Citation for published version:
Kubelka, V, Šálek, M, Tomkovich, P, Végvári, Z, Freckleton, RP & Székely, T 2018, 'Global pattern of nest predation is disrupted by climate change in shorebirds', *Science*, vol. 362, no. 6415, pp. 680-683. https://doi.org/10.1126/science.aat8695

DOI:
10.1126/science.aat8695

Publication date:
2018

Document Version
Peer reviewed version

Link to publication

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

Authors: Vojtěch Kubelka[1,2*], Miroslav Šálek[3], Pavel Tomkovich[4], Zsolt Végvári[5,6], Robert P. Freckleton[7], Tamás Székely[2,8,9,10*]

Affiliations:

[1]Department of Ecology, Charles University in Prague, Vinicna 7, 128 44, Prague, Czech Republic.

[2]Milner Centre for Evolution, University of Bath, Claverton Down, Bath BA2 7AY, UK.

[3]Faculty of Environmental Sciences, Czech University of Life Sciences Prague, Kamycka 129, 165 21, Prague, Czech Republic.

[4]Zoological Museum, Moscow MV Lomonosov State University, Bolshaya Nikitskaya Str 6, Moscow 125009, Russia.

[5]Department of Conservation Zoology, University of Debrecen, Egyetem tér 1, H-4032 Debrecen, Hungary.

[6]Hortobágy National Park Directorate, Sumen u. 2, H-4024 Debrecen, Hungary.

[7]Department of Animal and Plant Sciences, University of Sheffield, Alfred Denny Building, Western Bank, Sheffield S10 2TN, UK.

[8]Department of Evolutionary Zoology and Human Biology, University of Debrecen, Egyetem tér 1, H-4032, Debrecen, Hungary.

[9]State Key Laboratory of Biocontrol and College of Ecology and Evolution, Sun Yat-sen University, Guangzhou 510275, China.

[10]Ministry of Education Key Laboratory for Biodiversity Sciences and Ecological Engineering, College of Life Sciences, Beijing Normal University, Beijing 100875, China.

*Corresponding author. E-mail: kubelkav@gmail.com (V.K.); T.Szekely@bath.ac.uk (T.S.).

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.

References and notes:

1. B. R. Scheffers *et al.*, The broad footprint of climate change from genes to biomes to people. *Science* **354**, 719, aaf7671 (2016).

2. J. M. Tylianakis, R. K. Didham, J. Bascompte, D. A. Wardle, Global change and species interactions in terrestrial ecosystems. *Ecol. Lett.* **11**, 1351–1363 (2008).

3. C. Parmesan, Ecological and evolutionary responses to recent climate change. *Annu. Rev. Ecol. Evol. Syst.* **37**, 637–669 (2006).

4. J. L. Blois, P. L. Zarnetske, M. C. Fitzpatrick, S. Finnegan, Climate change and the past, present, and future of biotic interactions. *Science* **341**, 499–504 (2013).

5. C. Barbraud, H. Weimerskirch, Emperor penguins and climate change. *Nature* **411**, 183–186 (2001).

6. O. Gilg *et al.*, Climate change and the ecology and evolution of Arctic vertebrates. *Ann. N. Y. Acad. Sci.* **1249**, 166–190 (2012).

7. W. J. Sydeman, E. Poloczanska, T. E. Reed, S. A. Thompson, Climate change and marine vertebrates. *Science* **350**, 772–777 (2015).

8. D. Lack, *Population Studies of Birds* (Oxford Univeristy Press, Oxford, 1966).

9. P. M. Bennett, I. P. F. Owens, *Evolutionary Ecology of Birds: Life Histories, Mating Systems, and Extinction* (Oxford Univeristy Press, Oxford, 2002).

10. M. A. Colwell, *Shorebird Ecology, Conservation, and Management* (University of California Press, Berkeley and Los Angeles, California, 2010).

11. C. D. G. Harley, Climate change, keystone predation, and biodiversity loss. *Science* **334**, 1124–1127 (2011).

12. H. Meltofte *et al.*, *Effects of Climate Variation on the Breeding Ecology of Arctic Shorebirds –*

Meddelelser om Grønland Bioscience 59 (Danish Polar Center, Copenhagen, DK, 2007).

13. T. Caro, *Antipredator Defences in Birds and Mammals* (University of Chicago Press, Chicago, 2005).
14. R. Ricklefs, An analysis of nesting mortality in birds. *Smithson. Contrib. to Zool.* **9**, 1–48 (1969).
15. A. F. Skutch, Clutch size, nesting success, and predation on nests of Neotropical birds, reviewed. *Ornithol. Monogr.* **36**, 575–594 (1985).
16. T. M. Blackburn, P. Cassey, R. P. Duncan, K. L. Evans, K. J. Gaston, Avian extinction and mammalian introductions on oceanic islands. *Science* **305**, 1955–1958 (2004).
17. J. del Hoyo, A. Elliott, J. Sargatal, D. A. Christie, E. de Juana, Eds., *Handbook of the Birds of the World Alive* (Lynx Edicions, Barcelona, 2018); http://www.hbw.com/.
18. BirdLife International, IUCN Red List for birds (2018); http://datazone.birdlife.org/species/search.
19. Materials and methods are available as supplementary materials.
20. B. J. M. Stutchbury, E. S. Morton, *Behavioral Ecology of Tropical Birds* (Academic Press, San Diego, London, 2001).
21. B. A. DeGregorio, S. J. Chiavacci, T. J. Benson, J. H. Sperry, P. J. Weatherhead, Nest predators of North American birds: continental patterns and implications. *Bioscience* **66**, 655–665 (2016).
22. T. Piersma *et al.*, Simultaneous declines in summer survival of three shorebird species signals a flyway at risk. *J. Appl. Ecol.* **53**, 479–490 (2016).
23. C. E. Studds *et al.*, Rapid population decline in migratory shorebirds relying on Yellow Sea tidal mudflats as stopover sites. *Nat. Commun.* **8: 14895**, 1–7 (2017).
24. M. Roodbergen, B. van der Werf, H. Hötker, Revealing the contributions of reproduction and survival to the Europe-wide decline in meadow birds: review and meta-analysis. *J. Ornithol.* **153**, 53–74 (2012).
25. B. Y. M. Munro, What's killing the world's shorebirds? *Nature* **541**, 16–20 (2017).

26. R. A. Ims, J.-A. Henden, S. T. Killengreen, Collapsing population cycles. *Trends Ecol. Evol.* **23**, 79–86 (2008).

27. K. L. Kausrud *et al.*, Linking climate change to lemming cycles. *Nature* **456**, 93–98 (2008).

28. Y. Aharon-Rotman *et al.*, Loss of periodicity in breeding success of waders links to changes in lemming cycles in Arctic ecosystems. *Oikos* **124**, 861–870 (2014).

29. T. Cornulier *et al.*, Europe-wide dampening of population cycles in keystone herbivores. *Science* **340**, 63–66 (2013).

30. S. M. Bierman *et al.*, Changes over time in the spatiotemporal dynamics of cyclic populations of field voles (*Microtus agrestis* L.). *Am. Nat.* **167**, 583–590 (2006).

31. L. McKinnon *et al.*, Lower predation risk for migratory birds at high latitudes. *Science* **327**, 326–327 (2010).

32. M. A. Schlaepfer, M. C. Runge, P. W. Sherman, Ecological and evolutionary traps. *Trends Ecol. Evol.* **17**, 474–480 (2002).

33. J. A. van Gils *et al.*, Body shrinkage due to Arctic warming reduces red knot fitness in tropical wintering range. *Science* **352**, 819–821 (2016).

