Bewick's swans in a changing world

Species responses and the need for dynamic nature conservation

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References

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PE&RC Training and Education Statement

References

A

Abadi, F., Botha, A., Altwegg, R., 2013. Revisiting the Effect of Capture Heterogeneity on Survival Estimates in Capture-Mark-Recapture Studies: Does It Matter? PLoS One 8, 20–22.

Abadi, F., Gimenez, O., Arlettaz, R., Schaubb, M., 2010. An assessment of integrated population models: bias, accuracy, and violation of the assumption of independence. Ecology 91, 7–14.

ACIA, 2044. Impacts of a warming Arctic: Arctic Climate Impact Assessment. Cambridge University Press.

Adoram-Kershner, L., Bruce, T., Morris, C., Holser, R., Costa, D., Flikkema, P.G., Shafer, M.W., 2017. Modeling and testing solar power for globally migrating submarine systems. Ocean. IEEE. 1–9.

Alagador, D., Triviño, M., Cerdeira, J.O., Brás, R., Cabeza, M., Araújo, M.B., 2012. Linking like with like: Optimising connectivity between environmentally-similar habitats. Landsc. Ecol. 27, 291–301.

Aldred, J., 2014. Bewick's swan 50th "swanniversary" - in pictures. Guardian. 11-Feb-2014.

Alerstam, T., 1991. Bird flight and optimal migration. Trends Ecol. Evol. 6, 210–215.

Allan, B.M., Nimmo, D.G., Ierodiaconou, D., van der Wal, J., Koh, L.P., Ritchie, E.G., 2018. Futurecasting ecological research: the rise of technoecology. Ecosphere 9, e02163.

Altwegg, R., Jenkins, A., Abadi, F., 2014. Nestboxes and immigration drive the growth of an urban Peregrine Falcon *Falco peregrinus* population. Ibis. 156, 107–115.

Araújo, M.B., Cabeza, M., Thuiller, W., Hannah, L., Williams, P.H., 2004. Would climate change drive species out of reserves? An assessment of existing reserve-selection methods. Glob. Chang. Biol. 10, 1618–1626.

Arnaud, C.M., Becker, P.H., Dobson, F.S., Charmantier, A., 2013. Canalization of phenology in common terns: Genetic and phenotypic variations in spring arrival date. Behav. Ecol. 24, 683–690.

Arponen, A., 2012. Prioritizing species for conservation planning. Biodivers. Conserv. 21, 875–893.

Artemyev, A.V., Lapshin, N.V., Simonov, S.A., 2018. Stopovers of Swans (*Cygnus Cygnus* and *C. Bewickii*) (Anatidae, Aves) in the Agricultural Landscape of Southern Karelia During the Spring Migration. Povolzhskiy J. Ecol. 17, 127–135.

Augst, H., Hälterlein, B., Fabricius, K., 2019. From stopover to wintering : Bewick ' s Swans *Cygnus columbianus bewickii* in Schleswig-Holstein, northern Germany in winters 2016 / 2017 and 2017 / 2018. Wildfowl, Special Issue 5, 139–163.

B

Bairlein, F., 2016. Migratory birds under threat. Science. 354, 547–548.

Balmford, A., Bruner, A., Cooper, P., Costanza, R., Farber, S., Green, R.E., Jenkins, M., Jefferiss, P., Jessamy, V., Madden, J., Munro, K., Myers, N., Naeem, S., Paavola, J., Rayment, M., Rosendo, S., Roughgarden, J., Trumper, K., Turner, R.K., 2002. Ecology: Economic reasons for conserving wild nature. Science. 297, 950–953.

Bastmeijer, K., 2017. Natura 2000 en zoute en zilte natuur in Nederland – de ruimte voor dynamische en veerkrachtige ecosystemen. Natuurbeschermingsrecht 42, 42–44.

Batavia, C., Nelson, M.P., 2017. For goodness sake! What is intrinsic value and why should we care? Biol. Conserv. 209, 366–376.

Bates, D., Mächler, M., Bolker, B.M., Walker, S.C., 2015. Fitting linear mixed-effects models using lme4. J. Stat. Softw. 67.

Battley, P.F., 2006. Consistent annual schedules in a migratory shorebird. Biol. Lett. 2, 517–520.

Bauer, S., McNamara, J.M., Barta, Z., 2020. Environmental variability, reliability of information and the timing of migration. Proc. R. Soc. B 278, 20200622.

Bauer, S., Nolet, B.A., Giske, J., Chapman, J.W., Åkesson, S., Hedenström, A., Fryxell, J.M., 2011. Cues and decision rules in animal migration, In: Milner-Gulland, E.J., Fryxell, J.M., Sinclair, R.E. (Eds.), Animal Migration: A Synthesis. Oxford University Press, Oxford, pp. 68–87.

Bech, C., 1980. Body temperature, metabolic rate, and insulation in winter and summer acclimatized mute swans (*Cygnus olor*). J. Comp. Physiol. B 136, 61–66.

Beekman, J., Koffijberg, K., Wahl, J., Kowallik, C., Hall, C., Devos, K., Clausen, P., Hornman, M., Laubek, B., Luigujõe, L., Wieloch, M., Boland, H., Ŝvaẑas, S., Nilsson, L., Stipniece, A., Keller, V., Gaudard, C., Degen, A., Shimmings, P., Larsen, B.-H., Portolou, D., Langendoen, T., Wood, K., Rees, E.C., 2019. Long-term population trends and shifts in distribution of Bewick ' s Swans Cygnus columbianus bewickii wintering in northwest Europe. Wildfowl, Special Issue 5, 73–102.

Beekman, J.H., Nolet, B.A., Klaassen, M., 2002. Skipping swans: fuelling rates and wind conditions determine differential use of migratory stopover sites of Bewick's swans *Cygnus bewickii*. Ardea 90, 437–460.

Beekman, J.H., van Eerden, M.R., Dirksen, S., 1991. Bewick's swans *Cygnus columbianus bewickii* utilising the changing resource of Potamogeton pectinatus during autumn in the Netherlands. Wildfowl 1, 238–248.

Beekman, J.H., van Eerden, M.R., Mineyev, Y.N., Luigujõe, L., den Hollander, H.J., 1996. LANDSAT satellite images for detection of submerged macrophytes: in search of potential stop-over feeding sites for Bewick's Swans (*Cygnus columbianus bewickii*) along their migratory route. Game Wildl. 13, 421–450.

Bell, A.M., Hankison, S.J., Laskowski, K.L., 2009. The repeatability of behaviour: a meta-analysis. Anim. Behav. 77, 771–783.

Bellisario, B., Cerfolli, F., Nascetti, G., 2014. Climage effects on the distribution of wetland habitats and connectivity in networks of migratory waterbirds. Acta Oecologica 58, 5–11.

Beniston, M., 2014. European isotherms move northwards by up to 15 km year-1: Using climate analogues for awareness-raising. Int. J. Climatol. 34, 1838–1844.

Bentzen, R.L., Powell, A.N., 2012. Population dynamics of king eiders breeding in northern Alaska. J. Wildl. Manage. 76, 1011–1020.

Berthold, P., 1991. Genetic control of migratory behaviour in birds. Trends Ecol. Evol. 6, 254–257.

Besbeas, P., Freeman, S.N., Morgan, B.J.T., Catchpole, E.A., 2002. Integrating mark-recapture-recovery and census data to estimate animal abundance and demographic parameters. Biometrics 58, 540–547.

Besbeas, P., Morgan, B.J.T., 2014. Goodness-of-fit of integrated population models using calibrated simulation. Methods Ecol. Evol. 5, 1373–1382.

Bêty, J., Gauthier, G., Korpimäki, E., Giroux, J.F., 2002. Shared predators and indirect trophic interactions: Lemming cycles and arctic-nesting geese. J. Anim. Ecol. 71, 88–98.

Bêty, J., Giroux, J.F., Gauthier, G., 2004. Individual variation in timing of migration: Causes and reproductive consequences in greater snow geese (*Anser caerulescens atlanticus*). Behav. Ecol. Sociobiol. 57, 1–8.

Bijlsma, R.J., Jansen, A.J.M., Janssen, J.A.M., Maas, G.J., Schipper, P.C., 2016. Kansen voor meer natuurlijkheid in Natura 2000-gebieden, Alterra-rapport 2745.

Birdlife International, 2015. European Red List for Birds.

Bishop, C.M., Hawkes, L.A., Chua, B., Frappell, P.B., Milsom, W.K., Natsagdorj, T., Newman, S.H., Scott, G.R., Takekawa, J.Y., Wikelski, M., Butler, P.J., 2015. The roller coaster flight strategy of

bar-headed geese conserves energy during Himalayan migrations. Science. 347, 250–254.

Boden, T.A., Andres, R.J., Marland, G., 2017. Global, Regional and National Fossil-Fuel CO2 Emissions (1751-2014). *(V. 2017)*. United States: N. p., 2017. Web. doi:10.3334/CDIAC/00001_V2017.

Bom, R.A., Bouten, W., Piersma, T., Oosterbeek, K., van Gils, J.A., 2014. Optimizing acceleration-based ethograms: The use of variable-time versus fixed-time segmentation. Mov. Ecol. 2, 1–8.

Both, C., Bijlsma, R.G., Ouwehand, J., 2016. Repeatability in Spring Arrival Dates in Pied Flycatchers Varies Among Years and Sexes. Ardea 104, 3–21.

Both, C., Bijlsma, R.G., Visser, M.E., 2005. Climatic effects on timing of spring and breeding in a long-distance migrant, the pied flycatcher *Ficedula hypoleuca*. J. Avian Biol. 36, 368–373.

Bouten, W., Baaij, E.W., Shamoun-Baranes, J., Camphuysen, K.C.J., 2013. A flexible GPS tracking system for studying bird behaviour at multiple scales. J. Ornithol. 154, 571–580.

Boyce, M.S., Haridas, C. V., Lee, C.T., Boggs, C.L., Bruna, E.M., Coulson, T., Doak, D., Drake, J.M., Gaillard, J.M., Horvitz, C.C., Kalisz, S., Kendall, B.E., Knight, T., Mastrandrea, M., Menges, E.S., Morris, W.F., Pfister, C.A., Tuljapurkar, S.D., 2006. Demography in an increasingly variable world. Trends Ecol. Evol. 21, 141–148.

Bridge, E.S., Thorup, K., Bowlin, M.S., Chilson, P.B., Diehl, R.H., Fléron, R.W., Hartl, P., Kays, R., Kelly, J.F., Robinson, W.D., Wikelski, M., 2011. Technology on the Move: Recent and Forthcoming Innovations for Tracking Migratory Birds. Bioscience 61, 689–698.

Broell, F., Noda, T., Wright, S., Domenici, P., Steffensen, J.F., Auclair, J.-P., Taggart, C.T., 2013. Accelerometer tags: detecting and identifying activities in fish and the effect of sampling frequency. J. Exp. Biol. 216, 1255–1264.

Brooks, S.P., Gelman, A., 1998. General methods for monitoring convergence of iterative simulations? J. Comput. Graph. Stat. 7, 434–455.

Brooks, S.P., King, R., Morgan, B.J.T., 2004. Bayesian approach to combining animal abundance and demographic data. Anim. Biodivers. Conserv. 27, 515–529.

Brouwer, G.A., Tinbergen, L., 1939. De verspreiding der Kleine Zwanen, *Cygnus b. bewickii* Yarr., in de Zuiderzee, voor en na de verzoeting. Limosa 12, 1–18.

Brown, D.D., Kays, R., Wikelski, M., Wilson, R., Klimley, A.P., 2013. Observing the unwatchable through acceleration logging of animal behavior. Anim. Biotelemetry 1, 1–20.

Brown, D.D., LaPoint, S., Kays, R., Heidrich, W., Kümmeth, F., Wikelski, M., 2012. Accelerometer-informed GPS telemetry: Reducing the trade-off between resolution and longevity. Wildl. Soc. Bull. 36, 139–146.

Buckland, S.T., Magurran, A.E., Green, R.E., Fewster, R.M., 2005. Monitoring change in biodiversity through composite indices. Philos. Trans. R. Soc. B Biol. Sci. 360, 243–254.

Burnham, K.B., Anderson, D.R., 2002. Model selection and multimodel inference, 2nd ed. Springer, New York.

Butchart, S.H.M., Walpole, M., Collen, B., van Strien, A., Scharlemann, J.P.W., Almond, R.E.A., Bomhard, B., Brown, C., Bruno, J., Carpenter, K.E., Carr, G.M., Chanson, J., Chenery, A.M., Csirke, J., Davidson, N.C., Dentener, F., Foster, M., Galli, A., Galloway, J.N., Genovesi, P., Gregory, R., Hockings, M., Kapos, V., Lamarque, J.-F., Leverington, F., Loh, J., McGeoch, M.A., McRae, L., Minasyan, A., Morcillo, M.H., Oldfield, T.E.E., Pauly, D., Quader, S., Revenga, C., Sauer, J.R., Skolnik, B., Spear, D., Stanwell-Smith, D., Stuart, S.N., Symes, A., Tierney, M., Tyrrell, T.D., Vie, J.-C., Watson, R., 2010. Global Biodiversity: Indicators of recent declines. Science. 328, 1164–1168.

Buxbaum, P., 2018. China and Russia Collaborating on Arctic Port. Global Trade. 10-01-2018.

C

Cagnacci, F., Boitani, L., Powell, R.A., Boyce, M.S., 2010. Animal ecology meets GPS-based radiotelemetry: A perfect storm of opportunities and challenges. Philos. Trans. R. Soc. B Biol. Sci. 365, 2157–2162.

Cardillo, M., Mace, G.M., Jones, K.E., Bielby, J., Bininda-Emonds, O.R.P., Sechrest, W., Orme, C.D.L., Purvis, A., 2005. Evolution: Multiple causes of high extinction risk in large mammal species. Science. 309, 1239–1241.

Cardinale, B.J., Duffy, J.E., Gonzalez, A., Hooper, D.U., Perrings, C., Venail, P., Narwani, A., MacE, G.M., Tilman, D., Wardle, D.A., Kinzig, A.P., Daily, G.C., Loreau, M., Grace, J.B., Larigauderie, A., Srivastava, D.S., Naeem, S., 2012. Biodiversity loss and its impact on humanity. Nature 486, 59–67.

Carroll, G., Everett, J.D., Harcourt, R., Slip, D., Jonsen, I., 2016. High sea surface temperatures driven by a strengthening current reduce foraging success by penguins. Sci. Rep. 6, 1–13.

