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Wildlife and Environment

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Abstract

Environmental change is a pervasive and growing global threat to biodiversity and ecosystems. It has negatively affected most biological systems on our planet and is evolving into a distressing concern for the well-being and survival of many species. At an organism level, effects include decreased reproductive parameters and immuno-suppression that can directly lead to disease or increase the risk of acquiring disease. Living organisms strive to resist the environmental changes to maximum of their abilities. However, rigorous environmental changes may pose additional pressure on immuno-competence, which may seriously impact population viability and persistence. The importance of immune system for healthy survival is outlined and the effects of exposure to a rapidly changing environment are examined that primarily affect the immuno-competence. The potential deficits in reproductive parameters that might arise owing to new immune challenges in the context of a rapidly changing environment are highlighted. The future perspectives and research possibilities are also brought to light.

Keywords: disease, environment, health, immuno-competence, stress, wildlife

Introduction

Environment of an organism is its interaction with biotic and abiotic components of ecosystem that is required for its survival. Climate change is a persistent and growing global threat to biodiversity and ecosystems which affects individual species and the way they interact with other organisms and their habitats and alters the structure and function of ecosystems (Díaz *et al.*, 2019) [16]. The major factors that are responsible for environmental degradation are habitat loss (Berry, 2008) [8], soil erosion, deforestation, desertification (Andrew, 2013) [3], Climate shift, flooding, resource depletion, invasive species and habitat fragmentation (Berry, 2008) [8]. Consequences of environmental change on biodiversity take in multiple and complex dynamic processes. These can manifest at several levels. For example, habitat degradation not only decrease food availability and movement restriction in animals, but also may increase the opportunity for contact among humans, domestic livestock and wildlife (Deem *et al.*, 2001) [15], thereby enhancing disease transmission rates (Smith *et al.*, 2009) [5]. Pollutants can alter habitat quality and reduce nutrient availability which can indirectly affect the survival (Smith, 2003; Havens, 2008; Paul, 2008) [5, 26, 44], reproduction (Reusch and Wood, 2007; Sonne *et al.*, 2007) [46, 53] and immuno-competence (Selgrade, 2007) of sensitive species. Thus environmental change is likely to seriously impair the viability of wildlife.

Living organisms are accordingly well adapted to environmental pressures (Reusch and Wood, 2007) [46]. However, the current pace of environmental change is unprecedented (Thomas *et al.*, 2004) [56]. So, it is unknown whether the species can adapt to such changes. Data on the effects of environmental change on wildlife health is limited. Although climate change impacts are widespread, they are not uniform, and accumulating evidence indicates that climate change responses vary as a function of relative vulnerability due to differences in exposure, sensitivity, and adaptive capacity (Beever *et al.*, 2016; Foden and Young, 2016; Kovach *et al.*, 2019) [5, 20, 32]. Below, we discuss major impacts observed at the scale of individuals, populations, and species.

Changes in behavior and morphology

Behavioral responses to climate change can result from changes in temperature and manifest before changes at the population and species level, such as distribution changes or population declines (Beever *et al.*, 2017) [6]. Behavioral responses include seeking shade or refuge, altering feeding times, changing site use, and shifting circadian or circannual rhythms e.g., hibernation, migration (Bradshaw and Holzapfel, 2007; Beever *et al.*, 2017; McCann *et al.*, 2017) [10, 5, 39]. Morphological changes commonly entail changes in body size (Ozgul *et al.*, 2010; Eastman *et al.*, 2012; Cheung *et al.*, 2013) [42]. For example, increasing summer temperatures have been associated with reduced body size and increased wing length in migratory birds (Weeks *et al.*, 2019) [61]. In ectotherms, where metabolic rate is sensitive to temperature (Gardner *et al.*, 2011) [22], warmer temperatures can lead to faster growth rates but can ultimately lead to smaller body size (Atkinson, 1994) [4]. Morphological responses, however, are complex and highly variable: changes in phenotype may not be observed if genetic change is counteracted by environmental effects (Conover *et al.*, 2009) [13].