34. J. del Hoyo, N. J. Collar, Eds., *HBW and BirdLife International Ilustrated Checklist of the Birds of the World. Volume 1: Non-passerines* (Lynx Edicions, Barcelona, 2014).

35. F. Gill, D. Donsker, Eds., *IOC World Bird List (v 6.3)* (2016); http://www.worldbirdnames.org/.

36. A. Poole, Ed., *The Birds of North America Online* (Cornell Lab of Ornithology, Ithaca, 2015); http://bna.birds.cornell.edu/bna.

37. S. Cramp, K. E. L. Simmons, Eds., *Handbook of the Birds of Europe, the Middle East, and North Africa: The Birds of the Western Palearctic, Volume III: Waders to Gulls* (Oxford University Press, Oxford, 1983).

38. E. Lappo, P. Tomkovich, E. Syroechkovskiy, *Atlas of Breeding Waders in the Russian Arcic*

(Russian Academy of Sciences, Moscow, 2012).
39. E. K. Urban, C. H. Fry, S. Keith, Eds., *The Birds of Africa. Volume II: Game Birds to Pigeons* (Academic Press, Waltham, 1986).
40. J. del Hoyo, A. Elliott, J. Sargatal, Eds., *Handbook of the Birds of the World. Vol. 3. Hoatzin to Auks* (Lynx Edicions, Barcelona, 1996).
41. S. Marchant, P. J. Higgins, Eds., *Handbook of Australian, New Zealand and Antarctic Birds. Volume 2: Raptors to Lapwings* (Oxford University Press, Melbourne, 1993).
42. P. J. Higgins, S. J. J. F. Davies, Eds., *Handbook of Australian, New Zealand and Antarctic Birds. Volume 3: Snipe to Pigeons* (Oxford University Press, Melbourne, 1996).
43. M. A. MacDonald, M. Bolton, Predation on wader nests in Europe. *Ibis* **150** Suppl., 54–73 (2008).
44. E. L. Weiser *et al.*, Effects of environmental conditions on reproductive effort and nest success of Arctic-breeding shorebirds. *Ibis* **160**, 608–623 (2018).
45. J. M. Durant, D. Hjermann, G. Ottersen, N. C. Stenseth, Climate and the match or mismatch between predator requirements and resource availability. *Clim. Res.* **33**, 271–283 (2007).
46. T. D. Mitchell, P. D. Jones, An improved method of constructing a database of monthly climate observations and associated high-resolution grids. *Int. J. Climatol.* **25**, 693–712 (2005).
47. H. F. Mayfield, Suggestions for calculating nest success. *Wilson Bull.* **87**, 456–466 (1975).
48. H. Mayfield, Nesting success calculated from exposure. *Wilson Bull.* **73**, 255–261 (1961).
49. S. J. Dinsmore, G. C. White, F. L. Knopf, Advanced techniques for modeling avian nest survival. *Ecology* **83**, 3476–3488 (2002).
50. N. J. Aebischer, Multi-way comparisons and generalized linear models of nest success: extensions of the Mayfield method. *Bird Study* **46** Suppl., S22–S31 (1999).
51. D. H. Johnson, Estimating nest success: the Mayfield method and an alternative. *Auk* **96**, 651–661 (1979).

52. G. Kulesza, An analysis of clutch-size in New World passerine birds. *Ibis* **132**, 407–422 (1990).

53. N. P. Myhrvold *et al.*, An amniote life-history database to perform comparative analyses with birds, mammals, and reptiles. *Ecology* **96**, 3109 (2015).

54. G. Jehle, A. A. Yackel Adams, J. A. Savidge, S. K. Skagen, Nest survival estimation: A review of alternatives to the mayfield estimator. *Condor* **106**, 472–484 (2004).

55. A. J. Beintema, Inferring nest success from old records. *Ibis* **138**, 568–570 (1996).

56. M. Favero, Biologia reproductiva de la paloma Antárctica, *Chionis alba* (Charadriiformes) en las islas Shetland del sur Antartida [in Italian with English abstract]. *Riv. Ital. di Ornitol.* **63**, 33–40 (1993).

57. C. S. Moitoret, T. R. Walker, P. D. Martin, "Predevelopment surveys of nesting birds at two sites in the Kuparuk Oilfield, Alaska, 1988–1992" (U.S. Fish and Wildlife Service, NAES-TR-96-02, Fairbanks, AL, 1996).

58. A. F. Skutch, Do tropical birds rear as many young as they can nourish? *Ibis* **91**, 430–455 (1949).

59. T. Piersma, P. Wiersma, J. A. van Gils, The many unknowns about plovers and sandpipers of the world: introduction to a wealth of research opportunities highly relevant for shorebird conservation. *Wader Study Gr. Bull.* **82**, 23–33 (1997).

60. W. D. Robinson, G. Rompré, T. R. Robinson, Videography of Panama bird nests shows snakes are principal predators. *Ornitol. Neotrop.* **16**, 187–195 (2005).

61. P. J. Weatherhead, G. Blouin-Demers, Understanding avian nest predation: why ornithologists should study snakes. *J. Avian Biol.* **35**, 185–190 (2004).

62. J. J. Roper, R. R. Goldstein, A test of the Skutch hypothesis: does activity at nests increase nest predation risk? *J. Avian Biol.* **28**, 111–116 (1997).

63. E. M. Griebeler, T. Caprano, K. Böhning-Gaese, Evolution of avian clutch size along latitudinal gradients: do seasonality, nest predation or breeding season length matter? *J. Evol. Biol.* **23**, 888–

901 (2010).

64. J. J. Roper, K. A. Sullivan, R. E. Ricklefs, Avoid nest predation when predation rates are low, and other lessons: testing the tropical–temperate nest predation paradigm. *Oikos* **119**, 719–729 (2010).

65. W. Teunissen, H. Schekkerman, F. Willems, F. Majoor, Identifying predators of eggs and chicks of Lapwing *Vanellus vanellus* and Black-tailed Godwit *Limosa limosa* in the Netherlands and the importance of predation on wader reproductive output. *Ibis* **150** Suppl., 74–85 (2008).

66. P. Lloyd, Variation in nest predation among arid-zone birds. *Ostrich* **75**, 228–235 (2004).

67. M. L. Stephens, "Maternal care and polyandry in the Northern Jacana (*Jacana Spinosa*)" thesis, University of Chicago, Chicago, ILL (1984).

68. J. C. T. Menezes, M. Â. Marini, Predators of bird nests in the Neotropics: a review. *J. F. Ornithol.* **88**, 99–114 (2017).

69. L. Mckinnon, D. Berteaux, J. Bêty, Predator-mediated interactions between lemmings and shorebirds: A test of the alternative prey hypothesis. *Auk* **131**, 619–628 (2014).

70. D. Gallant, B. G. Slough, D. G. Reid, D. Berteaux, Arctic fox versus red fox in the warming Arctic: four decades of den surveys in north Yukon. *Polar Biol.* **35**, 1421–1431 (2012).

71. M. J. Crawley, *The R Book* (Wiley, Chichester, UK, 2013).

72. S. N. Wood, Thin plate regression splines. *J. R. Stat. Soc. Ser. B Stat. Methodol.* **65**, 95–114 (2003).

73. S. N. Wood, *Generalized Additive Models: An Introduction with R* (Chapman & Hall, Bristol, 2006).

74. R Development Core Team, R: A language and environment for statistical computing (2017); http://www.r-project.org.

75. H. Wickham, *ggplot2: Elegant Graphics for Data Analysis* (Springer Publishing Company, 2009).

76. W. Jetz, G. H. Thomas, J. B. Joy, K. Hartmann, A. O. Mooers, The global diversity of birds in

space and time. *Nature* **491**, 444–448 (2012).