Caswell, H., 2007. Sensitivity analysis of transient population dynamics. Ecol. Lett. 10, 1–15.

Caswell, H., 2000. Prospective and retrospective perturbation analyses: Their roles in conservation biology. Ecology 81, 619–627.

CBD, 2020a. Strategic plan for Biodiversity 2011-2020. Convention on Biological Biodiversity. https://www.cbd.int/sp/ (accessed 4.17.20).

CBD, 2020b. Convention on Biological Diversity. https://www.cbd.int/ (accessed 4.17.20).

CBD, 1992. Convention on Biological Diversity, convention text, preamble.

Ceballos, G., Garcia, A., Ehrlich, P.R., 2010. The sixth extinction crisis: Loss of animal populations and species. J. Cosmol. 8, 31.

Chan, K.M.A., Shaw, M.R., Cameron, D.R., Underwood, E.C., Daily, G.C., 2006. Conservation planning for ecosystem services. PLoS Biol. 4, 2138–2152.

Charmantier, A., Gienapp, P., 2014. Climate change and timing of avian breeding and migration: Evolutionary versus plastic changes. Evol. Appl. 7, 15–28.

Charrassin, J.-B., Hindell, M., Rintoul, S.R., Roquet, F., Sokolov, S., Biuw, M., Costa, D., Boehme, L., Lovell, P., Coleman, R., Timmermann, R., Meijers, A., Meredith, M., Park, Y.-H., Bailleul, F., Goebel, M., Tremblay, Y., Bost, C.-A., McMahon, C.R., Field, I.C., Fedak, M.A., Guinet, C., 2008. Southern Ocean frontal structure and sea-ice formation rates revealed by elephant seals. PNAS 105, 11634–11639.

Chen, I.-C., Hill, J.K., Ohlemuller, R., Roy, D.B., Thomas, C.D., 2011. Rapid Range Shifts of Species Associated with High Levels of Climate Warming. Science. 333, 1024–1026.

Chicco, D., 2017. Ten quick tips for machine learning in computational biology. BioData Min. 10, 1–17.

Chimienti, M., Cornulier, T., Owen, E., Bolton, M., Davies, I.M., Travis, J.M.J., Scott, B.E., 2016. The use of an unsupervised learning approach for characterizing latent behaviors in accelerometer data. Ecol. Evol. 6, 727–741.

Choquet, R., Lebreton, J.D., Gimenez, O., Reboulet, A.M., Pradel, R., 2009. U-CARE: Utilities for performing goodness of fit tests and manipulating CApture-REcapture data. Ecography. 32, 1071–1074.

Chovan, A., Kazannik, V., 2015. The present status of bewick's swans *Cygnus columbianus bewickii* in Ukraine. Wildfowl 65, 143–153.

Clausen, K.K., Madsen, J., Cottaar, F., Kuijken, E., Verscheure, C., 2018a. Highly dynamic wintering strategies in migratory geese: Coping with environmental change. Glob. Chang. Biol. 24, 3214–3225.

Clausen, K.K., Madsen, J., Nolet, B.A., Haugaard, L., 2018b. Maize stubble as foraging habitat for wintering geese and swans in northern Europe. Agric. Ecosyst. Environ. 259, 72–76. https://doi.org/10.1016/j.agee.2018.03.002

Clausen, P., 1997. Dark-bellied brent geese *Branta b. bernicla* use of the White Sea: a progress report, in: Nugteren, J.V. (Ed.), Dark-Bellied Brent Goose Branta Bernicla Bernicla Flyway Management Plan. Vol. C-17. pp. 174–183.

Conklin, J.R., Battley, P.F., Potter, M.A., 2013. Absolute Consistency: Individual versus Population Variation in Annual-Cycle Schedules of a Long-Distance Migrant Bird. PLoS One 8.

Cooch, E., Rockwell, R.F., Brault, S., 2001. Retrospective analysis of demographic responses to environmental change: A lesser snow goose example. Ecol. Monogr. 71, 377–400.

Cooke, S.J., Hinch, S.G., Wikelski, M., Andrews, R.D., Kuchel, L.J., Wolcott, T.G., Butler, P.J., 2004. Biotelemetry: a mechanistic approach to ecology. Trends Ecol. Evol. 19, 334–343.

Cooper, N.W., Murphy, M.T., Redmond, L.J., 2009. Age- and sex-dependent spring arrival dates of Eastern Kingbirds. J. F. Ornithol. 80, 35–41.

Cornes, R.C., van der Schrier, G., van den Besselaar, E.J.M., Jones, P.D., 2018. An Ensemble Version of the E-OBS Temperature and Precipitation Data Sets. J. Geophys. Res. Atmos. 123, 9391–9409.

Cotton, P.A., 2003. Avian migration phenology and global climate change. Proc. Natl. Acad. Sci. 100, 12219–12222.

Coumou, D., Rahmstorf, S., 2012. A decade of weather extremes. Nat. Clim. Chang. 2, 491–496.

Cox, S.L., Orgeret, F., Gesta, M., Rodde, C., Heizer, I., Weimerskirch, H., Guinet, C., 2018. Processing of acceleration and dive data on-board satellite relay tags to investigate diving and foraging behaviour in free-ranging marine predators. Methods Ecol. Evol. 9, 64–77.

D

de Cock, J., Li, Z., Manohara, M., Aaron, A., 2016. Complexity-based consistent-quality encoding in the cloud. Image Process. (ICIP), 2016 IEEE Int. Conf. 1484–1488.

de Klemm, C., Shine, C., 1993. Biological Diversity Conservation and the Law.

de Valpine, P., Hastings, A., 2002. Fitting population models incorporating process noise and observation error. Ecol. Monogr. 72, 57–76.

de Weerd, N., van Langevelde, F., van Oeveren, H., Nolet, B.A., Kölzsch, A., Prins, H.H.T., de Boer, W.F., 2015. Deriving animal behaviour from high-frequency GPS: Tracking cows in open and forested habitat. PLoS One 10, 1–17.

Dean, B., Freeman, R., Kirk, H., Leonard, K., Phillips, R.A., Perrins, C.M., Guilford, T., 2012. Behavioural mapping of a pelagic seabird: combining multiple sensors and a hidden Markov model reveals the distribution of at-sea behaviour. J. R. Soc. Interface. 10, 20120570.

Delgado-Baquerizo, M., Reich, P.B., Trivedi, C., Eldridge, D.J., Abades, S., Alfaro, F.D., Bastida, F., Berhe, A.A., Cutler, N.A., Gallardo, A., García-Velázquez, L., Hart, S.C., Hayes, P.E., He, J.-Z., Hseu, Z.-Y., Hu, H.-W., Kirchmair, M., Neuhauser, S., Pérez, C.A., Reed, S.C., Santos, F., Sullivan, B.W., Trivedi, P., Wang, J.-T., Weber-Grullon, L., Williams, M.A., Singh, B.K., 2020. Multiple elements of soil biodiversity drive ecosystem functions across biomes. Nat. Ecol. Evol. 4, 210–220.

Diamond, J., 2005. Collapse: how societies choose to fail or succeed. Penguin, New York.

Diehl, R.H., 2019. Timing of migration shifts en masse. Nat. Clim. Chang. 10: 18-19.

Dirksen, S., Beekman, J.H., 1989. Population size, breeding success and distribution of Bewick's Swans *Cygnus columbianus bewickii* wintering in Europe in 1986-87. Wildfowl 120–124.

Dirksen, S., Beekman, J.H., Slagboom, T.H., 1991. Bewick's swans *Cygnus columbianus bewickii* in the Netherlands: numbers, distribution and food choice during the wintering season. Wildfowl, Special Issue 1, 228–237.

Dokter, A.M., Fokkema, W., Ebbinge, B.S., Olff, H., van der Jeugd, H.P., Nolet, B.A., 2018.

Agricultural pastures challenge the attractiveness of natural saltmarsh for a migratory goose. J. Appl. Ecol. 55, 2707–2718.

Donald, P.F., Sanderson, F.J., Burfield, I.J., Bierman, S.M., Gregory, R.D., Waliczky, Z., 2007. International conservation policy delivers benefits for birds in Europe. Science. 317, 810–813.

Dunn, P.O., Winkler, D.W., 2010. Effects of climate change on timing of breeding and reproductive success in birds, in: edited by Anders Pape Møller, Wolfgang Fiedler, P.B. (Ed.), Effects of Climate Change on Birds. Oxford University Press, Oxford. pp. 113–128.

Duriez, O., Bauer, S., Destin, A., Madsen, J., Nolet, B. a., Stillman, R. a., Klaassen, M., 2009. What decision rules might pink-footed geese use to depart on migration? An individual-based model. Behav. Ecol. 20, 560–569.

Duriez, O., Kato, A., Tromp, C., Dell'Omo, G., Vyssotski, A.L., Sarrazin, F., Ropert-Coudert, Y., 2014. How cheap is soaring flight in raptors? A preliminary investigation in freely-flying vultures. PLoS One 9, e84887

E

Elmberg, J., Hessel, R., Fox, A.D., Dalby, L., 2014. Interpreting seasonal range shifts in migratory birds: A critical assessment of "short-stopping" and a suggested terminology. J. Ornithol. 155, 571–579.

Elsner, J.B., Kossin, J.P., Jagger, T.H., 2008. The increasing intensity of the strongest tropical cyclones. Nature 455, 92–95.

European Environment Agency, 2015. European Environment Agency, State of nature in the EU. Results from reporting under the nature directives 2007–2012.

European Commission, 2020. Natura 2000. ec.europa.eu/environment/nature/natura2000/index_en.htm (accessed 5.11.20).

European Commission, 2016. Fitness check of the EU Nature Legislation (Birds and Habitats Directives). Brussels.

European Commission, 2009. Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the conservation of wild birds.

European Commission, 2000. Beheer van "Natura 2000"-gebieden - De bepalingen van artikel 6 van de habitatrichtlijn (Richtlijn 92/43/EEG). Bureau voor officiele publicaties der Europese Gemeenschappen, Luxemburg.

European Commission, 1992. Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora.

European Commission, 1979. Council Directive 79/409/EEC of 2 April 1979 on the conservation of wild birds.

European Environment Agency, 2019. Natura 2000 Barometer. https://www.eea.europa.eu/data-and-maps/dashboards/natura-2000-barometer#tab-based-on-data (accessed 4.17.20).

Evans, D., 2012. Building the European union's natura 2000 network. Nat. Conserv. 1, 11.

Evans, D., Arvela, M., 2011. Assessment and reporting under Article 17 of the Habitats Directive - Explanatory notes and guidelines for the period 2007-2012.

Evans, K., Lea, M.-A., Patterson, T.A., 2013. Recent advances in bio-logging science: Technologies and methods for understanding animal behaviour and physiology and their environments. Deep Sea Res. Part II Top. Stud. Oceanogr. 88–89, 1–6.

Evans, M.E., 1982. Movements of Bewick's swan *Cygnus columbianus bewickii* marked at slimbridge, England from 1960 to 1979. Ardea 70, 59–76.

Evans, M.E., 1979. Aspects of the life cycle of the Bewick's swan, based on recognition of individuals

at a wintering site. Bird Study 26, 149–162.

F

Fedak, M., 2004. Marine animals as platforms for oceanographic sampling: "win/win" situation for biology and operational oceanography. Mem. Natl. Inst. Polar Res. 133–147.

Feranec, J., Soukup, T., Hazeu, G., Jaffrain, G., 2016. European landscape dynamics: CORINE land cover data. CRC Press.

Fijn, R.C., Krijgsveld, K.L., Tijsen, W., Prinsen, H.A.M., Dirksen, S., 2012. Habitat use, disturbance and collision risks for Bewick's Swans *Cygnus columbianus bewickii* wintering near a wind farm in the Netherlands. Wildfowl 62, 97–116.

Fisher, B., Turner, R.K., Morling, P., 2009. Defining and classifying ecosystem services for decision making. Ecol. Econ. 68, 643–653.

Flack, A., Nagy, M., Fiedler, W., Couzin, I.D., Wikelski, M., 2018. From local collective behavior to global migratory patterns in white stork. Science. 360, 911–914.

Foppen, R., Roomen, M. Van, Noordhuis, R., 2016. De ecologische haalbaarheid van de Natura 2000 instandhoudingsdoelen voor vogels. Sovon-rapport 2016/51. Sovon Vogelonderzoek Nederland, Nijmegen.

Fox, A.D., Dalby, L., Christensen, T.K., Nagy, S., Balsby, T.J.S., Crowe, O., Clausen, P., Deceuninck, B., Devos, K., Holt, C.A., Hornman M., Keller, V., Langendoen, T., Lehikoinen, A., Lorentsen, S.H., Molina, B., Nilsson, L., Stïpniece, A., Svenning, J.C., Wahl, J., 2016. Seeking explanations for recent changes in abundance of wintering Eurasian Wigeon (*Anas penelope*) in northwest Europe. Ornis Fenn. 93, 12–25.

Fox, A.D., Ebbinge, B.S., Mitchell, C., Heinicke, T., Aarvak, T., Colhoun, K., Clausen, P., Dereliev, S., Faragö, S., Koffijberg, K., Kruckenberg, H., Loonen, M.J.J.E., Madsen, J., Mooij, J., Musil, P., Nilsson, L., Pihl, S., van der Jeugd, H., 2010. Current estimates of goose population sizes in western Europe, a gap analysis and an assessment of trends. Ornis Svecica 20, 115–127.

Fox, A.D., Madsen, J., Boyd, H., Kuijken, E., Norriss, D.W., Tombre, I.M., Stroud, D.A., 2005. Effects of agricultural change on abundance, fitness components and distribution of two arctic-nesting goose populations. Glob. Chang. Biol. 11, 881–893.

Fridrich, J., Goljan, M., Du, R., 2015. Lossless data embedding for all image formats. Secur. Watermarking Multimed. Contents IV 4675, 572–584.

G

Gaillard, J., Festa-Bianchet, M., Yoccoz, N.G., 1998. Components and Population Dynamics of Large Herbivores. Trends Ecol. Evol. 13, 58–63.

Gális, M., Naďo, L., Hapl, E., Šmídt, J., Deutschová, L., Chavko, J., 2019. Comprehensive analysis of bird mortality along power distribution lines in Slovakia. Raptor J. 13, 1–25.

Gautier, D.L., Bird, K.J., Charpentier, R.R., Grantz, A., Houseknecht, D.W., Klett, T.R., Moore, T.E., Pitman, J.K., Schenk, C.J., Schuenemeyer, J.H., Sørensen, K., Tennyson, M.E., Valin, Z.C., Wandrey, C.J., 2009. Assessment of Undiscovered Oil and Gas in the Arctic. Science. 324, 1175–1179.

