96*), (Otwall 2005) (*97*)
75	Marsh Sandpiper (*Tringa stagnatilis*)	1	(Larionov 2015) (*185*)
76	Common Greenshank (*Tringa nebularia*)	1	(Christian & Hancock 2009) (*186*), M. Hancock in litt.
77	Wood Sandpiper (*Tringa glareola*)	2	(Pulliainen & Saari 1991) (*187*), (Larionov 2015) (*185*)
78	Willet (*Tringa semipalmata*)	1	(Kantrud & Higgins 1992) (*143*)
79	Terek Sandpiper (*Xenus cinereus*)	1	(Larionov 2015) (*185*)
80	Common Sandpiper (*Actitis hypoleucos*)	3	(Cuthbertson *et al.* 1952) (*188*), (Holland et al. 1982) (*189*), (Dolanský & Žďárek 2001) (*139*)

Table continued on next page. Species are taxonomically ordered according to IOC Word Bird List (ver. 6.3, 2016) (*35*). Complete references from this table are presented in the list of references.

Table S1. Shorebird species used in the study with number of populations and relevant data sources. – table continued from the previous page.

Species order	Species	N populations	Data sources
81	Spotted Sandpiper (*Actitis macularius*)	5	(Cialdini & Orians 1944) (*190*), (Miller & Miller 1948) (*191*), (Hays 1972) (*192*), (Oring & Knudson 1972) (*193*), (Alberico *et al.* 1991) (*194*)
82	Turnstone (*Arenaria interpres*)	2	(Kondratyev 1982) (*132*), (Perkins *et al.* 2007) (*195*)
83	Great Knot (*Calidris tenuirostris*)	1	(Tomkovich 2001) (*196*), P. Tomkovich unpublished data
84	Red Knot (*Calidris canutus*)	1	P. Tomkovich unpublished data
85	Sanderling (*Calidris alba*)	2	(Parmelee 1970) (*197*), (Hansen *et al.* 2010) (*198*), H. J. Hansen in litt.
86	Semipalmated Sandpiper (*Calidris pusilla*)	4	(Gratto *et al.* 1983) (*199*), (Moitoret *et al.* 1996) (*57*), (Sandercock 1997) (*200*), (Arctic Shorebird Demographics Network 2016) (*131*)
87	Western Sandpiper (*Calidris mauri*)	4	(Holmes 1972) (*201*), (Kondratyev 1982) (*132*), (Morozov & Tomkovich 1988) (*202*), (Sandercock 1997) (*200*)
88	Red-necked Stint (*Calidris ruficollis*)	1	(Morozov & Tomkovich 1988) (*202*)
89	Little Stint (*Calidris minuta*)	2	(Schekkerman *et al.* 2004) (*130*), (Arctic Shorebird Demographics Network 2016) (*131*)
90	Temminck's Stint (*Calidris temminckii*)	3	(Kondratyev 1982) (*132*), (Rönkä *et al*. 2003) (*203*), (Thompson *et al.* 2014) (*204*), P. Tomkovich unpublished data
91	Least Sandpiper (*Calidris minutilla*)	2	(Jehl 1971) (*136*), (Cooper and Miller 1997) (*137*)
92	White-rumped Sandpiper (*Calidris fuscicollis*)	2	(McKinnon & Bêty 2009) (*205*), (Arctic Shorebird Demographics Network 2016) (*131*)
93	Baird's Sandpiper (*Calidris bairdii*)	3	(Reid & Montgomerie 1985) (*206*), (McKinnon & Bêty 2009) (*205*), (Arctic Shorebird Demographics Network 2016) (*131*)
94	Pectoral Sandpiper (*Calidris melanotos*)	3	(Kondratyev 1982) (*132*), (Moitoret *et al.* 1996) (*57*), (Arctic Shorebird Demographics Network 2016) (*131*)
95	Sharp-tailed Sandpiper (*Calidris acuminata*)	1	(Soloviev *et al.* 2010) (*207*), (Arctic Shorebird Demographics Network 2016) (*131*), M. Soloviev in litt.
96	Curlew Sandpiper (*Calidris ferruginea*)	2	(Schekkerman *et al.* 1998) (*208*), (Schekkerman *et al.* 2004) (*130*)
97	Purple Sandpiper (*Calidris maritima*)	1	(Pierce *et al.* 2010) (*209*)
98	Rock Sandpiper (*Calidris ptilocnemis*)	1	P. Tomkovich unpublished data
99	Dunlin (*Calidris alpina*)	6	(Jehl 1971) (*136*), (Kondratyev 1982) (*132*), (Jönsson 1991) (*210*), (Moitoret *et al.* 1996) (*57*), (Jackson and Green 2000) (*96*), (Schekkerman *et al.* 2004) (*130*), (Arctic Shorebird Demographics Network 2016) (*131*)
100	Stilt Sandpiper (*Calidris himantopus*)	3	(Jehl 1971) (*136*), (Moitoret *et al.* 1996) (*57*), (Arctic Shorebird Demographics Network 2016) (*131*)
101	Spoon-billed Sandpiper (*Eurynorhynchus pygmeus*)	1	(Kondratyev 1982) (*132*)
102	Broad-billed Sandpiper (*Limicola falcinellus*)	1	(Soloviev *et al.* 2010) (*207*), (Arctic Shorebird Demographics Network 2016) (*131*), M. Soloviev & V. V. Golovnyuk in litt.
103	Buff-breasted Sandpiper (*Tryngites subruficollis*)	3	(Moitoret *et al.* 1996) (*57*), (Arctic Shorebird Demographics Network 2016) (*131*)
104	Ruff (*Philomachus pugnax*)	3	(Kondratyev 1982) (*132*), (Beintema & Müskens 1987) (*94*), (Arctic Shorebird Demographics Network 2016) (*131*)
105	Wilson's Phalarope (*Phalaropus tricolor*)	2	(Kagarise 1979) (*211*), (Kantrud & Higgins 1992) (*143*)
106	Red-necked Phalarope (*Phalaropus lobatus*)	5	(Moitoret *et al.* 1996) (*57*), (Walpole *et al.* 2008) (*212*), (Arctic Shorebird Demographics Network 2016) (*131*), M. Sládeček *et al*. in litt.
107	Red Phalarope (*Phalaropus fulicarius*)	2	(Moitoret *et al.* 1996) (*57*), (Arctic Shorebird Demographics Network 2016) (*131*)
108	Cream-coloured Courser (*Cursorius cursor*)	1	(Gonçalves 2014) (*213*), (Seymour *et al.* 2015) (*214*), Gonçalves in litt., K. Seymour in litt.
109	Double-banded Courser (*Rhinoptilus africanus*)	2	(Lloyd 2004) (*66*)
110	Collared Pratincole (*Glareola pratincola*)	1	(Hanane *et al.* 2010) (*215*)
111	Rock Pratincole (*Glareola nuchalis*)	2	(Brosset 1979) (*216*), (Williams *et al.* 1989) (*217*)