77. C. Küpper *et al.*, Kentish versus Snowy plover: Phenotypic and genetic analyses of *Charadrius alexandrinus* reveal divergence of Eurasian and American subspecies. *Auk* **126**, 839–852 (2009).

78. E. P. Martins, T. F. Hansen, Phylogenies and the comparative method: A general approach to incorporating phylogenetic information into the analysis of interspecific data. *Am. Nat.* **149**, 646–667 (1997).

79. T. Garland, A. R. Ives, Using the past to predict the present: Confidence intervals for regression equations in phylogenetic comparative methods. *Am. Nat.* **155**, 346–364 (2000).

80. W. Jetz, R. P. Freckleton, Towards a general framework for predicting threat status of data-deficient species from phylogenetic, spatial and environmental information. *Philos. Trans. R. Soc. B Biol. Sci.* **370**, 20140016 (2015).

81. R. P. Freckleton, W. Jetz, Space versus phylogeny: disentangling phylogenetic and spatial signals in comparative data. *Proc. R. Soc. B-Biological Sci.* **276**, 21–30 (2009).

82. T. Therneau, The lmekin function (2018); https://cran.r-project.org/web/packages/coxme/vignettes/lmekin.pdf.

83. D. Bates, M. Maechler, Package "lme4". R Package Version 0.999999-0 (2012); http://www2.uaem.mx/r-mirror/web/packages/lme4/lme4.pdf.

84. E. C. Taylor, "Stone curlews *Burhinus oedicnemus* and human disturbance: effects on behaviour, distribution and breeding success", thesis, University of Cambridge, Cambridge, UK (2006).

85. M. S. Nadeem, T. Mahmood, M. Mahmood-Ul-Hassan, Breeding success of the Stone Curlew *Burhinus oedicnemus* in Nag Valley (1999–2001), Kharan, Pakistan. *Turkish J. Zool.* **38**, 510–514 (2014).

86. R. Dobson, Breeding data on the Water Thicknee in the Mpenjati Nature Reserve. *Bird Numbers* **13**, 38–39 (2004).

87. C. Lishman, E. Nol, Ecology and habitat selection of the Magellanic Plover (*Pluvianellus socialis*): A little-known Patagonian shorebird. *Wilson J. Ornithol.* **124**, 487–496 (2012).

88. D. F. Tessler, L. S. Garding, "Black Oystercatcher Distribution and Productivity in the Beardslee Islands, Glacier Bay National Park and Preserve, Alaska" (Glacier Bay National Park and Preserve Gustavus, AL, 2006).

89. J. B. Sabine, J. M. Meyers, S. H. Schweitzer, A simple, inexpensive video camera setup for the study of avian nest activity. *J. F. Ornithol.* **76**, 293–297 (2005).

90. E. Barbieri, R. T. C. Delchiaro, Reprodução da ave piru-piru (*Haematopus palliatus*, Temminck 1820, Haematopodidae) no litoral sul do Estado de São Paulo, Brasil [in Portuguese with English abstract]. *Biota Neotrop.* **9**, 285–288 (2009).

91. K. M. Calf, L. G. Underhill, Productivity of African Black Oystercatchers *Haematopus moquini* on Robben Island, South Africa, in the 2001–2002 breeding season. *Wader Study Gr. Bull.* **99**, 45–49 (2002).

92. H. A. Scott, W. R. J. Dean, L. H. Watson, Breeding success and changes in numbers of African Black Oystercatchers *Hameotopus moquini* in relation to habitat quality and protection status. *Mar. Ornithol.* **39**, 189–199 (2011).

93. K. F. D. Hughey, "Hydrological factors influencing the ecology of riverbed breeding birds on the plains' reaches of Canterbury's braided rivers", thesis, University of Canterbury, Christchurch, NZ (1985).

94. A. J. Beintema, G. J. D. M. Müskens, Nesting success of birds breeding in Dutch agricultural grasslands. *J. Appl. Ecol.* **24**, 743–758 (1987).

95. A. G. Rudenko, The Oystercatcher *Haematopus ostralegus* in the Black Sea Nature Reserve. *Int. Wader Stud.* **10**, 261–263 (1998).

96. D. B. Jackson, R. E. Green, The importance of the introduced hedgehog (*Erinaceus europaeus*) as

a predator of the eggs of waders (Charadrii) on machair in South Uist, Scotland. *Biol. Conserv.* **93**, 333–348 (2000).

97. R. Ottvall, Nest survival among waders breeding on coastal meadows: the relative importance of predation and trampling damages by livestock [in Swedish with English summary]. *Ornis Svecica* **15**, 89–96 (2005).

98. B. Lauro, E. Nol, Patterns of habitat use for Pied and Sooty Oystercatchers nesting at the Furneaux Islands, Australia. *Condor* **97**, 920–934 (1995).

99. B. Michaux, Breeding records for variable oystercatchers (*Haematopus unicolor*) at Long Bay Regional Park and Okura Estuary, Auckland. *Notornis* **60**, 178–179 (2013).

100. P. J. Moore, C. Reid, Effectiveness of management on the breeding success of Chatham Island oystercatchers (*Haematopus chathamensis*). *New Zeal. J. Zool.* **36**, 431–446 (2009).

101. J. A. Cuervo, Hatching success in Avocet *Recurvirostra avosetta* and Black-winged Stilt *Himantopus himantopus*. *Bird Study* **52**, 166–172 (2003).

102. R. J. Pierce, Diferences in susceptibility to predation during nesting between Pied and Black Stilts (Himantopus ssp.). *Auk.* **103**, 273–280 (1986).

103. G. Herring, J. T. Ackerman, J. Y. Takekawa, C. A. Eagles-Smith, J. M. Eadie, Identifying nest predators of American Avocets (*Recurvirostra americana*) and Black-necked Stilts (*Himantopus mexicanus*) in San Srancisco Bay, California. *Southwest. Nat.* **56**, 35–43 (2011).

104. C. Bain, “Breeding wader habitats in a upland area of North Wales (Hiraethog)” (Sandy, 1987).

105. H. Galbraith, Effect of agriculture on the breeding ecology of Lapwings *Vanellus vanellus*. *J. Appl. Ecol.* **25**, 487–503 (1988).

106. D. Baines, The roles of predation, food and agricultural practice in determining the breeding success of the Lapwing (*Vanellus vanellus*) on upland grasslands. *J. Anim. Ecol.* **59**, 915–929 (1990).

107. Å. Berg, T. Lindberg, K. G. Källebrink, Hatching success of lapwings on farmland: differences between habitats and colonies of different sizes. *J. Anim. Ecol.* **61**, 469–476 (1992).

108. D. Blomqvist, O. C. Johansson, Trade-offs in nest site selection in coastal populations of Lapwings *Vanellus vanellus*. *Ibis* **137**, 550–558 (1995).

109. L.-Å. Flodin, H. Hirsimäki, L.-G. Norén, Associative breeding of waders on shore meadows in southwestern Sweden: predator protection or habitat selection? [in Swedish with English summary]. *Ornis Svecica* **5**, 23–30 (1995).

110. J. D. Hart, T. P. Milsom, A. Baxter, P. F. Kelly, W. K. Parkin, The impact of livestock on Lapwing *Vanellus vanellus* breeding densities and performance on coastal grazing marsh. *Bird Study* **49**, 67–78 (2002).

111. L. Schröpfer, Choice of breeding habitat, hatching success and local population density of Northern Lapwing (*Vanellus vanellus*) in South-west Bohemia in 1992-2001. [in Czech with German summary]. *Erica* **10**, 127–138 (2002).