Gienapp, P., Leimu, R., Merilä, J., 2007. Responses to climate change in avian migration time - Microevolution versus phenotypic plasticity. Clim. Res. 35, 25–35.

Gienapp, P., Teplitsky, C., Alho, J.S., Mills, J.A., Merilä, J., 2008. Climate change and evolution: Disentangling environmental and genetic responses. Mol. Ecol. 17, 167–178.

Gill, J.A., Alves, J.A., Gunnarsson, T.G., 2019. Mechanisms driving phenological and range change in migratory species. Philos. Trans. R. Soc. B Biol. Sci. 374, 20180047.

Gill, J.A., Alves, J.A., Sutherland, W.J., Appleton, G.F., Potts, P.M., Gunnarsson, T.G., 2014. Why is timing of bird migration advancing when individuals are not? Proc. R. Soc. B Biol. Sci. 281,

20132161–20132161.

Gill, R.E., Tibbitts, T.L., Douglas, D.C., Handel, C.M., Mulcahy, D.M., Gottschalck, J.C., Warnock, N., McCaffery, B.J., Battley, P.F., Piersma, T., 2009. Extreme endurance flights by landbirds crossing the Pacific Ocean: Ecological corridor rather than barrier? Proc. R. Soc. B Biol. Sci. 276, 447–457.

Gilroy, J.J., Gill, J.A., Butchart, S.H.M., Jones, V.R., Franco, A.M.A., 2016. Migratory diversity predicts population declines in birds. Ecol. Lett. 19, 308–317.

Gordo, O., Sanz, J.J., 2006. Climate change and bird phenology: A long-term study in the Iberian Peninsula. Glob. Chang. Biol. 12, 1993–2004.

Green, M., Alerstam, T., Clausen, P., Drent, R., Ebbinge, B.S., 2002. Site use by dark-bellied brent geese *Branta bernicla bernicla* on the Russian tundra as recorded by satellite telemetry : implications for East Atlantic Flyway conservation. Wildlife Biol. 8, 229–239.

Griffin, L., Rees, E.C., Hughes, B., 2016. Satellite tracking Bewick's swans migration in relation to offshore and onshore wind farm sites. WWT Final report to the Department of Energy and Climate change.

Gyimesi, A., de Vries, P.P., de Boer, T., Nolet, B.A., 2011. Reduced tuber banks of fennel pondweed due to summer grazing by waterfowl. Aquat. Bot. 94, 24–28.

Gyimesi, A., Lith, B. van, Nolet, B.A., 2012a. Commensal Foraging with Bewick's Swans *Cygnus bewickii* Doubles Instantaneous Intake Rate of Common Pochards *Aythya ferina*. Ardea 100, 55–62.

Gyimesi, A., Stillman, R.A., Nolet, B.A., 2010. Cryptic interference competition in swans foraging on cryptic prey. Anim. Behav. 80, 791–797.

Gyimesi, A., Varghese, S., de Leeuw, J., Nolet, B.A., 2012b. Net energy intake rate as a common currency to explain swan spatial distribution in a shallow lake. Wetlands 32, 119–127.

H

Hannah, L., 2008. Protected areas and climate change. Ann. N. Y. Acad. Sci. 1134, 201–212.

Hannah, L., Midgley, G., Hughes, G., Bomhard, B., 2005. The View from the Cape: Extinction Risk, Protected Areas, and Climate Change. Bioscience 55, 231.

Hardin, G., 1968. The tragedy of the commons. Science. 162, 1243–1248.

Harel, R., Horvitz, N., Nathan, R., 2016. Adult vultures outperform juveniles in challenging thermal soaring conditions. Sci. Rep. 6, 27865.

Harris, G., Thirgood, S., Hopcraft, J.G.C., Cromsigt, J.P.G.M., Berger, J., 2009. Global decline in aggregated migrations of large terrestrial mammals. Endanger. Species Res. 7, 55–76.

Hasselquist, D., Montràs-Janer, T., Tarka, M., Hansson, B., 2017. Individual consistency of long-distance migration in a songbird: significant repeatability of autumn route, stopovers and wintering sites but not in timing of migration. J. Avian Biol. 48, 91–102.

Hayward, M.W., Kerley, G.I.H., 2009. Fencing for conservation: Restriction of evolutionary potential or a riposte to threatening processes? Biol. Conserv. 142, 1–13.

Hedenstrom, A., Alerstam, T., 1998. How Fast Can Birds Migrate? J. Avian Biol. 29, 424–432.

Hedenström, A., Alerstam, T., 1997. Optimum fuel loads in migratory birds: Distinguishing between time and energy minimization. J. Theor. Biol. 189, 227–234.

Hedenström, A., Barta, Z., Helm, B., Houston, A.I., McNamara, J.M., Jonzén, N., 2007. Migration speed and scheduling of annual events by migrating birds in relation to climate change. Clim. Res. 35, 79–91.

Hedenström, A., Norevik, G., Warfvinge, K., Andersson, A., Bäckman, J., Åkesson, S., 2016. Annual 10-Month Aerial Life Phase in the Common Swift *Apus apus*. Curr. Biol. 26, 3066–3070.

Heerah, K., Cox, S.L., Blevin, P., Guinet, C., Charrassin, J.-B., 2019. Validation of Dive Foraging Indices Using Archived and Transmitted Acceleration Data: The Case of the Weddell Seal. Front. Ecol. Evol. 7, 1–15.

Helm, B., van Doren, B.M., Hoffmann, D., Hoffman, U., 2019. Evolutionary response to climate change in migratory pied flycatchers. Curr. Biol. 29, 3714–3719.

Hickling, R., Roy, D.B., Hill, J.K., Fox, R., Thomas, C.D., 2006. The distributions of a wide range of taxonomic groups are expanding polewards. Glob. Chang. Biol. 12, 450–455.

Hitch, A.T., Leberg, P.L., 2007. Breeding distributions of North American bird species moving north as a result of climate change. Conserv. Biol. 21, 534–539. h

Hoekman, S.T., Mills, L.S., Howerter, D.W., Devries, J.H., Ball, J., 2002. Sensitivity Analyses of the Life Cycle of Midcontinent Mallards. J. Wildl. Manage. 66, 883–900.

Hoffmann, A.A., Sgró, C.M., 2011. Climate change and evolutionary adaptation. Nature 470, 479–485.

Hornman, M., Hustings, F., Koffijberg, K., van Winden, E., van Els, P., Kleefstra, R., Zwanenwerkgroep, S.G. en, Soldaat, L., 2020. Watervogels in Nederland in 2017/2018.

Horvitz, C., Schemske, D.W., Caswell, H., 1997. The relative “importance” of life-history stages to population growth: prospective and retrospective analyses, in: Tuljapurkar, S., Caswell, H. (Eds.), Structured-Population Models in Marine, Terrestrial and Freshwater Systems. Chapman and Hall, New York, NY, pp. 247–271.

Hoye, B.J., Hahn, S., Nolet, B.A., Klaassen, M., 2012. Habitat use throughout migration: Linking individual consistency, prior breeding success and future breeding potential. J. Anim. Ecol. 81, 657–666.

Hoye, B.J., Munster, V., Huig, N., de Vries, P.P., Oosterbeek, K., Tijsen, W., Klaassen, M., Fouchier, R.A.M., van Gils, J.A., 2016. Hampered performance of migratory swans: intra- and inter-seasonal effects of avian influenza virus. Integr. Comp. Biol. 56, 317–329.

Huntley, B., Green, R.E., Collingham, Y.C., Willis, S.G., 2007. A Climatic Atlas of European breeding birds. Lynx Editions, Barcelona.

Hüppop, O., Hüppop, K., 2003. North Atlantic Oscillation and timing of spring migration in birds. Proc. R. Soc. B Biol. Sci. 270, 233–240.

Hussey, N.E., Kessel, S.T., Aarestrup, K., Cooke, S.J., Cowley, P.D., Fisk, A.T., Harcourt, R.G., Holland, K.N., Iverson, S.J., Kocik, J.F., Flemming, J.E.M., Whoriskey, F.G., 2015. Aquatic animal telemetry: A panoramic window into the underwater world. Science. 348, 1255642.

Hutton, J., Adams, W.M., Murombedzi, J.C., 2005. Back to barriers? Changing narratives in biodiversity conservation. Forum Dev. Stud. 32, 341–370.

I

IPBES, 2019. Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. IPBES Secretariat, Bonn, Germany.

IPCC, 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

IUCN, 2020. The IUCN Red List of Threatened Species. version 2020-1. https://www.iucnredlist.org (accessed 3.19.20).

IUCN UNEP-WCMC, 2019. The World Database on Protected Areas (WDPA) Cambridge (UK): UNEP World Conservation Monitoring Centre. January 2019 release. www.protectedplanet.net

Iwamura, T., Fuller, R.A., Possingham, H.P., 2014. Optimal Management of a Multispecies Shorebird Flyway under Sea-Level Rise. Conserv. Biol. 28, 1710–1720.

J

Jacoby, D.M.P., Freeman, R., 2016. Emerging Network-Based Tools in Movement Ecology. Trends Ecol. Evol. 31, 301–314.

Jankowiak, Ł., Skórka, P., Ławicki, Ł., Wylegała, P., Polakowski, M., Wuczyński, A., Tryjanowski, P., 2015. Patterns of occurrence and abundance of roosting geese: the role of spatial scale for site selection and consequences for conservation. Ecol. Res. 30, 833–842.

Janoska, Z., 2014. Trajectory similarity calculation using Dynamic Time Warping. https://rpubs.com/janoskaz/10351 (accessed 4.17.20).

Jeppesen, E., Sondergaard, M., Sondergaard, M., Christofferson, K., (eds), 1998. The structuring role of submerged macrophytes in lakes. Springer, New York, NY.

Johnson, F.A., Zimmerman, G.S., Jensen, G.H., Clausen, K.K., Frederiksen, M., Madsen, J., 2020. Using integrated population models for insights into monitoring programs: An application using pink-footed geese. Ecol. Modell. 415.

Jongejans, E., de Kroon, H., Tuljapurkar, S., Shea, K., 2010. Plant populations track rather than buffer climate fluctuations. Ecol. Lett. 13, 736–743.

Jonker, R.M., Kuiper, M.W., Snijders, L., Van Wieren, S.E., Ydenberg, R.C., Prins, H.H.T., 2011. Divergence in timing of parental care and migration in barnacle geese. Behav. Ecol. 22, 326–331.

Jónsson, J.E., Afton, A.D., 2015. Are Wintering Areas Shifting North? Learning from Lesser Snow Geese Banded in Southwest Louisiana. Southeast. Nat. 14, 293–307.

Jonzén, N., Lindén, A., Ergon, T., Knudsen, E., Vik, J.O., Rubolini, D., Piacentini, D., Brinch, C., Spina, F., Karlsson, L., Stervander, M., Andersson, A., Waldenström, J., Lehikoinen, A., Edvardsen, E., Solvang, R., Stenseth, N.C., 2006. Rapid advance of spring arrival dates in long-distance migratory birds. Science. 312, 1959–1961.

K

Kalnay, E., Kanamitsu, M., Kistler, R., Collins, W., Deaven, D., Gandin, L., Iredell, M., Saha, S., White, G., Woollen, J., Zhu, Y., Chelliah, M., Ebisuzaki, W., Higgins, W., Janowiak, J., Mo, K.C., Ropelewski, C., Wang, J., Leetmaa, A., Reynolds, R., Jenne, R., Joseph, D., 1996. The NCEP NCAR 40-Year Reanalysis Project. Bull. Am. Meteorol. Soc. 77, 437–472.

Katzner, T.E., Bragin, E.A., Milner-Gulland, E.J., 2006. Modelling populations of long-lived birds of prey for conservation: A study of imperial eagles (*Aquila heliaca*) in Kazakhstan. Biol. Conserv. 132, 322–335.

Kays, R., Crofoot, M.C., Jetz, W., Wikelski, M., 2015. Terrestrial animal tracking as an eye on life and planet. Science. 348, aaa2478.

Kays, R., Tilak, Sa., Crofoot, M., Fountain, T., Obando, D., Ortega, A., Kuemmeth, F., Mandel, J., Swenson, G., Lambert, T., Hirsch, B., Wikelski, M., 2011. Tracking Animal Location and Activity with an Automated Radio Telemetry System in a Tropical Rainforest. Comput. J. 54, 1931–1948.

Kellner, K., 2019. jagsUI: a wrapper around rjags to streamline JAGS analyses. R Packag. version 1.5.1. https//CRAN.R-project.org/package=jagsUI.

Kelly, A., Kelly, S., 2005. Are Mute Swans with elevated blood levels more likely to collide with overhead power lines? Waterbirds 28, 331–334.

Kemp, M.U., Emiel van Loon, E., Shamoun-Baranes, J., Bouten, W., 2012. RNCEP: Global weather and climate data at your fingertips. Methods Ecol. Evol. 3, 65–70.

Kéry, M., Schaub, M., 2011. Bayesian population analysis using WinBUGS: a hierarchical perspective. Academic Press. Academic Press.

Kissling, D.W., Pattemore, D.E., Hagen, M., 2014. Challenges and prospects in the telemetry of insects. Biol. Rev. 89, 511–530.

Kistenkas, F.H., 2013. Rethinking European nature conservation legislation: Towards sustainable

development. J. Eur. Environ. Plan. Law 10, 72–84.

Klaassen, M., Bauer, S., Madsen, J., Possingham, H., 2008. Optimal management of a goose flyway: Migrant management at minimum cost. J. Appl. Ecol. 45, 1446–1452.

Klaassen, M., Beekman, J.H., Kontiokorpi, J., Mulder, R.J.W., Nolet, B.A., 2004. Migrating swans profit from favourable changes in wind conditions at low altitude. J. Ornithol. 145, 142–151.

Koffijberg, K., Tijsen, W., 2018. Kleine zwaan Cygnus columbianus bewickii, in: Sovon Vogelonderzoek Nederland (Ed.), Vogelatlas van Nederland. Kosmos uitgevers, Utrecht/Antwerpen, pp. 84–85.

Koh, L.P., Dunn, R.R., Sodhi, N.S., Colwell, R.K., Proctor, H.C., Smith, V.S., 2004. Species coextinctions and the biodiversity crisis. Science. 305, 1632–1634.

