PREDATION

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

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

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 single database of 38,191 nests from 237 populations, we found that shorebirds have experienced a worldwide increase in nest predation over the past 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.

Climate change is affecting organisms at a global scale in several ways (*1*–*4*), including directly altering demographic parameters such as adult survival (*5*) and reproduction (*1*) or through 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 used nest predation data from shorebirds, a globally distributed group of ground-nesting birds that exhibit high interspecific similarity in nest appearance to potential predators and are exceptionally well-studied in the wild, including ecology, behavior, 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 past 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 (Figs. 1 and 2, A and B; fig. S2, A and B; 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

[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.).

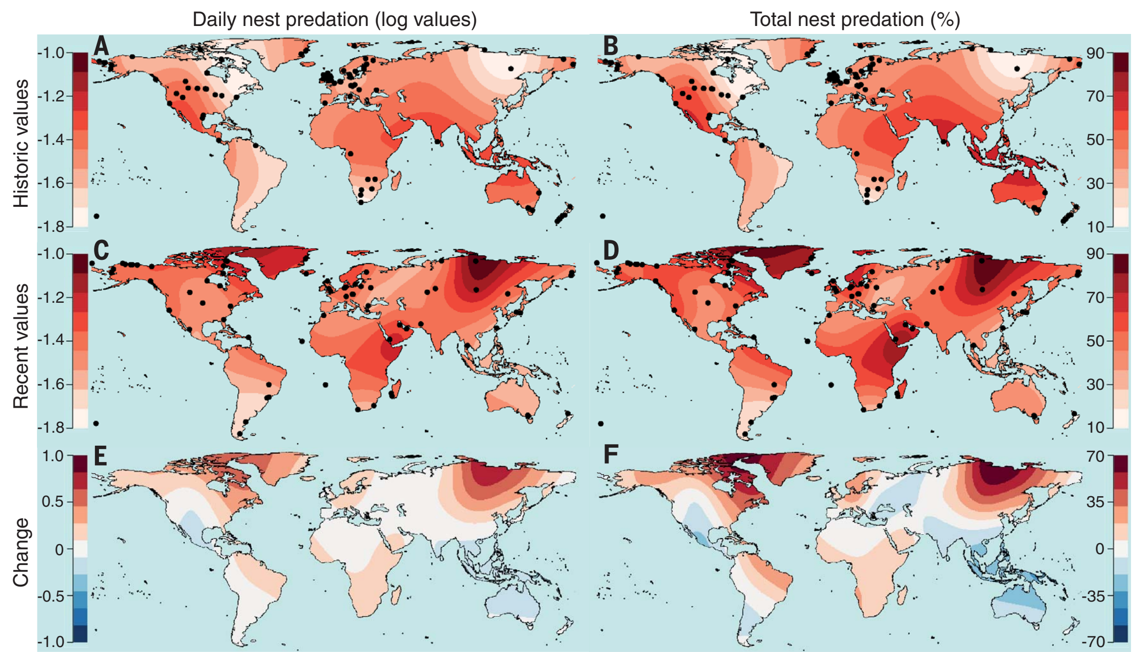

Fig. 1. Nest predation in shorebirds. (**A** and **B**) Historic rates of nest predation (1944–1999, 145 populations). (**C** and **D**) Recent rates of nest predation (2000–2016, 102 populations). (**E** and **F**) Changes between historic and recent nest predation rates. Dots show study locations.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