112. M. Šálek, P. Šmilauer, Predation on Northern Lapwing *Vanellus vanellus* nests: The effect of population density and spatial distribution of nests. *Ardea* **90**, 51–60 (2002).

113. H. Köster, H. A. Bruns, Haben Wiesenwögel in binnenländischen Schutzgebieten ein "Fuchsproblem"? [in German]. *Berichte zum vogelschutz* **40**, 57–74 (2003).

114. S. Junker, H. Düttmann, R. Ehrnsberger, Schlupferfolg und kükenmortalität beim Kiebitz (*Vanellus vanellus*) auf unterschiedlich gemanagten Grünlandflächen in der Stollhammer Wisch (Landkreis Wesermarsch, Niedersachsen) [in German with English summary]. *Osnabrücker Naturwissenschaftliche Mitteilungen* **32**, 111–122 (2006).

115. F. E. Sharpe, " Productivity and population trends of Northern Lapwing (*Vanellus vanellus*) in Britain" thesis, University of Bath, Bath, UK (2006).

116. S. Kragten, G. R. De Snoo, Nest success of Lapwings *Vanellus vanellus* on organic and

conventional arable farms in the Netherlands. *Ibis* **149**, 742–749 (2007).

117. A. Puchta, J. Ulmer, B. Schönenberger, A. Burtscher, Situation of Northern Lapwing *Vanellus vanellus* in the Austrian Rhine Valley [in German with English summary]. *Ornithol. Beobachter* **106**, 275–296 (2009).

118. V. Zámečník, V. Kubelka, M. Šálek, Visible marking of wader nests to avoid damage by farmers does not increase nest predation. *Bird Conserv. Int.* **28**, 293–301 (2018).

119. E. Makrigianni, S. Sgardelis, K. Poirazidis, A. Athanasiadis, Breeding biology and nesting site selection by the spur-winged plover *Hoplopterus spinosus* in the Evros Delta, NE Greece. *J. Nat. Hist.* **42**, 333–344 (2008).

120. B. Ade, Some observations on the breeding of Crowned Plowers (1977). *Bokmakierie* **31**, 9–16 (1979).

121. M. Takahashi, K. Ohkawara, Breeding behavior and reproductive success of Grey-headed Lapwing *Vanellus cinereus* on farmland in central Japan. *Ornithol. Sci.* **9**, 1–9 (2007).

122. Barlow, M. L., P. M. Muller, R. R. Sutton, Breeding data on the Spur-winged Plover in Southland, New Zealand. *Notornis* **19**, 212–249 (1972).

123. M. A. Giese, D. N. Jones, Timing and success of breeding in subtropical Masked Lapwings. *Corella* **20**, 69–74 (1996).

124. A. P. A. Cardilini, M. A. Westona, D. G. Nimmoa, P. Dann, C. D. H. Sherman, Surviving in sprawling suburbs: Suburban environments represent high quality breeding habitat for a widespread shorebird. *Landsc. Urban Plan.* **115**, 72–80 (2013).

125. M. Watson *et al.*, Nest survival and productivity of the critically endangered Sociable Lapwing *Vanellus gregarius*. *Ibis* **148**, 489–502 (2006).

126. R. D. Sheldon *et al.*, Breeding ecology of the globally threatened Sociable Lapwing *Vanellus gregarius* and the demographic drivers of recent declines. *J. Ornithol.* **154**, 501–516 (2013).

127. R. A. S. Cerboncini, T. V. Braga, J. J. Roper, F. C. Passos, How to capture breeding Southern Lapwing *Vanellus chilensis*. *Rev. Bras. Ornitol.* **23**, 1–4 (2015).

128. E. S. A. Santos, R. H. Macedo, https://doi.org/10.1101/179606 (2017).

129. I. Byrkjedal, Antipredator behaviour and breeding success in Greater Golden-Plover and Eurasian Dotterel. *Condor* **89**, 40–47 (1987).

130. H. Schekkerman, I. Tulp, K. M. Calf, J. J. de Leeuw, "Studies on breeding shorebirds at Medusa Bay, Taimyr, in summer 2002" (Wageningen, 2004).

131. Arctic Shorebird Demographics Network, Arctic Shorebird Demographics Network Data Archive (2016); https://www.aoncadis.org/dataset/ASDN.html.

132. A. Kondratyev, *Biologija Kulikov v Tundrach Severo-Vostoka Azii* [in Russian] (Nauka, Moscow, RU, 1982).

133. P. S. Tomkovich, A. G. Dondua, On peculiarities of the Grey Plover (*Pluvialis squatarola*) population on Wrangle Island, the Arctic Far East of Russia [in Russian with English summary]. *Ornitologia* **36**, 103–113 (2011).

134. D. E. Wills, J. Murray, R. G. Powlesland, Impact of management on the breeding success of the northern New Zealand dotterel (*Charadrius obscurus aquilonius*) on Matakana Island, Bay of Plenty. *Notornis* **50**, 1–10 (2003).

135. M. W. Pienkowski, Breeding biology and population dynamics of Ringed plovers *Charadrius hiaticula* in Britain and Greenland: nest-predation as a possible factor limiting distribution and timing of breeding. *J. Zool.* **202**, 83–114 (1984).

136. J. R. Jehl Jr., Patterns of hatching success in subarctic birds. *Ecology* **52**, 169–173 (1971).

137. E. H. Cooper, J. M. & Miller, in *The Ecology, Status and Conservation of Marine and Shoreline Birds of the Queen Charlotte Islands*, K. Vermeer, K. H. Morgan, Eds. (Canadian Wildlife Service, 1997), pp. 123–129.

138. N. Katayama, T. Amano, S. Ohori, The effects of gravel bar construction on breeding Long-billed Plovers. *Waterbirds* **33**, 162–168 (2010).

139. L. Dolanský, P. Žďárek, Breeding of the Common Sandpiper (*Actitis hypoleucos*) and the Little Ringed Plover (*Charadrius dubius*) on the Orlice river near Hradec Králové [in Czech with English summary]. *Panurus* **11**, 107–114 (2001).

140. E. Cepáková, M. Šálek, J. Cepák, T. Albrecht, Breeding of Little Ringed Plovers *Charadrius dubius* in farmland: do nests in fields suffer from predation? *Bird Study* **54**, 284–288 (2007).

141. P. W. Bergstrom, "Ecology of incubation in Wilson's Plover (*Charadrius wilsonius*)" thesis, University of Chicago, Chicago, ILL, (1982).

142. A. C. Brown, K. Brindock, Breeding success and nest site selection by a Caribbean population of Wilson's Plovers. *Wilson J. Ornithol.* **123**, 814–819 (2011).

143. K. F. Kantrud, H. & Higgins, Nest and nest site characteristics of some ground-nesting, non-passerine birds of northern grasslands. *Prairie Nat.* **24**, 67–84 (1992).

144. D. H. Catlin, J. D. Fraser, J. H. Felio, J. B. Cohen, Piping Plover habitat selection and nest success on natural, managed, and engineered sandbars. *J. Wildl. Manage.* **75**, 305–310.

145. I. M. G. Richardson, "Predator exclosures: a management technique to increase Piping Plover (*Charadrius melodus*) reproductive success in Canadian prairies" thesis, University of Alberta, Edmonton, CAN (1999).

146. C. L. White, "Reproductive ecology and nest attentiveness of Piping Plovers (*Charadrius melodus*) breeding at Chaplin Lake, Saskatchewan" thesis, University of Regina, Regina, CAN (2005).

147. S. Zefania, R. Ffrench-Constant, P. R. Long, T. Székely, Breeding distribution and ecology of the threatened Madagascar Plover *Charadrius thoracicus*. *Ostrich* **79**, 43–51 (2008).