Kölzsch, A., Bauer, S., de Boer, R., Griffin, L., Cabot, D., Exo, K.M., van der Jeugd, H.P., Nolet, B.A., 2015. Forecasting spring from afar? Timing of migration and predictability of phenology along different migration routes of an avian herbivore. J. Anim. Ecol. 84, 272–283.

Kölzsch, A., Flack, A., Müskens, G.J.D.M., Kruckenberg, H., Glazov, P., Wikelski, M., 2020. Goose parents lead migration V. J. Avian Biol. 51, 1–8. https://doi.org/10.1111/jav.02392

Kölzsch, A., Kleyheeg, E., Kruckenberg, H., Kaatz, M., Blasius, B., 2018. A periodic markov model to formalize animal migration on a network. R. Soc. Open Sci. 5.

Kölzsch, A., Müskens, G.J.D.M., Kruckenberg, H., Glazov, P., Weinzierl, R., Nolet, B.A., Wikelski, M., 2016. Towards a new understanding of migration timing: slower spring than autumn migration in geese reflects different decision rules for stopover use and departure. Oikos 125, 1496–1507.

Kölzsch, A., Neefjes, M., Barkway, J., Müskens, G.J.D.M., van Langevelde, F., de Boer, W.F., Prins, H.H.T., Cresswell, B.H., Nolet, B.A., 2016. Neckband or backpack? Differences in tag design and their effects on GPS/accelerometer tracking results in large waterbirds. Anim. Biotelemetry 4.

Koons, D.N., Arnold, T.W., Schaub, M., 2017. Understanding the demographic drivers of realized population growth rates: Ecol. Appl. 27, 2102–2115.

Koons, D.N., Gunnarsson, G., Schmutz, J.A., Rotella, J.A.Y.J., 2014. Drivers of waterfowl population dynamics: from teal to swans. Wildfowl 169–191.

Koons, D.N., Iles, D.T., Schaub, M., Caswell, H., 2016. A life-history perspective on the demographic drivers of structured population dynamics in changing environments. Ecol. Lett. 19, 1023–1031.

Koyama, K., Kasahara, S., Abe, S., 2013. Effects of the Climatic Conditions at Breeding, Stopover and Wintering Sites on the Number of Juvenile Whooper Swans *Cygnus cygnus* Wintering in Japan. Ornithol. Sci. 12, 107–115.

Krawchuk, M.A., Moritz, M.A., Parisien, M.A., Van Dorn, J., Hayhoe, K., 2009. Global pyrogeography: The current and future distribution of wildfire. PLoS One 4.

Krijgsveld, K.L., Akershoek, K., Schenk, F., Dijk, F., Dirksen, S., 2009. Collision Risk of Birds with Modern Large Wind Turbines. Ardea 97, 357–366.

Krivtsov, S.K., Mineyev, Y.N., 1991. Daily time and energy budgets of Whooper Swans *Cygnus cygnus* and Bewick's Swans *Cygnus bewickii* in the breeding season. Wildfowl Special Issue 1, 319-321.

L

Lameris, T.K., de Jong, M.E., Boom, M.P., van der Jeugd, H.P., Litvin, K.E., Loonen, M.J.J.E., Nolet, B.A., Prop, J., 2019. Climate warming may affect the optimal timing of reproduction for migratory geese differently in the low and high Arctic. Oecologia 191, 1003–1014.

Lameris, T.K., Jeugd, H.P. van der, Eichhorn, G., Dokter, A.M., Bouten, W., Boom, M.P., Litvin, K.E., Ens, B.J., Nolet, B.A., 2018. Arctic Geese Tune Migration to a Warming Climate but Still Suffer from a Phenological Mismatch. Curr. Biol. 28, 2467–2473.

Lameris, T.K., Scholten, I., Bauer, S., Cobben, M.M.P., Ens, B.J., Nolet, B.A., 2017. Potential for an Arctic-breeding migratory bird to adjust spring migration phenology to Arctic amplification. Glob. Chang. Biol. 23, 4058–4067.

Laplanche, C., Marques, T.A., Thomas, L., 2015. Tracking marine mammals in 3D using electronic tag data. Methods Ecol. Evol. 6, 987–996.

Laubek, B., Clausen, P., Nilsson, L., Wahl, J., Wieloch, M., Meissner, W., Shimmings, P., Larsen, B.H., Hornman, M., 2019. Whooper Swan *Cygnus cygnus* January population censuses for Northwest Mainland Europe , 1995 – 2015. Wildfowl. Special Issue 5, 103–122.

Laulajainen, R., 2008. The Arctic Sea Route. Int. J. Shipp. Transp. Logist. 1, 55–73.

Layton-Matthews, K., Loonen, M.J.J.E., Hansen, B.B., Coste, C.F.D., Sæther, B.E., Grøtan, V., 2019. Density-dependent population dynamics of a high Arctic capital breeder, the barnacle goose. J. Anim. Ecol. 88, 1191–1201.

le Roux, S.P., Wolhuter, R., Stevens, N., Niesler, T., 2018. Reduced Energy and Memory Requirements by On-Board Behavior Classification for Animal-Borne Sensor Applications. IEEE Sens. J. 18, 4261–4268.

Lebreton, J.D., Burnham, K.P., Clobert, J., Anderson, D.R., 1992. Modeling survival and testing biological hypotheses using marked animals: a unified approach with case studies. Ecol. Monogr. 62, 67–118.

Lebreton, J.D., Clobert, J., 1991. Bird population dynamics, management, and conservation: the role of mathematical modelling. Bird Popul. Stud. 105–125.

Lehikoinen, A., Jaatinen, K., Vähätalo, A. V., Clausen, P., Crowe, O., Deceuninck, B., Hearn, R., Holt, C.A., Hornman, M., Keller, V., Nilsson, L., Langendoen, T., Tománková, I., Wahl, J., Fox, A.D., 2013. Rapid climate driven shifts in wintering distributions of three common waterbird species. Glob. Chang. Biol. 19, 2071–2081.

Lehikoinen, A., Virkkala, R., 2016. North by North-West: Climate change and directions of density shifts in birds. Glob. Chang. Biol. 22, 1121–1129.

Lessells, C.M., Boag, P.T., 1987. Unrepeatable Repeatabilities : A Common MIstake. Auk 104, 116–121.

Liaw, A., Wiener, M., 2002. Classification and regression by randomForest. R News 2, 18–22.

Liechti, F., Bauer, S., Dhanjal-Adams, K.L., Emmenegger, T., Zehtindjiev, P., Hahn, S., 2018. Miniaturized multi-sensor loggers provide new insight into year-round flight behaviour of small trans-Sahara avian migrants. Mov. Ecol. 6, 1–10.

Lindström, Å., 2003. Fuel deposition rates in migrating birds: causes, constraints and consequences., in: Berthold, P., Gwinner, E., Sonnenschein, E. (Ed.), Avian Migration. Springer-Verlag, Berlin Heidelberg.

Lindström, Å., Alerstam, T., Hedenström, A., 2019. Faster fuelling is the key to faster migration. Nat. Clim. Chang. 9, 288–289.

Linssen, H., Van De Pol, M., Allen, A.M., Jans, M., Ens, B.J., Krijgsveld, K.L., Frauendorf, M., Van Der Kolk, H.J., 2019. Disturbance increases high tide travel distance of a roosting shorebird but only marginally affects daily energy expenditure. Avian Res. 10, 1–11.

López-López, P., García-Ripollés, C., Urios, V., 2014. Individual repeatability in timing and spatial flexibility of migration routes of trans-Saharan migratory raptors. Curr. Zool. 60, 642–652.

Louppova, J., 2018. Russia to build a new deep sea port in the north. port.today. https://port.today/russia-build-new-deep-port-north/

Lourenço, P.M., Kentie, R., Schroeder, J., Groen, N.M., Hooijmeijer, J.C.E.W., Piersma, T., 2011. Repeatable timing of northward departure, arrival and breeding in Black-tailed Godwits *Limosa l. limosa*, but no domino effects. J. Ornithol. 152, 1023–1032.

Luigujõe, L., Kuresoo, A., 2007. Bewick's swans at lake Peipsi.

Luigujõe, L., Kuresoo, A., Keskpaik, J., Ader, A., Leito, A., 1996. Migration and staging of the Bewick's Swan (*Cygnus columbianus bewickii*) in Estonia. Game Wildl. 13, 451–461.

Luigujõe, L., Kuresoo, A., Leivits, A., 2002. Numbers and distribution of Whooper Swans breeding, wintering and on migration in Estonia, 1990-2000. Waterbirds 25, 61–66.

Luigujõe, L., Kuresoo, A., Rattiste, K., 2013. Population status of the Bewick ' s Swan (*Cygnus columbianus bewickii*) and protection proposals in Estonia. Hirundo 26, 53–79.

M

Mace, G.M., 2014. Whose conservation? Changes in the perception and goals of nature conservation require a solid scientific basis. Science. 245, 1558–1560.

MacIver, M.A., Sharabash, N.M., Nelson, M.E., 2001. Prey-capture behavior in gymnotid electric fish: Motion analysis and effects of water conductivity. J. Exp. Biol. 204, 543–557.

Maclean, I.M.D., Austin, G.E., Rehfisch, M.M., Blew, J., Crowe, O., Delany, S., Devos, K., Deceuninck, B., Günther, K., Laursen, K., Van Roomen, M., Wahl, J., 2008. Climate change causes rapid changes in the distribution and site abundance of birds in winter. Glob. Chang. Biol. 14, 2489–2500.

Mansfield, K.L., Wyneken, J., Porter, W.P., Luo, J., 2014. First satellite tracks of neonate sea turtles redefine the "lost years" oceanic niche. Proc. R. Soc. Biol. Sci. 281.

Martin, G.R., 2011. Understanding bird collisions with man-made objects: a sensory ecology approach. Ibis. 153, 239–254.

Martin, G.R., Shaw, J.M., 2010. Bird collision with power lines: failing to see the way ahead? Biol. Conserv. 143, 2695–2702.

Martin, T.G., Chadès, I., Arcese, P., Marra, P.P., Possingham, H.P., Norris, D.R., 2007. Optimal conservation of migratory species. PLoS One 2, 3–7.

Mazaris, A.D., Papanikolaou, A.D., Barbet-Massin, M., Kallimanis, A.S., Jiguet, F., Schmeller, D.S., Pantis, J.D., 2013. Evaluating the Connectivity of a Protected Areas' Network under the Prism of Global Change: The Efficiency of the European Natura 2000 Network for Four Birds of Prey. PLoS One 8.

McLean, D.J., Skowron Volponi, M.A., 2018. trajr: An R package for characterisaion of animal trajectories. Ethology 124, 440–448.

Meine, C., 2013. Conservation Movement, Historical, Encyclopedia of Biodiversity: Second Edition. Elsevier Ltd.

Merilä, J., Hendry, A.P., 2014. Climate change, adaptation, and phenotypic plasticity: The problem and the evidence. Evol. Appl. 7, 1–14.

Merne, O.J., 1972. Bewick's swans feeding on waste potatoes and other agricultural crops. Br. birds 65, 394–395.

Millennium Ecosystem Assessment, 2005. Ecosystems and Human Well-being: Synthesis. Island Press, Washington, DC.

Millennium Ecosystem Assessment, 2003. Ecosystems and Human Well-being: a framework for assessment. Island Press, Washington, DC.

Mineyev, Y.N., 1991. Distribution and numbers of Bewick's swans *Cygnus bewickii* in the European northeast of the USSR. Wildfowl 1, 62–67.

Møller, A.P., Rubolini, D., Lehikoinen, E., 2008. Populations of migratory bird species that did not show a phenological response to climate change are declining. Proc. Natl. Acad. Sci. U.S.A. 105, 16195–16200.

Montibeller, B., Kmoch, A., Virro, H., Mander, U., Uuemaa, E., 2020. Increasing fragmentation of

forest cover in Brazil's Legal Amazon from 2011 to 2017. Sci. Rep. 10, 5803.

Morris, W.F., Doak, D.F., 2004. Buffering of Life Histories against Environmental Stochasticity: Accounting for a Spurious Correlation between the Variabilities of Vital Rates and Their Contributions to Fitness. Am. Nat. 163, 579–590.

Morrissette, M., Bêty, J., Gauthier, G., Reed, A., Lefebvre, J., 2010. Climate, trophic interactions, density dependence and carry-over effects on the population productivity of a migratory Arctic herbivorous bird. Oikos 119, 1181–1191.

Mullié, W.C., Poorter, E.P.R., 1977. Aantallen, verspreiding en terreinkeus van de kleine zwaan bij vijf landelijke tellingen in 1976 en 1977. Watervogels 2, 85–96.

N

Nagy, S., Petkov, N., Rees, E., Solokha, A., Hilton, G., Beekman, J., Nolet, B.A., 2012. International Single Species Action Plan for the Conservation of the notrhwest European population of Bewick's Swan (*Cygnus columbianus bewickii*), in: AEWA Technical Series No.44 Bonn, Germany: AEWA.

Nakagawa, S., Schielzeth, H., 2010. Repeatability for Gaussian and non-Gaussian data: A practical guide for biologists. Biol. Rev. 85, 935–956.

Nathan, R., Spiegel, O., Fortmann-Roe, S., Harel, R., Wikelski, M., Getz, W., 2012. Using tri-axial acceleration data to identify behavioral modes of free-ranging animals: general concepts and tools illustrated for griffon vultures. J. Exp. Biol. 215, 986–996.

Nespolo, R.F., Artacho, P., Verdugo, C., Castañeda, L.E., 2008. Short-term thermoregulatory adjustments in a South American anseriform, the black-necked swan (*Cygnus melanocoryphus*). Comp. Biochem. Physiol. - Part A Mol. Integr. Physiol. 150, 366–368.

Newth, J.L., Brown, M.J., Rees, E.C., 2011. Incidence of embedded shotgun pellets in Bewick's swans *Cygnus columbianus bewickii* and whooper swans *Cygnus cygnus* wintering in the UK. Biol. Conserv. 144, 1630–1637.

Newth, J.L., Cromie, R.L., Brown, M.J., Delahay, R.J., Meharg, A.A., Deacon, C., Norton, G.J., O'Brien, M.F., Pain, D.J., 2013. Poisoning from lead gunshot: Still a threat to wild waterbirds in Britain. Eur. J. Wildl. Res. 59, 195–204.