Species are taxonomically ordered according to IOC Word Bird List (ver. 6.3, 2016) (*35*). Complete references from this table are presented in the list of references.

Table S2. Nest predation in respect to time at different latitudes.

	Response variable	**Daily predation rate**				**Total predation rate**			
	Explantory variable	Estimate	SEM	*z-value*	*P-value*	Estimate	SEM	*z-value*	*P-value*
A, All data	(Intercept)	-32.7721	5.023			-12.1412	2.121		
n = 237 populations	Mean year	0.0148	0.003	5.87	< 0.001	0.0063	0.001	5.96	< 0.001
	log(Number of nests)	-0.0159	0.031	-0.51	0.610	-0.0027	0.013	-0.21	0.840
B, Subset of data – South temperate	(Intercept)	-17.1626	14.348			-4.4434	6.182		
latitudes from -62° to -30°	Mean year	0.0065	0.007	0.90	0.370	0.0023	0.003	0.74	0.460
n = 24 populations	log(Number of nests)	0.1159	0.107	1.08	0.280	0.0550	0.046	1.20	0.230
C, Subset of data – South tropics	(Intercept)	-11.2928	24.046			-4.7132	10.269		
latitudes from -30° to 0°	Mean year	0.0036	0.012	0.30	0.770	0.0025	0.005	0.48	0.630
n = 14 populations	log(Number of nests)	0.1494	0.135	1.11	0.270	0.0627	0.057	1.09	0.280
D, Subset of data – North tropics	(Intercept)	-19.1330	18.785			-5.6102	8.585		
latitudes from 0° to 30°	Mean year	0.0083	0.009	0.88	0.380	0.0032	0.004	0.74	0.460
n = 17 populations	log(Number of nests)	-0.1071	0.093	-1.16	0.250	-0.0401	0.042	-0.94	0.350
E, Subset of data – North temperate	(Intercept)	-28.1316	7.203			-11.2914	3.067		
latitudes from 30° to 60°	Mean year	0.0125	0.004	3.47	< 0.001	0.006	0.002	3.87	< 0.001
n = 96 populations	log(Number of nests)	-0.0475	0.043	-1.11	0.270	-0.0183	0.018	-1.01	0.310
F, Subset of data – Arctic	(Intercept)	-40.3296	8.232			-14.3587	3.394		
latitudes from 60° to 78°	Mean year	0.0187	0.004	4.49	< 0.001	0.0075	0.002	4.38	< 0.001
n = 86 populations	log(Number of nests)	-0.0371	0.064	-0.58	0.560	-0.0171	0.027	-0.64	0.520