148. F. Burns, N. McCulloch, T. Székely, M. Bolton, The impact of introduced predators on an island endemic, the St Helena Plover, *Charadrius sanctaehelenae*. *Bird Conserv. Int.* **23**, 125–135 (2013).

149. T. Székely, I. Karsai, T. D. Williams, Determination of clutch-size in the Kentish Plover *Charadrius alexandrinus*. *Ibis* **136**, 341–348 (1994).

150. L. Pietrelli, A. Tinelli, A. Cannavicci, M. Biondi, Breeding of some Charadriidae at Castelporziano and wire mesh predators enclosures management [in Italian with English summary]. *Uccelli d'Italia*. **26** Suppl., 53–58 (2001).

151. A. Kosztolányi *et al.*, Breeding ecology of Kentish Plover *Charadrius alexandrinus* in an extremely hot environment. *Bird Study* **56**, 244–252 (2009).

152. M. AlRashidi, A. Kozstolány, M. Shobrak, T. Székely, Breeding ecology of the Kentish Plover, *Charadrius alexandrinus*, in the Farasan Islands, Saudi Arabia. *Zology Middle East* **53**, 15–24 (2011).

153. K. Carmona-Isunza, M. C., Küpper, T. Serrano-Meneses, M. A. Székely, Courtship behavior differs between monogamous and polygamous plovers. *Behav. Ecol. Sociobiol.* **69**, 2035–2042 (2015).

154. M. AlRashidi, Breeding biology of the Kentish Plover *Charadrius alexandrinus* in the Sabkhat Al-Fasl Lagoons, Saudi Arabia (Aves: Charadriiformes). *Zool. Middle East* **62**, 105–111 (2016).

155. P. W. C. Paton, "Breeding ecology of snowy plovers at Great Salt Lake" thesis, Utah State University, Logan, UT (1994).

156. J. R. Rupert, "The brood-rearing habitat, brood home range, and fecundity of the Snowy Plover (*Charadrius alexandrinus*) in coastal Southern Texas" thesis, The University of Texas-Pan American, Edinburg, TX (1997).

157. K. K. Neuman, "Effect of predator management of Snowy Plowers in Monterey Bay, California" thesis, San Jose State University, San Jose, CA (2003).

158. S. A. Demers, C. W. Robinson-Nilsen, Monitoring Western Snowy Plover nests with remote surveillance systems in San Francisco Bay, California. *J. Fish Wildl. Manag.* **3**, 123–132 (2012).

159. L. X. L. Tan, K. L. Buchanan, G. S. Maguire, M. A. Weston, Cover, not caging, influences chronic physiological stress in a ground-nesting bird. *J. Avian Biol.* **46**, 482–488 (2015).

160. M. Yasué, M. Patterson, P. Dearden, Are saltfats suitable supplementary nesting habitats for Malaysian Plovers *Charadrius peronii* threatened by beach habitat loss in Thailand? *Bird Conserv. Int.* **17**, 211–223 (2007).

161. J. R. Keedwell, M. D. Sanders, Nest monitoring and predator visitation at nests of Banded Dotterels. *Condor* **104**, 899–902 (2002).

162. B. Dowling, M. A. Weston, Managing a breeding population of the Hooded Plover *Thinornis rubricollis* in a high-use recreational environment. *Bird Conserv. Int.* **9**, 255–270 (1999).

163. B. Baird, P. Daan, The breeding biology of hooded plovers, *Thinornis rubricollis,* on Phillip Island, Victoria. *Emu* **103**, 323–328 (2003).

164. A. Davis, Breeding biology of the New Zealand Shore Plover *Thinornis novaeseelandiae*. *Notornis* **41** Suppl., 195–208 (1994).

165. Y.-H. Hsu, L. L. Severinghaus, Nest-site selection of the Greater Painted Snipe (*Rostratula benghalensis benghalensis*) in fallow fields of I-Lan, Taiwan. *Taiwania* **56**, 195–200 (2011).

166. W. R. Tarboton, Aspects of breeding biology of the African Jacana. *Ostrich* **63**, 141–157 (1992).

167. S. H. M. Butchart, Population structure and breeding system of the sex-role reversed, polyandrous Bronze-winged Jacana *Metopidius indicus*. *Ibis* **142**, 93–102 (2000).

168. D. R. Osborne, Replacement nesting and polyandry in the Wattled Jacana. *Wilson Bull.* **94**, 206–208 (1982).

169. A. N. Hoodles, J. C. Coulson, Breeding biology of the Woodcock *Scolopax rusticola* in Britain. *Bird Study* **45**, 195–204 (1998).

170. H. E. Miller, M. J. Jordan, Relationship between exotic invasive shrubs and America Woodcock (*Scolopax minor*) nest success and habitat selection. *J. Pa. Acad. Sci.* **85**, 132–139 (2011).

171. C. M. Miskelly, Breeding systems of New Zealand Snipe *Coenocorypha aucklandic*a and Chatham Island Snipe *C. pusilla*; are they food limited? *Ibis* **132**, 366–379 (1990).

172. E. Mongin, "Snipes *Gallinago gallinago*, *Gallinago media* and *Lymnocryptes minimus* in Belarus" in *Snipes of the Eastern Baltic Region and Belarus*, S. Svazas, E. Mongin, G. Grishanov, A. Kuresoo, W. Meissner, Eds. (OMPO, Vilnius, 2002), pp. 15–35.

173. J. N. Yarovikova, Breeding biology of the Common Snipe in Kaliningrad region [in Russian with English summary]. *Berkut* **12**, 93–99 (2003).

174. N. M. Groen, L. Hemerik, Reproductive success and survival of Black-tailed Godwits *Limosa limosa* in a declining local population in The Netherlands. *Ardea* **90**, 239–248 (2002).

175. N. Groen, R. Mes, I. Fefelov, I. Tupitsyn, Eastern Black-tailed Godwits *Limosa limosa melanuroides* in the Selenga Delta, Lake Baikal, Siberia. *Wader Study Gr. Bull.* **110**, 48–53 (2006).

176. T. Larsen, J. Moldsvor, Antipredator behaviour and breeding assotiations of Bar-tailed Godwits and Whimbrels. *Auk* **109**, 601–608 (1992).

177. M. A. Skeel, Nesting success, density, philopatry, and nest-site selection of the Whimbrel (*Numenius phaeopus*) in different habitats. *Can. J. Zool.* **61**, 218–225 (1983).

178. E. Pulliainen, L. Saari, Breeding biology ofthe Whimbrel *Numenius phaeopus* in eastern Finnish Lapland. *Ornis Fenn.* **70**, 110–116 (1993).

179. B. Katrínardóttir, J. A. Alves, H. Sigurjónsdóttir, P. Hersteinsson, T. G. Gunnarsson, The effects of habitat type and volcanic eruptions on the breeding demography of Icelandic Whimbrels *Numenius phaeopus*. *PLoS One*. **10**, e0131395 (2015).

180. Å. Berg, Factors affecting nest-site choice and reproductive success of Curlews *Numenius arquata* on farmland. *Ibis* **134**, 44–51 (1992).

181. M. C. Grant *et al.*, Breeding success and causes of breeding failure of curlew *Numenius arquata* in Northern Ireland. *J. Appl. Ecol.* **36**, 59–74 (1999).

182. J. Valkama, D. Currie, E. Koprimäki, Differences in the intensity of nest predation in the curlew *Numenius arquata*: A consequence of land use and predator densities? *Écoscience* **6**, 497–504 (1999).