Newth, J.L., Mikhailova, G., Anufriev, V., Glazov, P., Chistiakov, A., Semenov, I., Dench, S., Belousova, A., Rees, E.C., 2019. The swan champions in the Russian Arctic: A community approach to reducing the poaching of Bewick's swans, in: Bolotov, I.N. (Ed.), Problems of Environmental Savety and Sustainable Development of the Arcic Territories. OM Media.

Newth, J.L., Rees, E.C., Cromie, R.L., McDonald, R.A., Bearhop, S., Pain, D.J., Norton, G.J., Deacon, C., Hilton, G.M., 2016. Widespread exposure to lead affects the body condition of free-living whooper swans *Cygnus cygnus* wintering in Britain. Environ. Pollut. 209, 60–67.

Newth, Julia L., Wood, K.A., McDonald, R.A., Nuno, A., Semenov, I., Chistyakov, A., Mikhaylova, G., Bearhop, S., Belousova, A., Glazov, P., Cromie, R.L., Rees, E.C., 2019. Conservation implications of misidentification and killing of protected species. Conserv. Sci. Pract. 1, e24.

Noda, T., Kawabata, Y., Arai, N., Mitamura, H., Watanabe, S., 2014. Animal-mounted gyroscope/accelerometer/magnetometer: In situ measurement of the movement performance of fast-start behaviour in fish. J. Exp. Mar. Bio. Ecol. 451, 55–68.

Nõges, P., Nõges, T., 2006. Indicators and criteria to assess ecological status of the large shallow temperate polymictic lakes Peipsi (Estonia/Russia) and Võrtsjärv (Estonia). Boreal Environ. Res. 11, 67–80.

Nõges, T., Laugaste, R., Loigu, E., Nedogarko, I., Skakalski, B., Nõges, P., 2005. Is the destabilisation of lake Peipsi ecosystem caused by increased phosphorus loading or decreased nitrogen loading? Water Sci. Technol. 51, 267–274.

Nolet, B.A., Bauer, S., Feige, N., Kokorev, Y.I., Popov, I.Y., Ebbinge, B.S., 2013. Faltering lemming cycles reduce productivity and population size of a migratory Arctic goose species. J. Anim. Ecol.

82, 804–813.

Nolet, B.A., Bevan, R.M., Klaassen, M., Langevoord, O., van der Heijden, Y.G.J.T., 2002. Habitat switching by Bewick's swans: maximisation of average long-term enery gain? J. Anim. Ecol. 71, 979-993.

Nolet, B.A., 2006. Speed of spring migration of Tundra Swans Cygnus columbianus in accordance with income or capital breeding strategy? Ardea 94, 579–591.

Nolet, B.A., Andreev, V.A., Clausen, P., Poot, M.J.M., Wessel, E.G.J., 2001. Significance of the White Sea as a stopover for Bewick's Swans *Cygnus columbianus bewickii* in spring. Ibis. 143, 63–71.

Nolet, B.A., Bevan, R.M., Klaassen, M., Langevoord, O., Van Der Heijden, Y.G.J.T., 2002. Habitat switching by Bewick's swans: maximization of average long-term energy gain? J. Anim. Ecol. 71, 979–993.

Nolet, B.A., de Boer, T., de Vries, P.P., 2007. Habitat Quality Estimated from Head-Dipping Time in Trampling Swans. Isr. J. Ecol. Evol. 53.

Nolet, B.A., Drent, R.H., 1998. Bewick ' s Swans Refuelling on Pondweed Tubers in the Dvina Bay (White Sea) during Their Spring Migration: First Come , First Served. J. Avian Biol. 29, 574–584.

Nolet, B.A., Fuld, V.N., van Rijswijk, M.E.C. 2006. Foraging costs and accessibility as determinants of giving-up densities in a swan-pondweed system. Oikos 112, 353-362.

Nolet, B.A., Gyimesi, A., 2013. Underuse of stopover site by migratory swan. J. Ornithol. 154, 695–703.

Nolet, B.A., Gyimesi, A., van Krimpen, R.R.D., de Boer, W.F., Stillman, R.A., 2016a. Predicting Effects of Water Regime Changes on Waterbirds: Insights from Staging Swans. PLoS One 11, e0147340.

Nolet, B.A., Gyimesi, A., van Lith, B., 2014. Lower foraging efficiency of offspring constrains use of optimal habitat in birds with extended parental care. Ibis. 156, 387–394.

Nolet, B.A., Klaassen, M., 2009. Retrodicting patch use by foraging swans in a heterogeneous environment using a set of functional responses. Oikos 118, 431–439.

Nolet, B.A., Klaassen, M., 2005. Time and energy constraints in demanding phases of the annual cycle: an example of time limitation in refuelling migratory swans. Oikos 111, 302–310.

Nolet, B.A., Kölzsch, A., Elderenbosch, M., van Noordwijk, A.J., 2016b. Scaring waterfowl as a management tool: how much more do geese forage after disturbance? J. Appl. Ecol. 53, 1413–1421.

Nolet, B.A., Langevoord, O., Bevan, R.M., Engelaar, K.R., Klaassen, M., Mulder, R.J.W., van Dijk, S., 2001. Spatial variation in tuber depletion by swans explained by differences in net intake rates. Ecology 82, 1655–1667.

Nolet, B.A., Schreven, K.H.T., Boom, M.P., Lameris, T.K., 2020. Contrasting effects of the onset of spring on reproductive success of Arctic-nesting geese. Auk 137, 1–9.

Noordhuis, R., van der Molen, D.T., van den Berg, M.S., 2002. Response of herbivorous water-birds to the return of Chara in Lake Veluwemeer, The Netherlands. Aquat. Bot. 72, 349–367.

Norkin, A., De Cock, J., Mavlankar, A., Aaron, A., 2016. More Efficient Mobile Encodes for Netflix Downloads. Netflix Technol. Blog. https://medium.com/netflix-techblog/more-efficient-mobile-encodes-for-netflix-downloads-625d7b082909 (accessed 9.5.18).

Norris, D.R., Taylor, C.M., 2005. Predicting the consequences of carry-over effects for migratory populations. Biol. Lett. 2, 148–151.

Nuijten, R. J. M., Gerrits, T., Shamoun-Baranes, J. & Nolet, B. A. (2019). Data from: Less is more: on-board lossy compression of accelerometer data increases biologging capacity. Dryad Digital Repository, https://doi.org/10.5061/dryad.6djh9w0x9.

Nuijten, R.J.M., Kölzsch, A., van Gils, J.A., Hoye, B.J., Oosterbeek, K., de Vries, P.P., Klaassen, M., Nolet, B.A., 2014. The exception to the rule: retreating ice front makes Bewick's swans *Cygnus columbianus bewickii* migrate slower in spring than in autumn. J. Avian Biol. 45, 113–122.

Nuijten, R.J.M., Shamoun-baranes, J., Gerrits, T., Nolet, B.A., 2020a. Less is more : On-board lossy compression of accelerometer data increases biologging capacity. J. Anim. Ecol. 89, 237–247.

Nuijten, R.J.M., Wood, K.A., Rees, E.C., Nolet, B.A., 2020b. Concurrent shifts in wintering distribution and phenology in migratory swans, Dryad, Dataset, https://doi.org/10.5061/dryad.dfn2z34xp.

Nuijten, R.J.M, Prins, E.F., LAmmers, J., Mager, C., Nolet, B.A., 2020c. Calibrating tri-axial accelerometers for remote behavioural observations in Bewick's swans. J. Zoo and Aq. Res. *in press.*

O

Ogilvie, M.A., 1972. Large Numbered Leg Bands for Individual Identification of Swans. J. Wildl. Manage. 36, 1261–1265.

Opermanis, O., MacSharry, B., Aunins, A., Sipkova, Z., 2012. Connectedness and connectivity of the Natura 2000 network of protected areas across country borders in the European Union. Biol. Conserv. 153, 227–238.

Opermanis, O., MacSharry, B., Evans, D., Sipkova, Z., 2013. Is the connectivity of the Natura 2000 network better across internal or external administrative borders? Biol. Conserv. 166, 170–174.

Oppel, S., Hilton, G., Ratcliffe, N., Fenton, C., Daley, J., Gray, G., Vickery, J., Gibbons, D., 2014. Assessing population viability while accounting for demographic and environmental uncertainty. Ecology 95, 1809–1818.

P

Pagano, A.M., Rode1, K.D., Cutting, A., Owen, M.A., Jensen, S., Ware, J. V., Robbins, C.T., Durner, G.M., Atwood, T.C., Obbard, M.E., Middel, K.R., Thiemann, G.W., Williams, T.M., 2017. Using tri-axial accelerometers to identify wild polar bear behaviors. Endanger. Species Res. 32, 19–33.

Parmesan, C., Yohe, G., 2003. A globally coherent fingerprint of climate change impacts across natural systems. Nature 421, 37–42.

Patel, A., Stocks, B., Fisher, C., Nicolls, F., Boje, E., 2017. Tracking the Cheetah Tail Using Animal-Borne Cameras, GPS, and an IMU. IEEE Sensors Lett. 1, 1–4.

Pavón-Jordán, D., Clausen, P., Dagys, M., Devos, K., Encarnaçao, V., Fox, A.D., Frost, T., Gaudard, C., Hornman, M., Keller, V., Langendoen, T., Ławicki, Ł., Lewis, L.J., Lorentsen, S.H., Luigujoe, L., Meissner, W., Molina, B., Musil, P., Musilova, Z., Nilsson, L., Paquet, J.Y., Ridzon, J., Stipniece, A., Teufelbauer, N., Wahl, J., Zenatello, M., Lehikoinen, A., 2019. Habitat- and species-mediated short- and long-term distributional changes in waterbird abundance linked to variation in European winter weather. Divers. Distrib. 25, 225–239.

Pebesma, E.J., Bivand, R.S., 2005. Classes and methods for spatial data in R. R news 5, 9–13.

Peters, R.L., Darling, J.D.S., 1985. The greenhouse effect and nature reserves. Bioscience 35, 707–717.

Petrie, S.A., Wilcox, K.L., 2003. Migration chronology of Eastern-Population Tundra Swans. Can. J. Zool. 81, 861–870.

Pfister, C.A., 1998. Patterns of variance in stage-structured populations: Evolutionary predictions and ecological implications. Proc. Natl. Acad. Sci. 95, 213–218.

Phillips, G., Willby, N., Moss, B., 2016. Submerged macrophyte decline in shallow lakes: What have we learnt in the last forty years? Aquat. Bot. 135, 37–45.

Piersma, T., Lok, T., Chen, Y., Hassell, C.J., Yang, H.Y., Boyle, A., Slaymaker, M., Chan, Y.C., Melville, D.S., Zhang, Z.W., Ma, Z., 2016. Simultaneous declines in summer survival of three shorebird species signals a flyway at risk. J. Appl. Ecol. 53, 479–490.

Pimm, S.L., Russel, G.J., Gittleman, J.L., Brooks, T.M., 1995. The future of biodiversity. Science. 269, 347–350.

Plummer, M., 2003. JAGS: A program for analysis of Bayesian graphical models using Gibbs sampling. Proc. 3rd Int. Work. Distrib. Stat. Comput. 124, 1–10.

Podhrázský, M., Musil, P., Musilová, Z., Zouhar, J., Adam, M., Závora, J., Hudec, K., 2017. Central European Greylag Geese *Anser anser* show a shortening of migration distance and earlier spring arrival over 60 years. Ibis. 159, 352–365.

Poorter, E.P.R., 1991. Bewick's swans *Cygnus columbianus bewickii*, an analysis of breeding success and changing resources.

Post, E., Forchhammer, M.C., 2008. Climate change reduces reproductive success of an Arctic herbivore through trophic mismatch. Philos. Trans. R. Soc. B Biol. Sci. 363, 2369–2375.

Pounds, J.A., 2001. Climate and amphibian declines. Nature 410, 639–640.

R

Raworth, K., 2017. A Doughnut for the Anthropocene: humanity's compass in the 21st century. lancet Planet. Heal. 1, 48–49.

R Core Team, 2019. R: A language and environment for statistical computing.

Redford, K.H., Padoch, C., Sunderland, T., 2013. Fads, Funding, and Forgetting in Three Decades of Conservation. Conserv. Biol. 27, 437–438.

Rees, E.C., 2012. Impacts of wind farms on swans and geese: A review. Wildfowl 62, 37–72.

Rees, E.C., 2006. Bewick's Swan. T. & A.D. Poyser, London, UK.

Rees, E.C., 1991. Distribution within the USSR of Bewick's swans *Cygnus columbianus bewickii* marked in Britain. Wildfowl 209–213.

Rees, E.C., 1982. The effect of photoperiod on the timing of spring migration in the Bewick's swan. Wildfowl 33, 119–132.

Rees, E.C., Bacon, P.J., 1996. Migratory tradition in Bewick's swans (*Cygnus columbianus bewickii*). Game Wildl. 13, 407–420.

Rees, E.C., Beekman, J.H., 2010. Northwest European Bewick's Swans: a population in decline. Br. Birds 103, 640–650.

Rees, E.C., Bowler, J., 1996. Fifty years of swan research and conservation by the Wildfowl and Wetlands Trust. Wildfowl1 47, 248–263.

Rees, E.C., Bowler, J.M., 1991. Feeding activities of Bewicks' Swan at a migratory site in the Estonian SSR. Wildfowl, Specisl Issue 1, 249–255.

Rees, E.C., Bowler, J.M., Beekman, J.H., 1997. Cygnus columbianus Bewick's swan and Whistling swan., in: Ogilvie, M.A. (Ed.), Birds of the Western Palearctic Update. Oxford University Press, Oxford, pp. 63–74.

Rice, J.C., Garcia, S.M., 2011. Fisheries, food security, climate change, and biodiversity: characteristics of the sector and perspectives on emerging issues. ICES J. Mar. Sci. 68, 1343–1353.

Riehl, C., Frederickson, M.E., 2016. Cheating and punishment in cooperative animal societies. Philos. Trans. R. Soc. B Biol. Sci. 371.

Ripple, W.J., Wolf, C., Newsome, T.M., Galetti, M., Alamgir, M., Crist, E., Mahmoud, M.I., Laurance, W.F., 2017. World scientists' warning to humanity: A second notice. Bioscience 67, 1026–1028.

Robinson, R.A., Crick, H.Q.P., Learmonth, J.A., Maclean, I.M.D., Thomas, C.D., Bairlein, F., Forchhammer, M.C., Francis, C.M., Gill, J.A., Godley, B.J., Harwood, J., Hays, G.C., Huntley, B., Hutson, A.M., Pierce, G.J., Rehfisch, M.M., Sims, D.W., Begoña Santos, M., Sparks, T.H., Stroud, D.A., Visser, M.E., 2009. Travelling through a warming world: Climate change and migratory species. Endanger. Species Res. 7, 87–99.