Linear mixed-effects kinship models with control for phylogeny (species level of phylogeny + random effect of the species), spatial autocorrelation and number of nests per population, see (*19*) for details. Mean year = the mean year of the data collection, log(N number of nests) = logarithm of the number of nests.

Table S3. Robustness of temporal trend in nest predation to shorebird clades and daily nest predation computation method.

	Response variable	**Daily predation rate**				**Total predation rate**			
	Explantory variable	Estimate	SEM	*z-value*	*P-value*	Estimate	SEM	*z-value*	*P-value*
A, All data	(Intercept)	-32.7721	5.023			-12.1412	2.121		
n = 237 populations	Mean year	0.0148	0.003	5.87	< 0.001	0.0063	0.001	5.96	< 0.001
	log(Number of nests)	-0.0159	0.031	-0.51	0.610	-0.0027	0.013	-0.21	0.840
B, Subset of data – Charadrii	(Intercept)	-28.7906	8.643			-10.3532	3.704		
n = 110 populations	Mean year	0.0127	0.004	2.94	0.003	0.0054	0.002	2.93	0.003
	log(Number of nests)	0.0045	0.045	0.10	0.920	0.0026	0.019	0.14	0.890
C, Subset of data – Scolopaci	(Intercept)	-36.7972	6.176			-12.9052	2.608		
n = 127 populations	Mean year	0.0168	0.003	5.43	< 0.001	0.0067	0.001	5.15	< 0.001
	log(Number of nests)	-0.0180	0.044	-0.41	0.680	-0.0057	0.018	-0.31	0.760
D, Subset of data – given DPR	(Intercept)	-27.8570	9.197			-9.1005	3.737		
n = 97 populations	Mean year	0.0125	0.005	2.73	0.006	0.0049	0.002	2.63	0.009
	log(Number of nests)	-0.0851	0.047	-1.80	0.071	-0.0280	0.019	-1.46	0.140
E, Subset of data – computed DPR	(Intercept)	-26.4563	6.347			-10.1864	2.792		
n = 140 populations	Mean year	0.0114	0.003	3.56	< 0.001	0.0053	0.001	3.74	< 0.001
	log(Number of nests)	0.0594	0.042	1.42	0.160	0.0301	0.018	1.63	0.100

Linear mixed-effects kinship models with control for phylogeny (species level of phylogeny + random effect of the species), spatial autocorrelation and number of nests per population, see (*19*) for details. Mean year = the mean year of the data collection, log(N number of nests) = logarithm of the number of nests.

Table S4. Within-population variation in historic and recent nest predation.