183. A. I. Antonov, Nesting ecology of the Eastern Curlew, *Numenius madagascariensis* (Linnaeus, 1766) in the South of the species range. *Russ. J. Ecol.* **41**, 345–346 (2010).

184. R. L. Redmond, D. A. Jenni, Population ecology of Long-billed Curlew (*Numenius americanus*) in Western Idaho. *Auk* **103**, 755–767 (1986).

185. A. G. Larionov, On biology of some species of shorebirds (*Tringa glareola*, *T. stagnatilis*, *Xenus cinereus*) of the Lena-Amga River junction [in Russian]. *Rus. Ornitol. Zhurnal* **24**, 3253–3260 (2015).

186. N. Christian, M. H. Hancock, A 25-year study of breeding Greenshanks territory occupancy, breeding success and the effects of new woodland. *Br. Birds* **102**, 203–210 (2009).

187. E. Pulliainen, L. Saari, Breeding biology of the Wood Sandpiper *Tringa glareola* in eastern Finnish Lapland. *Ornis Fenn.* **68**, 127–128 (1991).

188. E. I. Cuthbertson, G. T. Foggitt, M. A. Bell, A census od common sandpipers in the Sedbergh area, 1951. *Br. Birds* **45**, 171–175 (1952).

189. P. K. Holland, J. E. Robson, D. W. Yalden, The breeding biology of the Common Sandpiper *Actitis hypoleucos* in the Peak District. *Bird Study* **29**, 99–110 (1982).

190. R. Cialdini, G. Orians, Nesting studies of the Spotted Sandpiper. *Passeng. Pigeon* **6**, 79–81 (1944).

191. J. R. Miller, J. T. Miller, Nesting of the Spotted Sandpiper at Detroit, Michigan. *Auk* **65**, 558–567 (1948).

192. H. Hays, Polyandry in the Spotted Sandpiper. *Living Bird* **11**, 43–57 (1972).

193. L. W. Oring, M. L. Knudson, Monogamy and polyandry in the Spotted Sandpiper. *Living Bird* **11**, 59–73 (1972).

194. J. A. R. Alberico, J. M. Reed, L. W. Oring, Nesting near the Common Tern colony increases and decreases Spotted Sandpiper nest predation. *Auk* **108**, 904–910 (1991).

195. D. E. Perkins, P. A. Smith, G. H. Gilchrist, The breeding ecology of ruddy turnstones (*Arenaria interpres*) in the eastern Canadian Arctic. *Polar Rec.* **43**, 135–142 (2007).

196. P. S. Tomkovich, Breeding biology of the Great Knot, *Calidris tenuirostris* [in Russian with English summary]. *Bulleteň Mosk. obščestva Ispit. Prir. otděl Biol.* **106**, 13–22 (2001).

197. D. F. Parmelee, Breeding behaviour of the Sanderling in the Canadian High Arctic. *Living Bird* **1970**, 97–146 (1970).

198. J. Hansen, L. H. Hansen, N. M. Schmidt, Bird monitoring at Zackenberg, Northeast Greenland, 2007. *Bird Popul.* **10**, 56–67 (2010).

199. C. L. Gratto, F. Cooke, R. I. G. Morrison, Nesting success of yearling and older breeders in the Semipalmated Sandpiper, *Calidris pusilla*. *Can. J. Zool.* **61**, 1133–1137 (1983).

200. B. K. Sandercock, Incubation capacity and clutch size determination in two calidrine sandpipers: A test of the four-egg threshold. *Oecologia* **110**, 50–59 (1997).

201. R. T. Holmes, Ecological factors influencing the breeding season schedule of Western Sandpipers (*Calidris mauri*) in Subarctic Alaska. *Am. Midl. Nat.* **87**, 472–491 (1972).

202. V. V. Morozov, P. S. Tomkovich, "Breeding biology of Red-necked Stint (*Calidris ruficollis*) on eastern Chukotski Peninsula. [in Russian with English summary]" in *Ptitsy osvaivajemych tetritorij, Sbornik trudov Zoologičeskogo muzeja MGU*, O. I. Rossolimo, Ed. (1988), pp. 184–206.

203. A. Rönkä, K. Koivula, M. Ojanen, K. Pakanen, V-M., Pohjojsmäki, M., Rannikko, P. Rauhala, Increased nest predation in a declining and threatened Temminck's Stint *Calidris temminckii* population. *Ibis* **148**, 55–65 (2006).

204. R. L. Thompson *et al.*, Providing parental care entails variable mating opportunity costs for male Temminck's stints. *Behav. Ecol. Sociobiol.* **68**, 1261–1272 (2014).

205. L. McKinnon, J. Bêty, Effect of camera monitoring on survival rates of High-Arctis shorebird nests. *J. F. Ornithol.* **80**, 280–288 (2009).

206. M. L. Reid, R. D. Montgomerie, Seasonal patterns of nest defence by Baird's sandpipers. *Can. J. Zool.* **63**, 2207–2211 (1985).

207. M. Soloviev, V. Golovnyuk, A. Popovkina, "Breeding conditions and numbers of birds on Taimyr, 2009" (2010).

208. H. Schekkerman, L. G. Van Roomen, M. W. J. Underhill, Growth, behaviour of broods and weather-related variation in breeding productivity of Curlew Sandpipers *Calidris ferruginea*. *Ardea* **86**, 153–168 (1998).

209. E. P. Pierce, L. W. Oring, E. Røskaft, J. T. Lifjeld, Why don't female purple sandpipers perform brood care? A removal experiment. *Behav. Ecol.* **21**, 275–283 (2010).

210. P. E. Jönsson, Reproduction and survival in a declining population of the Southern Dunlin *Calidris alpina schinzii*. *Wader Study Gr. Bull.* **60** Suppl., 56–68 (1991).

211. C. M. Kagarise, Breeding biology of the Wilson's Phalarope in North Dakota. *Bird Band.* **50**, 12–22 (1979).

212. B. Walpole, E. Nol, V. Johnston, Breeding habitat preference and nest success of Red-necked Phalaropes on Niglintgak Island, Northwest Territories. *Can. J. Zool.* **68**, 1346–1357 (2008).

213. A. T. Gonçalves, "Monitoring Cream-coloured cursors *Cursorius cursor exsul* on the island of Maio, Cabo Verde" (University of Bath, 2014).

214. K. Seymour, P. Harding, C. Carmona-Isunza, T. Székely, "Breeding ecology of the endemic subspecies of cream-coloured courser, *Cursorius cursor exsul*, in Maio, Cape Verde" (University of Bath, 2015).

215. S. Hanane, J. Boukhriss, S. Selmi, Breeding ecology of Collared Pratincoles *Glareola pratincola* in two coastal habitats in northwest Morocco. *Bird Study* **57**, 236–243 (2010).

216. A. Brosset, Le cycle de reproduction de la Glareole *Glareola nuchalis*; ses determinants ecologiques et comportementaux [in French with English summary]. *Rev. D Ecol. Terre La Vie*. **33**, 95–108 (1979).

217. G. D. Williams, M. P. Coppinger, G. L. Maclean, Distribution and breeding of the Rock Pranticole on the Upper and Middle Zambezi river. *Ostrich* **60**, 55–64 (1989).