REFERENCES AND NOTES

1. B. R. Scheffers *et al*., *Science* **354**, aaf7671 (2016).
2. J. M. Tylianakis, R. K. Didham, J. Bascompte, D. A. Wardle, *Ecol. Lett.* **11**, 1351–1363 (2008).
3. C. Parmesan, *Annu. Rev. Ecol. Evol. Syst.* **37**, 637–669 (2006).
4. J. L. Blois, P. L. Zarnetske, M. C. Fitzpatrick, S. Finnegan, *Science* **341**, 499–504 (2013).
5. C. Barbraud, H. Weimerskirch, *Nature* **411**, 183–186 (2001).
6. O. Gilg *et al*., *Ann. N. Y. Acad. Sci.* **1249**, 166–190 (2012).
7. W. J. Sydeman, E. Poloczanska, T. E. Reed, S. A. Thompson, *Science* **350**, 772–777 (2015).
8. D. Lack, *Population Studies of Birds* (Oxford Univ. Press, 1966).
9. P. M. Bennett, I. P. F. Owens, *Evolutionary Ecology of Birds: Life Histories, Mating Systems, and Extinction* (Oxford Univ. Press, 2002).
10. M. A. Colwell, *Shorebird Ecology, Conservation, and Management* (Univ. of California Press, 2010).
11. C. D. G. Harley, *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, 2007).
13. T. Caro, *Antipredator Defences in Birds and Mammals* (Univ. of Chicago Press, 2005).
14. R. Ricklefs, *Smithson. Contrib. Zool.* **9**, 1–48 (1969).
15. A. F. Skutch, *Ornithol. Monogr.* **36**, 575–594 (1985).
16. T. M. Blackburn, P. Cassey, R. P. Duncan, K. L. Evans, K. J. Gaston, *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, 2018); 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, 2001).
21. B. A. DeGregorio, S. J. Chiavacci, T. J. Benson, J. H. Sperry, P. J. Weatherhead, *Bioscience* **66**, 655–665 (2016).
22. T. Piersma *et al*., *J. Appl. Ecol.* **53**, 479–490 (2016).
23. C. E. Studds *et al*., *Nat. Commun.* **8**, 14895 (2017).
24. M. Roodbergen, B. van der Werf, H. Hötker, *J. Ornithol.* **153**, 53–74 (2012).
25. M. Munro, *Nature* **541**, 16–20 (2017).
26. R. A. Ims, J.-A. Henden, S. T. Killengreen, *Trends Ecol. Evol.* **23**, 79–86 (2008).
27. K. L. Kausrud *et al*., *Nature* **456**, 93–97 (2008).
28. Y. Aharon-Rotman *et al*., *Oikos* **124**, 861–870 (2014).
29. T. Cornulier *et al*., *Science* **340**, 63–66 (2013).
30. S. M. Bierman *et al*., *Am. Nat.* **167**, 583–590 (2006).
31. L. McKinnon *et al*., *Science* **327**, 326–327 (2010).
32. M. A. Schlaepfer, M. C. Runge, P. W. Sherman, *Trends Ecol. Evol.* **17**, 474–480 (2002).
33. J. A. van Gils *et al*., *Science* **352**, 819–821 (2016).
34. V. Kubelka *et al.*, Data and R codes from: Global pattern of nest predation is disrupted by climate change in shorebirds. Dryad (2018); doi: 10.5061/dryad.45g90h4.

ACKNOWLEDGMENTS

We thank the 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 for providing logistical support at Zackenberg Research Station. We thank the people who helped us with gray literature and useful contacts: T. Braga, S. Ferrari, P. Gonzales, N. Karniolova, J. Mlíkovský, R. Sheldon, O. Thorup, T. Sviridova, and N. Warncock. We appreciate the suggestions of S. Ancona, C. Carmona, L. Eberhart-Phillips, D. Frynta, D. Horák, L. D. Hurst, L. Kratochvíl, Vít Kubelka, C. Küpper, P. Linhart, J. Mlíkovský, A. Petrusek, J. Reif, M. Sládecek, D. Storch, and K. Weidinger on various stages of this work. V.K. has special thanks to S. Wilcox, Alexander Library librarian in Oxford; V. Dočekalová, who helped with Shorebird Demographics Network data processing; and 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), and 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.P.F. developed the methods; V.K. and R.P.F. analyzed the data with input from T.S., Z.V., and M.Š.; and V.K. wrote the paper with inputs from all coauthors. **Competing interests:** The authors declare that they have no competing interests. **Data and materials availability:** Climatic data are freely available at 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 (*34*).

SUPPLEMENTARY MATERIALS

www.sciencemag.org/content/362/6415/680/suppl/DC1
Materials and Methods
Figs. S1 to S3
Tables S1 to S8
References (*35–218*)

12 April 2018; accepted 5 September 2018
10.1126/science.aat8695