Species	Location	Latitude	Longitude	Period	DPR	SEM	TPR (%)	Years	Mean year	N nests	Exposure
Northern Lapwing	Czech Rep.	49.115	14.268	historic	0.023	0.002	50.64	10	1993	375	6883
Vanellus vanellus				recent	0.044	0.002	65.84	8	2006	505	6694.8
Hudsonian Godwit	Canada	58.701	-93.802	historic	0.005	0.005	13.53	4	1965	12	186.3
Limosa haemastica				recent	0.034	0.012	60.67	3	2013	21	235.5
Whimbrel	Canada	58.701	-93.802	historic	0.018	0.004	40.78	6	1969	80	1172.8
Numenius phaeopus				recent	0.050	0.006	77.37	4	2012	138	1481.5
Common Greenshank	Scotland	58.533	-4.232	historic	0.018	0.011	40.40	18	1992	24	275.925
Tringa nebularia				recent	0.027	0.011	53.81	7	2004	27	297.15
Sanderling	Greenland	74.478	-20.555	historic	0.019	0.008	44.53	4	1997	36	365.8
Calidris alba				recent	0.054	0.010	74.95	6	2003	38	405.7
Western Sandpiper	Alaska	64.449	-164.977	historic	0.027	NA	49.20	3	1994	126	1071
Calidris mauri				recent	0.050	0.005	72.26	3	2013	196	2280
Temminck's Stint	Finland	65.021	24.72	historic	0.026	0.003	47.60	19	1992	424	4642.56
Calidris temminckii				recent	0.039	0.007	62.45	4	2004	76	877.92
Pectoral Sandpiper	Alaska	70.380	-149.534	historic	0.011	0.003	25.67	4	1990	123	1762.8
Calidris melanotos				recent	0.051	0.017	74.56	2	2011	18	195
Dunlin	Canada	58.701	-93.802	historic	0.000	NA	0.00	4	1965	13	195
Calidris alpina				recent	0.017	0.004	34.62	4	2012	114	1483.5

Historic values are prior 2000 and recent after the year 2000, DPR = daily nest predation, TPR % = total nest predation values, Years refer to the number of breeding seasons involved, exposure is given in days. Standard error computation follows Johnson (*51*); it was impossible to compute it in the historic period for Western Sandpiper because the number of all failed nests was not given and for the Dunlin due to zero nest predation. For data sources see table S1. Species are taxonomically ordered according to IOC Word Bird List (ver. 6.3, 2016) (*35*).

Table S5. Within-population variation in historic and recent nest predation – statistics.

Response variable	**Daily nest predation**				**Total nest predation**			
Explanatory variable	Estimate	SEM	*t-value*	*P-value*	Estimate	SEM	*t-value*	*P-value*
(Intercept)	-3.8687	1.033			0.3572	0.457		
Period	0.5475	0.216	2.54	< 0.001	0.2698	0.092	2.93	< 0.001
Latitude	0.0115	0.016	0.71	0.414	0.0042	0.007	0.58	0.508

Linear mixed effect model with the random effect of species, n = 9 populations, for details see table S4.

Table S6. Effect of latitude (A, B and C) and time (A) on nest predation.

	Response variable	**Daily predation rate**				**Total predation rate**			
	Explantory variable	Estimate	SEM	*z-value*	*P-value*	Estimate	SEM	*z-value*	*P-value*
A, All data	(Intercept)	-34.0867	4.883			12.6453	2.076		
n = 237 populations	Mean year	0.0153	0.002	6.24	< 0.001	0.0065	0.001	6.28	< 0.001
	Hemisphere	0.4058	0.111	3.66	< 0.001	0.1655	0.047	3.42	< 0.001
	abs(Latitude)	-0.0013	0.002	-0.52	0.610	-0.0009	0.001	-0.93	0.350
	log(Number of nests)	-0.0161	0.030	-0.53	0.600	-0.0024	0.013	-0.19	0.850
separate model for interaction effect	Mean year : Hemisphere	0.0031	0.008	0.38	0.700	0.0019	0.003	0.55	0.580
separate model for interaction effect	Hemisphere : abs(Latitude)	0.0160	0.008	1.90	0.057	0.0067	0.004	1.88	0.060
separate model for interaction effect	Mean year : abs(Latitude)	0.0003	< 0.001	1.84	0.066	0.0001	< 0.001	1.67	0.095
B, Subset of historic data	(Intercept)	-3.5763	0.244			0.4477	0.108		
(before year 2000)	Hemisphere	0.3929	0.144	2.74	0.006	0.1607	0.063	2.54	0.011
n = 145 populations	abs(Latitude)	-0.0064	0.003	-1.86	0.063	-0.0034	0.002	-2.25	0.025
	log(Number of nests)	0.0137	0.039	0.35	0.730	0.0049	0.017	0.29	0.770
separate model for interaction effect	Hemisphere : abs(Latitude)	0.0087	0.012	0.73	0.460	0.0032	0.005	0.61	0.540
C, Subset of recent data	(Intercept)	-3.7969	0.310			0.3199	0.129		
(after year 2000)	Hemisphere	0.3511	0.172	2.04	0.041	0.1476	0.071	2.07	0.038
n = 102 populations	abs(Latitude)	0.0049	0.004	1.35	0.180	0.0014	0.002	0.96	0.340
	log(Number of nests)	0.0208	0.052	0.40	0.690	0.0135	0.021	0.63	0.530
separate model for interaction effect	Hemisphere : abs(Latitude)	0.0301	0.013	2.25	0.025	0.0138	0.006	2.52	0.012