Acknowledgements: We thank to people who provided us with previously unpublished data or additional information in regards to published articles: A. I. Antonov, C. Carmona, E. Cepáková, R. A. Cerboncini, V. L. D'Amico, P. Donald, L. Eberhart-Phillips, I. Fisher, M. Hancock, G. D. Hevia, V. V. Golovnyuk, A. T. Gonçalves, S. Junker, C. Lishman, B. Katrínardóttir, M. C. López, R. H. Macedo, E. Makrigianni, M. S. Nadeem, E. Santos, K. Seymour, M. Sládeček, M. Soloviev, M. L. Stephens and V. Štorek. H. J. Hansen from Aarhus University is thanked for data from Zackenberg Northeast Greenland, and Aarhus University is thanked from providing logistical support at Zackenberg research Station. We thank to people who helped us with grey literature and useful contacts: T. Braga, S. Ferrari, P. Gonzales, N. Karniolova, J. Mlíkovský, R. Sheldon, O. Thorup, T. Sviridova, N. Warncock. We are in debt to S. Ancona, C. Carmona, L. Eberhart-Phillips, D. Frynta, D. Hořák, L. Kratochvíl, Vít Kubelka, C. Küpper, P. Linhart, J. Mlíkovský, A. Petrusek, J. Reif, M. Sládeček, D. Storch and K. Weidinger for advice or fruitful discussion. V.K. has a special thanks to S. Wilcox, Alexander library librarian in Oxford, to V. Dočekalová who helped with Shorebird Demographics Network data processing and to A. Tószögyová and L. Eberhart-Phillips for graphical advice and help. J. Reif, K. Weidinger, L. Eberhart-Phillips, D. Hořák and D. Storch helped us with their critical comments on the previous versions of the manuscript.

Funding: We appreciate the following funding sources to V.K. (Charles University Grant Agency, GAUK 927516), M.Š. (Ministry of Education, Youth and Sports of the Czech Republic, Kontakt II LH

13278), P.T. (MSU Zoological Museum, AAAA-A16-116021660077-3), T.S. (Royal Society Wolfson Merit Award, NKFIH-2558-1/2015 and ÉLVONAL-KKP 126949 of Hungarian government). **Author Contributions:** V.K., T.S. and M.Š. conceived the study; V.K. collected the data with the help from P.T., M.Š., Z.V. and T.S.; V.K., T.S., M.Š. and R.F. developed the methods; V.K. and R.F. analysed the data with input from T.S., Z.V. and M.Š.; V.K. wrote the paper with inputs from all co-authors. **Competing interests:** The authors declare that they have no competing interests. **Data and materials availability:** Climatic data are freely available at http://www.cru.uea.ac.uk/data. Sources of primary nest predation data are presented in table S1. Data and R codes are available at Dryad at: http://xxxxxxxx. – we will provide the Dyad number soon.

Supplementary materials:

Materials and Methods

Figures S1 to S3

Tables S1 to S8

References (*34–217*)

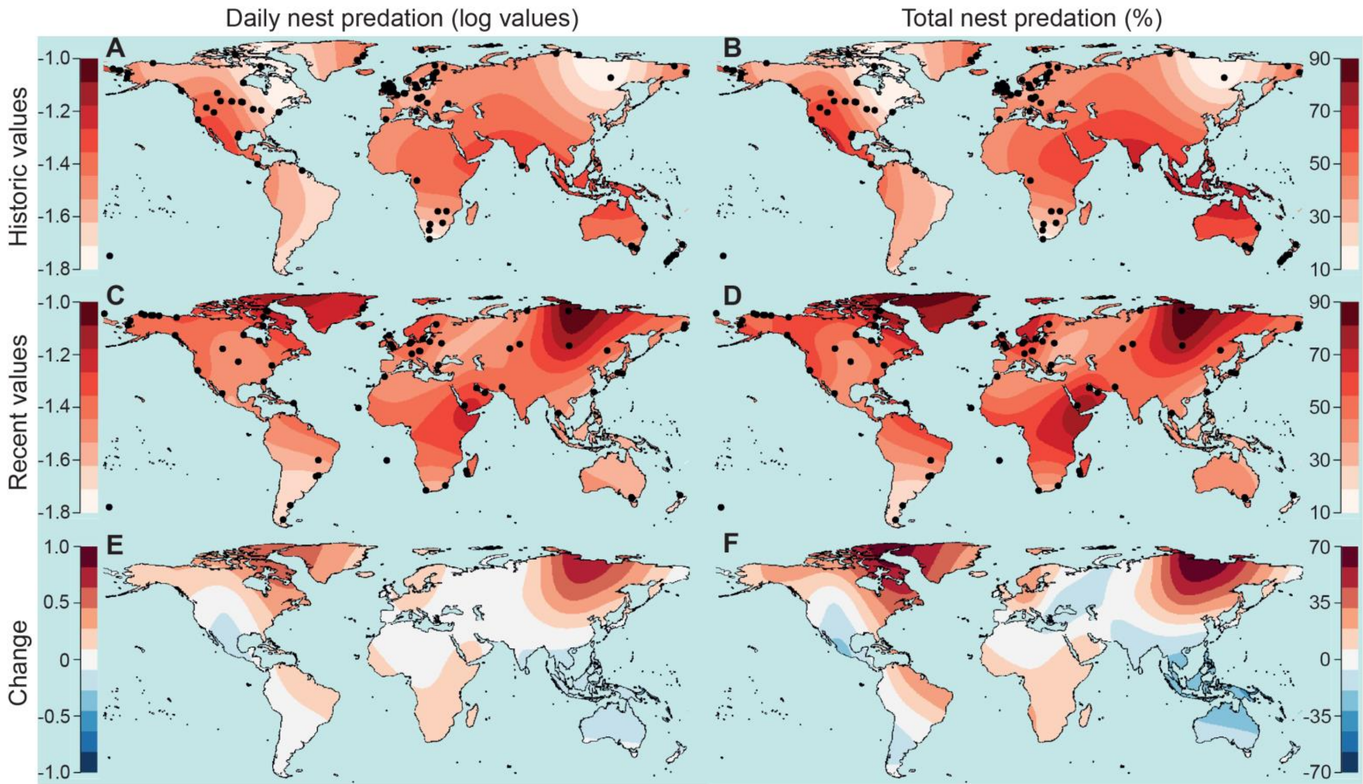

Fig. 1. Nest predation in shorebirds. (**A** and **B**) Historic rates of nest predation (1944–1999, 145 populations). (**C** and **D**) Recent rates of nest predation (2000–2016, 102 populations). **(E** and **F**) Changes between historic and recent nest predation rates. Dots show study locations. (A, C, and E) Daily nest predation (log transformed, see Materials and methods). (B, D and F) Total nest predation (percentage, see Materials and methods, and fig. S1 for geographic coverage).