Robinson, R.A., Morrison, C.A., Baillie, S.R., 2014. Integrating demographic data: Towards a framework for monitoring wildlife populations at large spatial scales. Methods Ecol. Evol. 5, 1361–1372.

Rockstrom, J., Steffen, W., Noone, K., Persson, A., Chapin III, F.S., Lambin, E.F., Lenton, T.M., Scheffer, M., Folke, C., Schellnhuber, H.J., Nykvist, B., de Wit, C.A., Hughes, T., van der Leeuw, S., Rodhe, H., Sorlin, S., Snyder, P.K., Costanza, R., Svedin, U., Falkenmark, M., Karlberg, L., Corell, R.W., Fabry, V.J., Hansen, J., Walker, B., Liverman, D., Richardson, K., Crutzen, P., Foley, J.A., 2009. A safe operating space for humanity. Nature 461, 472–275.

Ropert-Coudert, Y., Wilson, R.P., 2005. Trends and perspectives in animal-attached remote sensing. Front. Ecol. Environ. 3, 437–444.

Runge, C.A., Watson, J.E.M., Butchart, S.H.M., Hanson, J.O., Possingham, H.P., Fuller, R.A., 2015. Protected areas and Global conservation of migratory birds. Science. 350, 1255–1258.

Ryan, P.G., Petersen, S.L., Peters, G., Grémillet, D., 2004. GPS tracking a marine predator: The effects of precision, resolution and sampling rate on foraging tracks of African Penguins. Mar. Biol. 145, 215–223.

S

Sæther, B.E., Bakke, Ø., 2000. Avian life history variation and contribution of demographic traits to the population growth rate. Ecology 81, 642–653.

Sala, J.E., Pisoni, J.P., Quintana, F., 2017. Three-dimensional temperature fields of the North Patagonian Sea recorded by Magellanic penguins as biological sampling platforms. Estuar. Coast. Shelf Sci. 189, 203–215.

Sayer, C.D., Davidson, T.A., Jones, J.I., 2010. Seasonal dynamics of macrophytes and phytoplankton in shallow lakes: A eutrophication-driven pathway from plants to plankton? Freshw. Biol. 55, 500–513.

Schaub, M., Abadi, F., 2011. Integrated population models: a novel analysis framework for deeper insights into population dynamics. J. Ornithol. 152, S227–S237.

Schaub, M., Fletcher, D., 2015. Estimating immigration using a Bayesian integrated population model: choice of parametrization and priors. Environ. Ecol. Stat. 22, 535–549.

Schaub, M., Reichlin, T.S., Abadi, F., Kéry, M., Jenni, L., Arlettaz, R., 2012. The demographic drivers of local population dynamics in two rare migratory birds. Oecologia 168, 97–108.

Scheffer, M., 1990. Multiplicity of stable states in freshwater systems. Hydrobiologia 200/201, 475–

486.

Scheffer, M., Hosper, S.H., Meijer, M.L., Moss, B., Jeppesen, E., 1993. Alternative equilibria in shallow lakes. Trends Ecol. Evol. 8, 275–279.

Scott, D.K., 1978. Identification of individual Bewick's swans by bill pattern., in: Stonehouse, B. (Ed.), Animal Marking. Palgrave, London, pp. 160–168.

Sergio, F., Tanferna, A., De Stephanis, R., Jiménez, L.L., Blas, J., Tavecchia, G., Preatoni, D., Hiraldo, F., 2014. Individual improvements and selective mortality shape lifelong migratory performance. Nature 515, 410–413.

Shaffer, S.A., Cockerham, S., Warzybok, P., Bradley, R.W., Jahncke, J., Clatterbuck, C.A., Lucia, M., Jelincic, J.A., Cassell, A.L., Kelsey, E.C., Adams, J., 2017. Population-level plasticity in foraging behavior of western gulls (*Larus occidentalis*). Mov. Ecol. 5, 27.

Shamoun-Baranes, J., Bom, R., van Loon, E.E., Ens, B.J., Oosterbeek, K., Bouten, W., 2012. From sensor data to animal behaviour: An oystercatcher example. PLoS One 7, 28–30.

Shamoun-Baranes, J., Bouten, W., van Loon, E.E., Meijer, C., Camphuysen, C.J., 2016. Flap or soar? How a flight generalist responds to its aerial environment. Philos. Trans. R. Soc. B Biol. Sci. 371.

Shchadilov, Y.M., 2002. Annual variation in the proportion of Whooper Swans and Bewick's Swans breeding in northern European Russia. Waterbirds 25, 86–94.

Skinner, W.R., Jefferies, R.L., Carleton, T.J., Rockwell, R.F., Abraham, K.F., 1998. Prediction of reproductive success and failure in lesser snow geese based on early season climatic variables. Glob. Chang. Biol. 4, 3–16.

Smith, P.A., Elliott, K.H., Gaston, A.J., Gilchrist, H.G., 2010. Has early ice clearance increased predation on breeding birds by polar bears? Polar Biol. 33, 1149–1153.

Sokal, R.R., Rohlf, F.J., 1962. The comparison of dendrograms by objective methods. Taxon 11, 33–40.

Soule, M.E., 1987. Viable populations for conservation. Cambridge University Press.

Spaans, B., van der Veer, W., Ebbinge, B.S., 1999. Cost of incubation in a Greater Whit-fronted Goose. Waterbirds 22, 151–155.

Stanley, C.Q., MacPherson, M., Fraser, K.C., McKinnon, E.A., Stutchbury, B.J.M., 2012. Repeat tracking of individual songbirds reveals consistent migration timing but flexibility in route. PLoS One 7, 5–10.

Steffen, W., Crutzen, P.J., McNeill, J.R., 2007. The Anthropocene: are humans now overwhelming the great forces of nature". AMBIO A J. Hum. Environ. 36, 614–621.

Stirnemann, R.L., O'Halloran, J., Ridgway, M., Donnelly, A., 2012. Temperature-related increases in grass growth and greater competition for food drive earlier migrational departure of wintering Whooper Swans. Ibis. 154, 542–553.

Stocker, T.F., Qin, D., Plattner, G.K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, B., Midgley, B.M., 2013. Climate change 2013: the physical science basis. Contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change., IPCC. Cambridge University Press.

Stott, I., Townley, S., Hodgson, D.J., 2011. A framework for studying transient dynamics of population projection matrix models. Ecol. Lett. 14, 959–970.

Suter, W., van Eerden, M.R., 1992. Simultaneous mass starvation of wintering diving ducks in

Switserland and the Netherlands: a wrong decision in the right strategy? Ardea 80, 229–242.

Sutherland, W.J., 1998. Evidence for Flexibility and Constraint in Migration Systems. J. Avian Biol. 29, 441–446.

Svenning, J.C., Pedersen, P.B.M., Donlan, C.J., Ejrnæs, R., Faurby, S., Galetti, M., Hansen, D.M., Sandel, B., Sandom, C.J., Terborgh, J.W., Vera, F.W.M., 2016. Science for a wilder Anthropocene: Synthesis and future directions for trophic rewilding research. Proc. Natl. Acad. Sci. U. S. A. 113, 898–906.

T

Tavecchia, G., Besbeas, P., Coulson, T., Morgan, B.J.T., Clutton-Brock, T.H., 2009. Estimating population size and hidden demographic parameters with state-space modeling. Am. Nat. 173, 722–733.

Tempel, D.J., Peery, M.Z., Gutiérrez, R.J., 2014. Using integrated population models to improve conservation monitoring: California spotted owls as a case study. Ecol. Modell. 289, 86–95.

Therrien, J.F., Gauthier, G., Bêty, J., 2012. Survival and reproduction of adult snowy owls tracked by satellite. J. Wildl. Manage. 76, 1562–1567.

Thomas, C.D., Cameron, A., Green, R.E., Bakkenes, M., Beaumont, L.J., Collingham, Y.C., Erasmus, B.F.N., Ferreira de Siqueira, M., Grainger, A., Hannah, L., Hughes, L., Huntley, B., van Jaarsveld, A.S., Midgley, G.F., Miles, L., Ortega-Huerta, M.A., Townsend Peterson, A., Phillips, O.L., Williams, S.E., 2004. Extinction risk from climate change. Nature 427, 145–148.

Tijsen, W., Koffijberg, K., 2015. Dertig jaar ganzen- en zwanentellingen in de Kop van Noord-Holland. Limosa 88, 83–95.

Tombre, I.M., Høgda, K.A., Madsen, J., Griffin, L.R., Kuijken, E., Shimmings, P., Rees, E., Verscheure, C., 2008. The onset of spring and timing of migration in two arctic nesting goose populations: The pink-footed goose *Anser bachyrhynchus* and the barnacle goose *Branta leucopsis*. J. Avian Biol. 39, 691–703.

Tombre, I.M., Oudman, T., Shimmings, P., Griffin, L., Prop, J., 2019. Northward range expansion in spring-staging barnacle geese is a response to climate change and population growth, mediated by individual experience. Glob. Chang. Biol. 25, 3680-3693.

Tomkiewicz, S.M., Fuller, M.R., Kie, J.G., Bates, K.K., 2010. Global positioning system and associated technologies in animal behaviour and ecological research. Philos. Trans. R. Soc. London. Biol. Sci. 365, 2163–76.

Tomotani, B.M., van der Jeugd, H., Gienapp, P., de la Hera, I., Pilzecker, J., Teichmann, C., Visser, M.E., 2018. Climate change leads to differential shifts in the timing of annual cycle stages in a migratory bird. Glob. Chang. Biol. 24, 823–835.

Tondare, S.M., Panchal, S.D., Kushnure, D.., 2014. Evolutionary steps from 1G to 4.5 G. Int. J. Adv. Res. Comput. Commun. Eng. 3.

Trinder, M.N., Hassell, D., Votier, S., 2009. Reproductive performance in arctic-nesting geese is influenced by environmental conditions during the wintering, breeding and migration seasons. Oikos 118, 1093–1101.

Tuljapurkar, S., 1990. Population dynamics in variable environments. Springer-Verlag, New York, New York, USA.

Turchin, P., 1995. Population regulation: old arguments and a new synthesis, in: Cappucino, N., Price, P.W. (Eds.), Population Dynamics: New Approaches and Synthesis. Academic Press San Diego,

California, pp. 19–40.

V

van de Pol, M., Wright, J., 2009. A simple method for distinguishing within- versus between-subject effects using mixed models. Anim. Behav. 77, 753–758.

van der Kolk, H.-J., Ens, B.J., Oosterbeek, K., Bouten, W., Allen, A.M., Frauendorf, M., Lameris, T.K., Oosterbeek, T., Deuzeman, S., de Vries, K., Jongejans, E., van de Pol, M., 2019. Shorebird feeding specialists differ in how environmental conditions alter their foraging time. Behav. Ecol. 31, 371–382.

van Eerden, M.R., Drent, R.H., Stahl, J., Bakker, J.P., 2005. Connecting seas: Western Palaearctic continental flyway for water birds in the perspective of changing land use and climate. Glob. Chang. Biol. 11, 894–908.

van Eerden, M.R., Zijlstra, M., van Roomen, M., Timmerman, A., 1996. The response of Anatidae to changes in agricultural practice: long-term shifts in the carrying capacity of wintering waterfowl. Gibier Faune Sauvag. 13, 681–707.

van Gils, J.A., Gyimesi, A., van Lith, B., 2007. Avian herbivory: an experiment, a field test, and an allometric comparison with mammals. Ecology 88, 2926–2935.

van Gils, J.A., Tijsen, W., 2007. Short-term foraging costs and long-term fueling rates in central-place foraging swans revealed by giving-up exploitation times. Am. Nat. 169, 609–620.

van Teeffelen, A.J., Cabeza, M., Poyry, J., Raatikainen, K., Kuussaari, M., 2008. Maximizing conservation benefit for grassland species with contrasting management requirements. J. Appl. Ecol. 45, 1401–1409.

van Vierssen, W., Hootsmans, M., Vermaat, J., 1994. Lake Veluwe, a macrophyte-dominated system under eutrophication stress., vol 21. Geobotany. Kluwer Academic Publishers, Dordrecht.

van Wijk, R.E., Bauer, S., Schaub, M., 2016. Repeatability of individual migration routes, wintering sites, and timing in a long-distance migrant bird. Ecol. Evol. 6, 8679–8685.

van Wijk, R.E., Schaub, M., Bauer, S., 2017. Dependencies in the timing of activities weaken over the annual cycle in a long-distance migratory bird. Behav. Ecol. Sociobiol. 71.

Vangeluwe, D., Rozenfeld, S., Kazantzidis, S., 2016. The odyssey of the Bewick's swan - another route to Greece. Swan News 12, 10–11.

Vangeluwe, D., Rozenfeld, S.B., Volkov, S.V., Kazantzidis, S., Morosov, V.V., Zamyatin, D.O., Kirtaev, G.V., 2018. Migrations of Bewick's swan (*Cygnus bewickii*): new data on tagging the migration routes, stopovers, and wintering sites. Biol. Bull. 45, 706–717.

Vansteelant, W.M.G., Shamoun-Baranes, J., van Manen, W., van Diermen, J., Bouten, W., 2017. Seasonal detours by soaring migrants shaped by wind regimes along the East Atlantic Flyway. J. Anim. Ecol. 86, 179–191.

Vardanis, Y., Klaassen, R.H.G., Strandberg, R., Alerstam, T., 2011. Individuality in bird migration: Routes and timing. Biol. Lett. 7, 502–505.

Vardanis, Y., Nilsson, J.Å., Klaassen, R.H.G., Strandberg, R., Alerstam, T., 2016. Consistency in long-distance bird migration: Contrasting patterns in time and space for two raptors. Anim. Behav. 113, 177–187.

Veasey, J.S., Waran, N.K., Young, R.J., 1996. On Comparing the Behaviour of Zoo Housed Animals With Wild Conspecifics As a Welfare Indicator. Anim. Welf. 13–24.

Verhoeven, M.A., Loonstra, A.H.J., Hooijmeijer, J.C.E.W., Masero, J.A., Piersma, T., Senner, N.R., 2018. Generational shift in spring staging site use by a long-distance migratory bird. Biol. Lett. 14, 20170663.

Verschuuren, J., 2015. Connectivity: is Natura 2000 only an ecological network on paper?, in: Born, A., Cliquet, H., Schoukens, H., Misonne, D., van Hoorick, G. (Eds.), The Habitats Directive in Its EU Environmental Law Context. European Nature's Best Hope? Abingdon: Routledge, pp. 285–302.