Linear mixed-effects kinship models with control for phylogeny (species level of phylogeny + random effect of the species), spatial autocorrelation and number of nests per population. The sum of historic and recent nest predation values is 247 data points because 10 populations were divided into two subsets. We ran individual models including all predictors, additionally separate models for possible interaction effects were fitted, then non-significant interactions deleted. See (*19*) for details. Mean year = the mean year of the data collection, Hemisphere = Northern and Southern hemisphere, abs(Latitude) = absolute value of latitude, log(N number of nests) = logarithm of the number of nests.

Table S7. Climate change in relation to nest predation.

Response variable	**Daily predation rate**				**Total predation rate**			
Explantory variable	Estimate	SEM	*z-value*	*P-value*	Estimate	SEM	*z-value*	*P-value*
(Intercept)	-3.4586	0.147			0.4441	0.065		
Temperature slope 30	6.8118	1.272	5.36	< 0.001	2.7528	0.540	5.10	< 0.001
log(Number of nests)	-0.0160	0.032	-0.51	0.610	-0.0500	0.013	-0.37	0.710
(Intercept)	-3.5177	0.149			0.4192	0.065		
Temperature slope 40	8.5660	1.625	5.27	< 0.001	3.4748	0.690	5.03	< 0.001
log(Number of nests)	-0.0030	0.032	-0.10	0.920	0.0005	0.013	0.04	0.970
(Intercept)	-3.4189	0.149			0.4587	0.065		
Temperature slope 20	4.3937	0.986	4.53	< 0.001	1.7097	0.412	4.15	< 0.001
log(Number of nests)	-0.0111	0.032	-0.35	0.730	-0.0023	0.014	-0.17	0.870
(Intercept)	-3.3508	0.152			0.4854	0.065		
Temperature slope 10	0.4753	0.413	1.15	0.250	0.1551	0.175	0.89	0.370
log(Number of nests)	-0.0060	0.033	-0.18	0.860	< 0.0001	0.014	0.00	1.000
(Intercept)	-3.754	0.182			0.3634	0.081		
Temperature sd 30	0.3903	0.133	2.93	0.003	0.1251	0.058	2.17	0.030
log(Number of nests)	0.0176	0.033	0.53	0.590	0.0070	0.014	0.49	0.620
(Intercept)	-3.8077	0.182			0.3407	0.082		
Temperature sd 40	0.4379	0.130	3.36	< 0.001	0.1463	0.057	2.59	0.010
log(Number of nests)	0.0196	0.033	0.59	0.550	0.0077	0.014	0.55	0.580
(Intercept)	-3.6842	0.180			0.3910	0.082		
Temperature sd 20	0.3117	0.129	2.42	0.016	0.0898	0.056	1.62	0.110
log(Number of nests)	0.0165	0.033	0.49	0.620	0.0056	0.014	0.39	0.700
(Intercept)	-3.5598	0.166			0.4410	0.076		
Temperature sd 10	0.2072	0.123	1.69	0.091	0.0569	0.052	1.09	0.280
log(Number of nests)	0.0079	0.033	0.24	0.810	0.0027	0.014	0.19	0.850

N = 247 population measurements (10 populations were divided into two subsets), see (*19*) for details and climatic variables preparation.

Table S8. Correlation matrix of four potential predictors of nest predation.

Correlation matrix (Spearman's rank correlation)

Variable	Latitude	Year	Temperature slope 30	Temperature sd 30
Latitude	1			
Mean year	-0.003	1		
Temperature slope 30	0.230	0.672	1	
Temperature sd 30	0.701	0.202	0.484	1

Correlation matrix with Spearman's correlation test P-values

Variable	Latitude	Year	Temperature slope 30	Temperature sd 30
Latitude				
Mean year	0.115			
Temperature slope 30	< 0.000	< 0.001		
Temperature sd 30	< 0.001	0.001	< 0.001	

N = 247 population measurements (10 populations were divided into two subsets), see (*19*) for details.