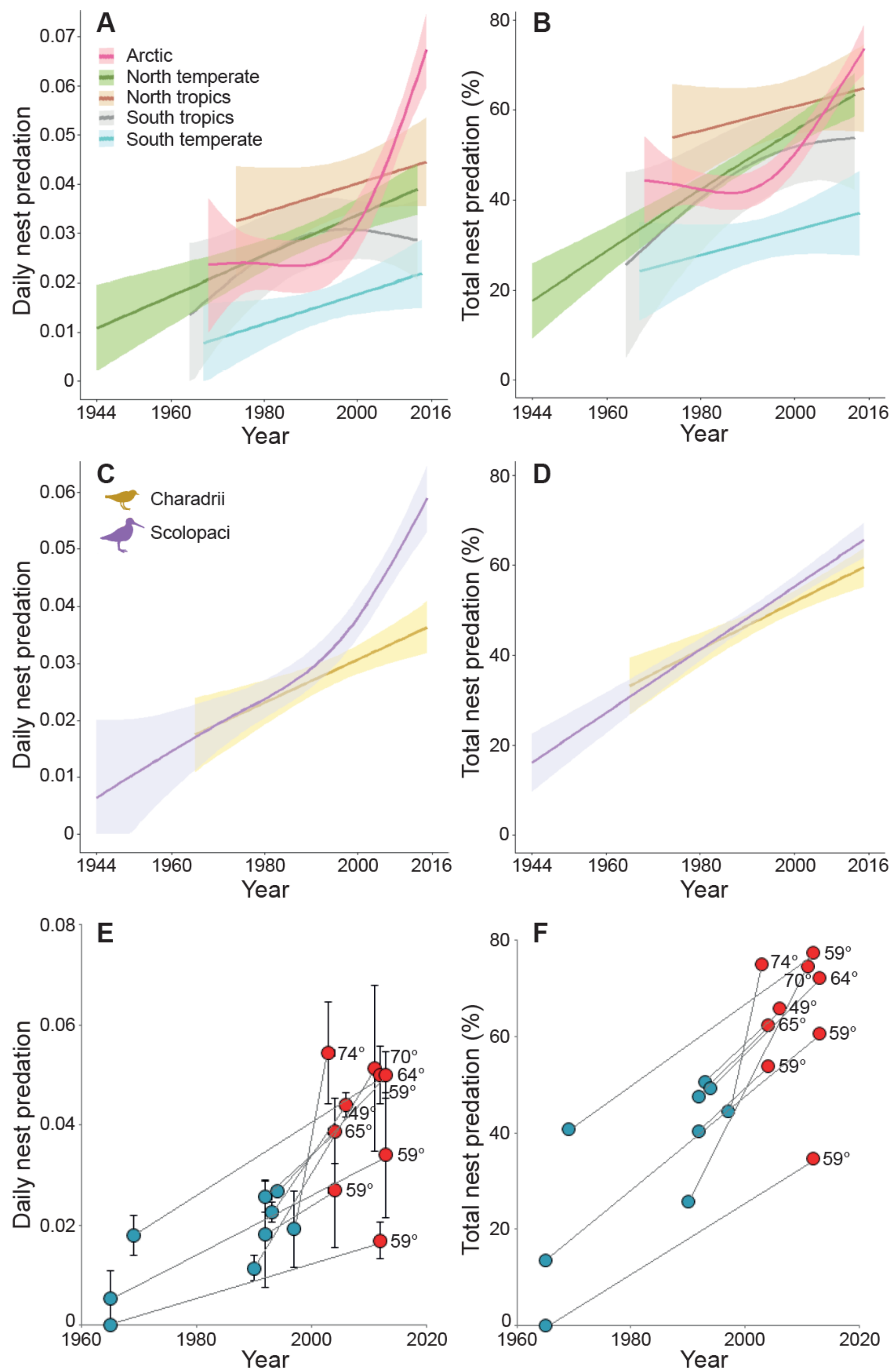

Fig. 2. Temporal changes in nest predation of shorebirds. (**A** and **B**) Nest predation rates for five latitudinal areas (Arctic n = 86 populations, North temperate n = 96 populations, North tropics n = 17 populations, South tropics n = 14 populations, South temperate n = 24 populations), see (*19*)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

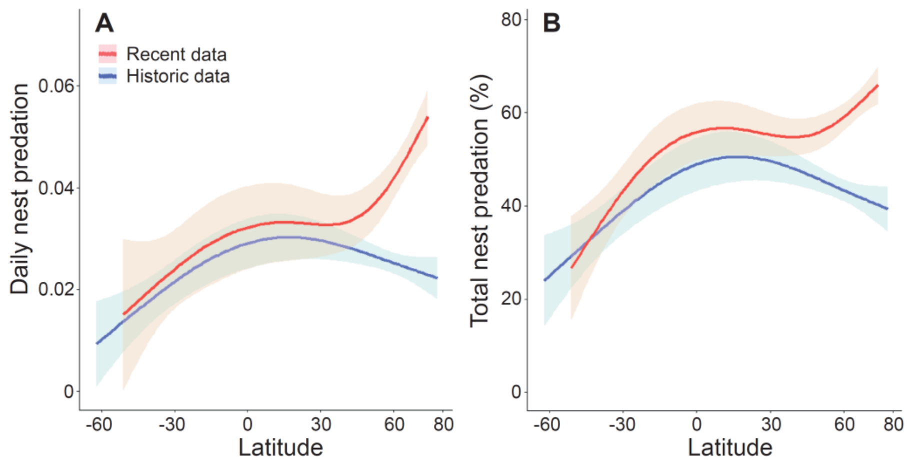

Fig. 3. Latitudinal gradient in historic versus recent nest predation of shorebirds. Daily (**A**) and total (**B**) nest predation rates (historic data 1944–1999, n = 145 populations; recent data 2000–2016, n = 102 populations), generalized additive model fits with 95% confidence intervals, see (*19*)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

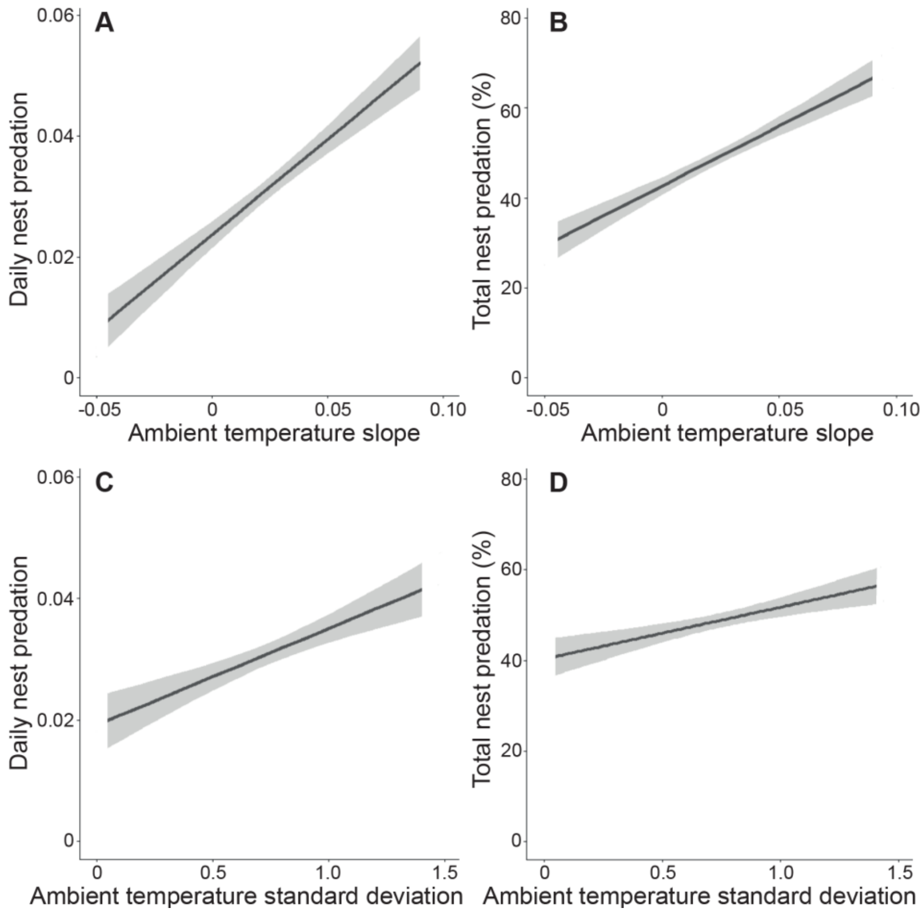

Fig. 4. Climate change predicts nest predation rates in shorebirds. (**A** and **B**) Relationship between daily (A) or total (B) nest predation rates and the slope of mean year temperatures. (**C** and **D**) Relationship between daily (C) or total (D) nest predation rates and the standard deviation 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 model descriptions.