Visser, M.E., Both, C., 2005. Shifts in phenology due to global climate change: The need for a yardstick. Proc. R. Soc. B Biol. Sci. 272, 2561–2569.

Visser, M.E., Perdeck, A.C., van Balen, J.H., Both, C., 2009. Climate change leads to decreasing bird migration distances. Glob. Chang. Biol. 15, 1859–1865.

Vos, C.C., Berry, P., Opdam, P., Baveco, H., Nijhof, B., O'Hanley, J., Bell, C., Kuipers, H., 2008. Adapting landscapes to climate change: examples of climate-proof ecosystem networks and priority adaptation zones. J. Appl. Ecol. 45, 1722–1731.

W

Wahl, J., Degen, A., 2009. Rastbestand und Verbreitung von Singschwan *Cygnus cygnus* und Zwergschwan *C. bewickii* im Winter 2004 / 05 in Deutschland. Vogelwelt 24, 1–24.

Wallace, K.J., 2007. Classification of ecosystem services: Problems and solutions. Biol. Conserv. 139, 235–246.

Walther, G.-R., Post, E., Convey, P., Menzel, A., Parmesan, C., Beebee, T.J.C., Fromentin, J.-M., Hoegh-Guldberg, O., Bairlein, F., 2002. Ecological responses to recent climate change. Nature 416, 389–395.

Ward, J.D., Sutton, P.C., Werner, A.D., Costanza, R., Mohr, S.H., Simmons, C.T., 2016. Is decoupling GDP growth from environmental impact possible? PLoS One 11, 1–14.

Wascher, C.A.F., Kotrschal, K., Arnold, W., 2018. Free-living greylag geese adjust their heart rates and body core temperatures to season and reproductive context. Sci. Rep. 8, 2142.

Watanabe, S., Izawa, M., Kato, A., Ropert-Coudert, Y., Naito, Y., 2005. A new technique for monitoring the detailed behaviour of terrestrial animals: A case study with the domestic cat. Appl. Anim. Behav. Sci. 94, 117–131.

Watanabe, Y., Mitani, Y., Sato, K., Cameron, M.F., Naito, Y., 2003. Dive depths of Weddell seals in relation to vertical prey distribution as estimated by image data. Mar. Ecol. Prog. Ser. 252, 283–288.

Watanabe, Y.Y., Ito, M., Takahashi, A., 2014. Testing optimal foraging theory in a penguin-krill system. Proc. R. Soc. Biol. Sci. 281, 20132376.

Weegman, M.D., Bearhop, S., Fox, A.D., Hilton, G.M., Walsh, A.J., Mcdonald, J.L., Hodgson, D.J., 2016. Integrated population modelling reveals a perceived source to be a cryptic sink. J. Anim. Ecol. 85, 467–475.

Wetlands International, 2020. Waterbird Population Estimates. wpe.wetlands.org (accessed 5.4.20).

Wikelski, M., Kays, R.W., Kasdin, N.J., Thorup, K., Smith, J.A., Swenson, G.W., 2007. Going wild: what a global small-animal tracking system could do for experimental biologists. J. Exp. Biol. 210, 181–186.

Wilcove, D.S., Wikelski, M., 2008. Going, going, gone: Is animal migration disappearing? PLoS Biol. 6,

1361–1364.

Williams, S.E., Shoo, L.P., Isaac, J.L., Hoffmann, A.A., Langham, G., 2008. Towards an integrated framework for assessing the vulnerability of species to climate change. PLoS Biol. 6.

Williams, T.M., Wolfe, L., Davis, T., Kendall, T., Richter, B., Wang, Y., Bryce, C., Elkaim, G.H., Wilmers, C.C., 2014. Instantaneous energetics of puma kills reveal advantage of felid sneak attacks. Science. 346, 81–85.

Wilmers, C.C., Nickel, B., Bryce, C.M., Smith, J.A., Wheat, R.E., Yovovich, V., 2015. The golden age of bio-logging: how animal-borne sensors are advancing the frontiers of ecology. Ecology 96, 1741–1753.

Wilson, A.D.M., Wikelski, M., Wilson, R.P., Cooke, S.J., 2015. Utility of biological sensor tags in animal conservation. Conserv. Biol. 29, 1065–1075.

Wilson, H.M., Flint, P.L., Powell, A.N., Grand, J.B., Moran, C.L., 2012. Population ecology of breeding Pacific common eiders on the Yukon-Kuskokwim Delta, Alaska. Wildl. Monogr. 1–28.

Wilson, K.A., Underwood, E.C., Morrison, S.A., Klausmeyer, K.R., Murdoch, W.W., Reyers, B., Wardell-Johnson, G., Marquet, P.A., Rundel, P.W., McBride, M.F., Pressey, R.L., Bode, M., Hoekstra, J.M., Andelman, S., Looker, M., Rondinini, C., Kareiva, P., Shaw, M.R., Possingham, H.P., 2007. Conserving biodiversity efficiently: what to do, where, and when? PLOS Biol. 5.

Wilson, R.P., Holton, M.D., di Virgilio, A., Williams, H., Shepard, E.L.C., Lambertucci, S., Quintana, F., Sala, J.E., Balaji, B., Lee, E.S., Srivastava, M., Scantlebury, D.M., Duarte, C.M., 2018. Give the machine a hand: A Boolean time-based decision-tree template for rapidly finding animal behaviours in multisensor data. Methods Ecol. Evol. 9, 2206–2215.

Wilson, R.P., Shepard, E.L.C., Liebsch, N., 2008. Prying into the intimate details of animal lives: use of a daily diary on animals. Endanger. Species Res. 4, 123–137.

Winger, B.M., Auteri, G.G., Pegan, T.M., Weeks, B.C., 2019. A long winter for the Red Queen: rethinking the evolution of seasonal migration. Biol. Rev. 94, 737–752.

Wood, K.A., Newth, J.L., Brides, K., Burdekin, M., Harrison, A.L., Heaven, S., Kitchin, C., Marshall, L., Mitchell, C., Ponting, J., Scott, D.K., Smith, J., Tijsen, W., Hilton, G.M., Rees, E.C., 2019. Are long-term trends in Bewick's Swan Cygnus columbianus bewickii numbers driven by changes in winter food resources? Bird Conserv. Int. 479–496.

Wood, K.A., Newth, J.L., Hilton, G.M., Nolet, B.A., Rees, E.C., 2016. Inter-annual variability and long-term trends in breeding success in a declining population of migratory swans. J. Avian Biol. 47, 597–609.

Wood, K.A., Nuijten, R.J.M., Newth, J.L., Haitjema, T., Vangeluwe, D., Ioannidis, P., Harrison, A.L., Mackenzie, C., Hilton, G.M., Nolet, B.A., Rees, E.C., 2018. Apparent survival of an Arctic-breeding migratory bird over 44 years of fluctuating population size. Ibis. 160, 413–430.

Worden, J., Cranswick, P.A., Crowe, O., McElwaine, G., Rees, E.C., 2006. Numbers and distribution of Bewick's Swan Cygnus columbianus bewickii wintering in Britain and Ireland: results of international censuses, January 1995, 2000 and 2005. Wildfowl 56, 3–22.

WWF, 2018. Living Planet Report - 2018: Aiming Higher. Grooten, M. and Almond, R.E.A. (Eds.). WWF, Gland, Switserland.

X

Xu, F., Si, Y., 2019. The frost wave hypothesis: How the environment drives autumn departure of migratory waterfowl. Ecol. Indic. 101, 1018–1025.

Xu, Y., Si, Y., Takekawa, J., Liu, Q., Prins, H.H.T., Yin, S., Prosser, D.J., Gong, P., de Boer, W.F., 2020. A network approach to prioritize conservation efforts for migratory birds. Conserv. Biol. 34, 416–426.

Y

Yang, H.Y., Chen, B., Barter, M., Piersma, T., Zhou, C.F., Li, F.S., Zhang, Z.W., 2011. Impacts of tidal land reclamation in Bohai Bay, China: Ongoing losses of critical Yellow Sea waterbird staging and wintering sites. Bird Conserv. Int. 21, 241–259.

Yoda, K., Naito, Y., Sato, K., Takahashi, A., Nishikawa, J., Ropert-Coudert, Y., Kurita, M., Le Maho, Y., 2001. A new technique for monitoring the behaviour of free-ranging Adelie penguins. J. Exp. Biol. 685–690.

Yoda, K., Sato, K., Niizuma, Y., Kurita, M., Bost, C.A., Le Maho, Y., Naito, Y., 1999. Precise monitoring of porpoising behaviour of Adélie penguins determined using acceleration data loggers. J. Exp. Biol. 31021–3126.

Z

Zaynagutdinova, E.M., Kouzov, S.A., Batova, P.R., Mikhailov, Y.M., Kravchuk, A. V, 2019. Spring migration stopovers of swans *Cygnus sp*. in the Russian part of the Gulf of Finland. Wildfowl, Special Issue 5, 123–138.

Zhao, Q., Arnold, T.W., Devries, J.H., Howerter, D.W., Clark, R.G., Weegman, M.D., 2019. Land-use change increases climatic vulnerability of migratory birds: Insights from integrated population modelling. J. Anim. Ecol. 88, 1625–1637.

Zimmerman, P.H., Bolhuis, J.E., Willemsen, A., Meyer, E.S., Noldus, L.P.J.J., 2009. The observer XT: A tool for the integration and synchronization of multimodal signals. Behav. Res. Methods 41, 731–735.

Zipkin, E.F., Saunders, S.P., 2018. Synthesizing multiple data types for biological conservation using integrated population models. Biol. Conserv. 217, 240–250.

Ziv, G., Baran, E., Nam, S., Rodríguez-Iturbe, I., Levin, S.A., 2012. Trading-off fish biodiversity, food security, and hydropower in the Mekong River Basin. Proc. Natl. Acad. Sci. U.S.A. 109, 5609–5614.

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Chapter 2 RJMN, SJGV and BAN conceptualized the study. TH, ECR and BAN provided data. RJMN and SGJV built the model, analyzed the data. BAN and EJ consulted on model design. RJMN and SJGV wrote the manuscript. KAW, ECR, EJ, BAN provided comments on the manuscript.

Chapter 3 RJMN conceptualized the study. EFP, JL CM facilitated data collection in the zoo. RJMN collected and analyzed the data. BAN consulted on the initial results. RJMN wrote the manuscript. EFP, JL, CM and BAN provided comments.

Chapter 4 RJMN and TG conceptualized the study. TG designed and produced the GPS/GSM collars, and hosted the server for data retrieval. RJMN and BAN performed the field work. RJMN analyzed the data. RJMN wrote the manuscript. TG provided technical consultation. JS-B and BAN provided comments on the manuscript.

Chapter 5 RJMN and BAN conceptualized the study. RJMN and BAN performed the field work. RJMN analyzed the data. RJMN and BAN wrote the manuscript.

Box 1 RJMN and BAN conceptualized the study, and performed the field work. AK provided initial script (R code). RJMN analyzed the data. RJMN wrote the text. BAN provided comments.

Chapter 6 RJMN and BAN conceptualized the study. TH, ECR and BAN provided data. RJMN analyzed the data. BAN consulted on initial results. RJMN wrote the manuscript. KAW, TH, ECR and BAN provided comments on the manuscript.

Chapter 7 RJMN and EK conceptualized the study. JW, TH, ECR and BAN provided data. RJMN analyzed the data. EK consulted on data analysis and manuscript writing. RJMN wrote the manuscript. JW, TH and BAN provided comments.

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PE&RC Training and Education Statement

PE&RC TRAINING AND EDUCATION STATEMENT

With the training and education activities listed below the PhD candidate has complied with the requirements set by the C.T. de Wit Graduate School for Production Ecology and Resource Conservation (PE&RC) which comprises of a minimum total of 32 ECTS (= 22 weeks of activities)

Review of literature (4.5 ECTS)

- Unravelling the annual cycle of an Artic migrant in search of the cause of its decline

Post-graduate courses (6.9 ECTS)

- Integrated population modelling using BUGS and JAGS; Swiss Ornithological Institute and university of Cape Town (2015)
- Animal movement ecology; IBED, UVA (2015)
- Laboratory animal science designing procedures and projects and bird specific module; KNAW (2016)

Invited review of (unpublished) journal manuscript (7 ECTS)

- Global Change Biology: demography migratory birds (2015)
- Biological Conservation: migratory connectivity (2016)
- Global Change Biology: demography migratory birds (2016)
- Ecology and Evolution: conservation whooping cranes (2016)
- Bird Conservation International: stopover site protection (2017)
- Biology and Environment: bird monitoring Ireland (2017)

Competence strengthening / skills courses (2.8 ECTS)

- Workshop clim-win R-package; NIOO-KNAW (2016)
- An introduction to R for spatial analysis and mapping; Datacamp (2016)
- Systematic literature review; WGS (2016)

Scientific integrity / ethics in science activity (0.3 ECTS)

- Workshop on ethics in science; SENSE (2015)

PE&RC ANNUAL MEETINGS, SEMINARS AND THE PE&RC WEEKEND (1.2 ECTS)

- PE&RC Day (2016, 2017)
- PE&RC Weekend (2017)

DISCUSSION GROUPS / LOCAL SEMINARS / OTHER SCIENTIFIC MEETINGS (8.4 ECTS)

- Netherlands annual ecology meeting (2015-2017)
- NIOO Journal club (2015-2020)
- NIOO Theme global environmental change (2017-2019)

INTERNATIONAL SYMPOSIA, WORKSHOPS AND CONFERENCES (6.6 ECTS)

- British Ornithological union conference; oral presentation; Warwick (2017)
- International ornithological conference; poster presentation; Vancouver (2018)
- 6th International swan symposium; oral presentation; Tartu (2018)

SOCIETALLY RELEVANT EXPOSURE (1.5 ECTS)

- Pinguïn veren verraden migratieroute; Nieuws & Co, NPO Radio 1 (2017)
- Wetenschappers wereldwijd: mens verziekt aarde op grote schaal; Nieuws & Co, NPO Radio 1 (2017)
- Uitkijk over afnemende biodiversiteit; Nieuws & Co, NPO Radio 1 (2018)
- Waar zijn de kleine zwanen?; Vroege Vogels, NPO Radio 1 (2020)

- Scientific American’s 60 second science (2020)

SUPERVISION OF STUDENTS (12 ECTS)

- Integrated population model Bewick’s swan
- Distribution shift Bewick’s swan
- Migration phenology
- Behavioural classification

Summary / Samenvatting

Summary

Many species are currently threatened with extinction due to global environmental changes. Their ability to respond to these changes will determine their fate. Our efforts to protect nature, are often fixed in both time and space. This could undermine the effectiveness of conservation efforts. Therefore, it is argued, that nature conservation may benefit from a more dynamic approach.