Phenology

Phenology, or the seasonal timing of recurring biological events, is a critical part of ecological relationships (Rudolf, 2019) [48], and a primary indicator of species responses to climate change (Staudinger *et al.*, 2019) [54]. Migratory birds provide clear examples of phenological shifts, with extensive documentation of earlier migration (Lehikoinen *et al.*, 2019) [34] and earlier breeding (Lany *et al.*, 2016) [33] in response to rising temperatures and altered precipitation patterns. Phenological shifts in marine and aquatic habitats are less well documented in comparison to terrestrial systems, largely due to difficulty detecting and tracking aquatic organisms (Staudinger *et al.*, 2019) [54]. Marine phytoplankton can respond rapidly to such abiotic changes, resulting in altered timing of phytoplankton blooms (Wasmund *et al.*, 2019) [60], which in turn can create a mismatch with secondary consumers and change the foodweb structure (Sundby *et al.*, 2016; Post, 2017) [55, 45]. Differential shifts in phenology among interacting organisms could drive population declines through reduced reproductive success and/or increased predation or competition (Zimova *et al.*, 2016; Visser and Gienapp, 2019; Wann *et al.*, 2019) [62, 58].

Immune suppression

Stress to animals can be of any form, be it a predator, overcrowding, an infective parasite or thermal extremes (Husband and Bryden, 1996) [28]. A number of mechanisms are used by animals to counteract or mitigate negative effects of stress responses, such as seasonal modulation of responses (Romero, 2002) [14], acclimatization (French *et al.*, 2008) [21] and reduction in hypothalamic-pituitary-adrenal (HPA) activity (Cyr *et al.*, 2007) [14]. These mechanisms allow individuals to survive, despite environmental changes. However, it is possible that co-occurring or unpredictable stressors may exceed those mechanisms (Romero, 2002) [14]. The consequences of facing and dealing with unpredictable stressors arising from erratic environments may pose additional pressures on the optimal functioning of the immune system and ultimately harm the health and survival of wild populations (Martin, 2009) [36].

To fully understand the impacts of environmental change on wildlife health, potential immunosuppressive effects of chronic and unpredictable stressors must be taken into account. Environmental changes have led to the emergence of over 40 infectious diseases since 1970, such as HIV/AIDS, Ebola and other viral haemorrhagic diseases, new strains of cholera, ranavirus and chytrodiomycosis in amphibians and antibiotic-resistant tuberculosis, and this trend is predicted to increase in the future (Aguirre and Tabor, 2008; Jones *et al.*, 2008; Smith *et al.*, 2009) [2, 5, 30].

Diseases

Climate change has altered physical and biological components of the environment, causing shifts in temperature ranges and rainfall indexes and altering the abundance and distribution of predator and prey species, as well as of pathogens and hosts (MacLeod *et al.*, 2007; Tibbetts, 2007; Patz *et al.*, 2008) [35, 57, 43]. Droughts and scarcity of food associated with climate change are regular occurrences and are expected to become more frequent, particularly in arid and semi-arid ecosystems (Easterling *et al.*, 2000) [37]. During these extreme climatic events, poor nutrition (i.e. suboptimal levels of protein, vitamins and other essential nutrients) and dehydration will lead to depletion of fat reserves, poor body condition (Beldomenico *et al.*, 2008) [7] and may decrease innate and acquired immune responses. This will reduce resistance to infection, which in turn can impair nutrient absorption owing to altered gut permeability and inflammation, leading to aggravation of the nutritional status (Katona and Katona-Apte, 2008) [31] and further decreasing the chances of survival (Matthews *et al.*, 2006; Beldomenico *et al.*, 2008) [38, 7]. For wildlife, such events could have disastrous consequences for already depleted populations. Meeting the energetic demands placed by nutritional stress in order to survive is likely to impact upon the demands of other physiological processes, such as immunity, growth, maintenance and reproduction (Houston *et al.*, 2007) [27], even though this resource allocation might result in decreased population fitness. Under this assumption, animals faced with nutritional stress will invest less in reproduction or in maintaining optimal immune responses because in that situation it is more important to reduce the immediate risk of death from starvation, malnutrition or dehydration.