Within this thesis I studied individual and population level changes of a migratory bird, the Bewick's swan *Cygnus columbianus bewickii*, in a period of environmental change. The western population of Bewick's swan, wintering in North-Western Europe and breeding at the Russian Arctic tundra, was shown to be declining between 1995-2015. In search of the cause of this decline we first studied the demographic rates of the population. Previous research based on a capture-mark-resighting survival analysis did not yield concluding results. By including population counts and reproductive counts in an integrated analysis with mark-resighting data, we were able to show a decreasing trend in apparent breeding success and a simultaneous increasing trend in juvenile survival (**Chapter 2**). None of the explanatory variables (except for year) explained the decline in apparent breeding success, while both water level in autumn and temperature in summer/autumn positively affected juvenile survival. The results raised the question whether juvenile survival might be able to compensate for low breeding success.

As was confirmed by the population model (Chapter 2), the Bewick's swans showed a negative population trend between 1995 and 2015. The shape of this curve was however dependent on the range country. Further analysis of capture-mark-resighting data revealed that the population as well as swans have significantly shifted their wintering distribution eastwards (i.e. 'short-stopping; **Chapter 6**) which can explain the drastic declines in the western part of the range (Ireland and UK) when compared to counts in the east (Germany and Poland). In addition, the swan population also shortened their stay in the wintering area (i.e. 'short-staying'; Chapter 6). These changes happened in parallel with climate warming in NW Europe.

Zooming in to the wintering area even more, the wintering area of the swans can be described as a well-connected network of sites, between which the swans traverse to fulfill their needs (**Chapter 7**). The importance of the different sites changed over time, partly in concordance with the eastward shift, but also related to the habitat of the sites. Agricultural field gained interest by the swans, whereas grasslands were used less in recent years.

Capture-mark-resighting data can yield valuable information on both the individual and, when analyzed in concordance, population level. Especially in species with high detection probabilities like the Bewicks's swan. However, these detection probabilities are only reached on the wintering grounds, where observer density is high. GPS tracking provides much more detail and is independent of observer efforts and differences therein between geographic areas.

Following the rapid development in GPS tracking devices, 3D printed GPS/GSM collars where extended with an accelerometer and conductivity sensor to collect additional data during the migration of the Bewick's swans. Through thorough calibration by testing the collars on captive

individuals, 6 different behavioural classes could be identified with 91% accuracy (**Chapter 3**). Time-activity budgets during spring migration of individual swans showed considerable variation in levels of aquatic foraging, although the seasonal patterns were similar between individuals, with increased levels of aquatic foraging in Estonia and in the White Sea area (Russia).

As a solution to the technical challenges that came with GPS/GSM tracking of a species that is outside phone reception for part of the year, a lossy data reduction method was developed to be able to collect accelerometer with small intervals (**Chapter 4**). The use of the 'summary statistics' rather than the raw accelerometer data increased the monitoring frequency (limited by the energy and storage capacity of the device) by a factor six, without compromising the ability to remotely detect behaviour in the downloaded data.

Between 2007 and 2019, 81 individual spring migration tracks and 68 individual autumn migration tracks were collected (**Box 1**). Although variation was small, swans were shown to time their migration in response to year-to-year variation in environmental conditions. At the same time, an analysis of multiple year tracks from the same individuals convincingly showed that both migration speed and their relative route (expressed as sinuosity) were highly consistent within individuals between years. Furthermore, we found that, although juveniles accompany their parents on their first autumn and spring migrations, they start developing their own migratory tradition in subsequent years. This finding has implications for how we perceive the development of migratory behaviour in species with extended parental care.

Reflecting on the status of the Bewick's swan population as 'Threatened' on the European Red List of Birds, we assessed whether current protective measures in NW Europe (mainly the Natura 2000 network) are sufficient to secure key habitats for this population. As these key sites have shifted over time (**Chapter 7**) it was found that, especially in recent years, some important sites were not protected. Considering the short-stopping process observed in this population (Chapter 6), it is to be expected that the mismatch between the important sites for the swans and the Natura 2000 protected areas with conservation objectives for this species will increase.

A similar analysis during the spring migration season showed ambiguous results. The stopover sites that were known to be important for the swans, were still used in recent years (**Chapter 5**). In the southern part of the migratory route, where circumstances regarding macrophyte coverage and condition are relatively well known, the swans predominantly foraged within the boundaries of protected areas. However, in the northern part, less protected areas are in place and Bewick's swans were found to frequently use areas that are not protected. The increasing pressure of human development in combination with lucrative oil and gas exploitation in the area poses a significant threat to the existence of vital stopover areas for the swans and other migratory waterfowl in this flyway (Chapter 5).

Taking in the results of this thesis, it can be concluded that the western population of Bewick's swans has shown considerable changes over the study period of ~ 50 years. These changes can in part explain the population decline and have shown that the observed Bewick's swan population trend is liable to the geographic scale and the timing of monitoring. Conjointly however, the increasing mismatch between swan site use with Natura 2000 protected areas and the foreseen threats to some vital stopover sites on this species flyway, make the

population vulnerable to declines. To effectively protect species such as the Bewick's swan that show changes over time in their site use and timing, a dynamic form of nature conservation is proposed in which ecological knowledge drives decisions made on the local level.

Samenvatting

Veel soorten worden momenteel met uitsterven bedreigd als gevolg van wereldwijde veranderingen in bijvoorbeeld landgebruik en het klimaat. Hun vermogen om op deze veranderingen te reageren zal hun lot bepalen. Onze inspanningen om de natuur te beschermen, liggen vaak vast in tijd en ruimte. Dit kan de effectiviteit van de inspanningen voor natuurbehoud ondermijnen. Daarom wordt gesteld, dat natuurbehoud kan profiteren van een meer dynamische aanpak.

Binnen dit proefschrift heb ik de individuele en populatieveranderingen van een trekvogel, de kleine zwaan *Cygnus columnbianus bewickii*, bestudeerd in een periode van veranderingen in klimaat en landgebruik. De westelijke populatie van de Bewick's zwaan, die overwintert in NW Europa en broedt op de Russische Arctische toendra, toonde een dalende populatietrend tussen 1995 en 2015. Op zoek naar de oorzaak van deze daling hebben we eerst de demografie van de populatie bestudeerd. Eerder onderzoek op basis van terugmeldingen van individueel gemerkte individuen leverde geen sluitende resultaten op. Door het combineren van populatietellingen en reproductieve tellingen in een geïntegreerde analyse met de terugmeldingen, konden we een dalende trend in schijnbaar broedsucces en een gelijktijdige stijgende trend in juveniele overleving aantonen (**hoofdstuk 2**). Geen van de verklarende variabelen (behalve het jaartal) verklaarde de afname van het schijnbare broedsucces, terwijl zowel het waterpeil in de herfst als de temperatuur in de zomer/herfst de overleving van de jongen positief beïnvloedde. De resultaten roepen de vraag op of juveniele overleving een laag broedsucces zou kunnen compenseren.

Zoals bevestigd door het populatiemodel (hoofdstuk 2), vertoonden de kleine zwanen tussen 1995 en 2015 een negatieve populatietrend. Opvallend was echter dat de vorm van deze curve verschilde, afhankelijk van het land waar geteld werd. Een analyse van de terugmelding toonde aan dat de populatie, maar ook individuele zwanen, hun overwinteringsgebied aanzienlijk naar het oosten hebben verschoven (d.w.z. *'short-stopping*'; **hoofdstuk 6**), wat de drastische dalingen in het westelijke deel van het verspreidingsgebied (Ierland en het Verenigd Koninkrijk) kan verklaren in vergelijking met de tellingen meer in het oosten (Duitsland en Polen). Daarnaast heeft de populatie van de kleine zwaan ook zijn verblijf in het overwinteringsgebied verkort (d.w.z. '*short-staying*'; hoofdstuk 6). Deze veranderingen vonden plaats parallel aan de opwarming van het klimaat in NW Europa.

Door nog meer in te zoomen op het overwinteringsgebied werd duidelijk dat dit kan worden omschreven als een goed verbonden netwerk van gebieden, waartussen de zwanen zich verplaatsen om in hun behoeften te voorzien (**hoofdstuk 7**). Het belang van de verschillende gebieden veranderde in de loop van de tijd, deels in overeenstemming met de verschuiving naar het oosten, maar ook in verband met de habitat van de gebieden. Velden met landbouwgewassen werden meer gebruikt in recente jaren, en grasland werd juist minder belangrijk.

Terugmeldingen kunnen waardevolle informatie opleveren over zowel het individu als het populatieniveau, vooral bij soorten met zo'n hoge detectiekansen als de kleine zwaan. Deze detectiekansen worden echter alleen gehaald in de overwinteringsgebieden, waar de dichtheid van de waarnemers hoog is. GPS-tracking geeft veel meer details en is onafhankelijk van de inspanningen van de waarnemers en de verschillen tussen de geografische gebieden.

In navolging van de snelle ontwikkeling van GPS-trackingapparaten werden 3D geprinte GPS/GSM-halsbanden uitgebreid met een versnellingsmeter en een watersensor om extra gegevens te verzamelen tijdens de migratie van de kleine zwanen. Door grondige kalibratie door het testen van de halsbanden op kleine zwanen in gevangenschap konden 6 verschillende gedrags-categorieën met 91% nauwkeurigheid worden geïdentificeerd (**hoofdstuk 3**). De activiteitsbudgetten tijdens de voorjaarsmigratie van de individuele zwanen lieten een aanzienlijke individuele variatie zien in de mate van aquatisch foerageren, hoewel de patronen over het seizoen tussen de individuen vergelijkbaar waren, met verhoogde niveaus van aquatisch foerageren in Estland en in het Witte Zee-gebied in Rusland.

Als een oplossing voor de technische uitdagingen die gepaard gingen met GPS/GSM-tracking van een soort die een deel van het jaar buiten de telefoonontvangst leeft, werd een methode ontwikkeld om met hoge frequentie versnellingsmeter gegevens te kunnen verzamelen (**hoofdstuk 4**). Door het gebruik van de 'samenvattende statistieken' in plaats van de ruwe versnellingsmeter gegevens werd de meet-frequentie (beperkt door de energie en de opslagcapaciteit van het apparaat) met een factor 6 verhoogd, zonder afbreuk te doen aan het vermogen om het gedrag in de gedownloade gegevens te detecteren.

Tussen 2007 en 2019 werden 81 individuele voorjaarsmigraties en 68 individuele herfstmigraties verzameld (**Box 1**). Hoewel de variatie klein was, werd duidelijk dat de zwanen tot op zekere hoogte reageerden op de jaar-op-jaar-variatie in de omgevingsvariabelen. Tegelijkertijd toonde een analyse van individuen die meerdere jaren gevolgd waren overtuigend aan dat zowel de migratiesnelheid als hun relatieve route (uitgedrukt als ‘bochtigheid’) binnen de individuen tussen de jaren zeer consistent waren. Verder vonden we dat, hoewel jonge vogels hun ouders vergezellen op hun eerste herfst- en voorjaarsmigratie, ze hun eigen migratietraditie beginnen te ontwikkelen in hun zelfstandige jaren. Deze bevinding heeft implicaties voor de manier waarop we de ontwikkeling van het migratiegedrag bij soorten met uitgebreide ouderlijke zorg bekijken.

In het licht van de bedreigde status van de kleine zwanen populatie in NW Europa op de Europese Rode Lijst van Vogels is beoordeeld of de huidige beschermingsmaatregelen in NW Europa (voornamelijk het Natura 2000-netwerk) voldoende zijn om belangrijke gebieden voor deze populatie veilig te stellen. Aangezien deze belangrijke gebieden voor de kleine zwaan in de loop van de tijd zijn verschoven (**hoofdstuk 7**), werd vastgesteld dat sommige belangrijke gebieden in de recente jaren niet beschermd waren. Met het oog op het ‘*short-stopping*’ proces dat bij deze populatie is waargenomen, valt te verwachten dat de *mismatch* tussen de belangrijke gebieden voor de zwanen en de beschermde Natura 2000-gebieden met een instandhoudings-doelstelling voor deze soort zal toenemen.

Een gelijksoortige analyse tijdens het voorjaarsmigratieseizoen liet verschillende resultaten zien. De pleisterplaatsen waarvan bekend was dat ze belangrijk waren voor de zwanen, werden in recente jaren nog steeds gebruikt (**hoofdstuk 5**). In het zuidelijke deel van de trekroute, waar de aanwezigheid en de conditie van de macrofyten relatief goed bekend zijn, foerageren de zwanen voornamelijk binnen de grenzen van de beschermde gebieden. In het noordelijke deel zijn er echter minder beschermde gebieden en de zwanen bleken vaak gebruik te maken van gebieden die niet beschermd zijn. De toenemende druk van de menselijke ontwikkeling in combinatie met de lucratieve olie- en gaswinning in het gebied is een onbekende en potentieel significante bedreiging voor het bestaan van vitale pleisterplaatsen voor de zwanen en andere trekkende watervogels in deze migratie flyway (hoofdstuk 5).

Op basis van de resultaten van dit proefschrift kan worden geconcludeerd dat de westelijke populatie van de kleine zwanen in de loop van de studieperiode van ~ 50 jaar aanzienlijke veranderingen heeft laten zien. Deze veranderingen kunnen voor een deel de afname van de populatie verklaren en hebben aangetoond dat de waargenomen populatiegrootte onderhevig is aan de geografische schaal en de timing van de telling. Tegelijkertijd maakt de toenemende *mismatch* tussen het gebruik van de gebieden door de zwanen en de beschermde Natura 2000-gebieden met een instandhoudingsdoelstelling voor de kleine zwaan, in combinatie met de voorziene bedreigingen voor enkele vitale pleisterplaatsen tijdens de voorjaarsmigratie, deze populatie kwetsbaar voor achteruitgang. Om deze en andere soorten die in de loop van de tijd veranderingen in het verspreiding en fenologie laten zien effectief te beschermen, wordt een dynamische vorm van natuurbehoud voorgesteld, waarbij ecologische kennis de basis vormt voor beslissingen die op lokaal niveau worden genomen.

Thank you