Cancer

Although it is likely that the malignant tumors reported for wildlife only account for a fraction of the real cases, the striking difference in incidence rates 4.5% or less in captive and free-ranging wildlife compared with 30% in humans (Nagy *et al.*, 2007) [40], suggests that cancer is not normally a significant health problem for wildlife. However, there are exceptions like epithelial-cell carcinomas of urogenital origin (Gulland *et al.*, 1996; Buckles *et al.*, 2006) [1, 9]. Genetic factors seem to play a role in this disease, with high levels of inbreeding (Acevedo-Whitehouse *et al.*, 2003) [51] and specific MHC alleles found to be associated with an increased risk for cancer (Bowen *et al.*, 2005) [9]. The emergence of this condition in sea lions is an excellent example of the complex ways in which environmental change can affect wildlife health.

Reproductive failure

One of the major complications for wildlife health arises from the link between the immune and reproductive systems because of resource partitioning. Maintaining a competent immune system will incur an energetic cost; thus, the resources required to mount specific immune responses may be drawn away from other key physiological processes, such as growth and reproduction (Norris and Evans, 2000; Sheldon and Verhulst, 1996) [41, 50]. Devoting resources for reproduction might decrease future reproductive success through the investment in immune responses (Gustafsson *et al.*, 1994) [24]. If the energetic demands to cover an immune response were not met, the likely consequence would be the occurrence of disease, which might then lead to reduced host performance and increased mortality (Hanssen *et al.*, 2003) [25]. A growing number of experimental studies have shown that increased immune activity diverts resources from traits such as development of sexual ornamentation (e.g. Zuk and Johnsen, 2000) [63], clutch size (e.g. Martin *et al.*, 2001) [37], nestling provisioning (e.g. Ilmonen *et al.*, 2000) [29] and offspring growth rates (e.g. Fair *et al.*, 1999) [19].

Conclusions and future directions

Wildlife health is closely related to environment. Environment is undergoing rapid change, which have the potential to perilously inflict severe damage on the health of wild animals. Consequences are not only important at an individual level (e.g. cancer and immuno-suppression), but can have important population level implications (e.g. reduced reproduction; population decline; reduced immune responses; increased infectious disease). The mounting rates of both infectious and non-infectious diseases in wildlife are of great concern. While examining the influences of environmental change on the health of wild animals, multiple factors and the interactions between them need to be considered. There is insufficient research done on this topic. The abundant data and laboratory tools developed for studies of humans can be exceptionally useful for wildlife health too. This approach will certainly allow researchers to examine the root causes of troublesome health conditions and potential future diseases for wildlife in the perspective of a rapidly changing environment. Natural resource managers need proactive, flexible adaptation strategies that consider historical and future outlooks to minimize costs over the long term. Many organizations are beginning to explore these approaches, but implementation is not yet prevalent or systematic across the world.

References

1. Acevedo-Whitehouse K, Gulland F, Greig D, Amos W. Inbreeding: disease susceptibility in California sea lions. Nature 2003; 422: 35. (https://doi:10.1038/422035a)
2. Aguirre AA, Tabor GM. Global factors driving emerging infectious diseases. Ann. NY Acad. Sci. 2008; 1149:1-3. (https://doi:10.1196/annals.1428.052)
3. Andrew S. Resource Depletion, Climate Change, and Economic Growth. Global citizen foundation, 2013, 1-49.
4. Atkinson D. Temperature and organism size - a biological law for ectotherms. Adv. Ecol. Res, 1994; 25:1-58.
5. Beever EA, Hall LE, Varner J, Loosen AE, Dunham JB, Gahl MK, Smith FA, Lawler JJ. Behavioral flexibility as a mechanism for coping with climate change. Front. Ecol. Environ, 2017; 15:299-308. (https://doi.org/10.1002/fee.1502)
6. Beever EA, O’Leary J, Mengelt C, West JM, Julius S, Green N, *et al*. Improving conservation outcomes with a new paradigm for understanding species’ fundamental and realized adaptive capacity. Conserv. Lett, 2016; 9:131-137. (https://doi.org/10.1111/conl.12190)
7. Beldomenico PM, Telfer S, Gebert S, Lukomski L, Bennett M, Begon M, *et al*. Poor condition and infection: a vicious circle in natural populations. Proc. R. Soc. B, 2008; 275:1753-1759. (https://doi:10.1098/rspb.2008.0147)
8. Berry L. The impact of environmental degradation on refugee-host relations: a case study from Tanzania, 2008, 1-27.
9. Bowen L, Aldridge BM, Delong R, Melin S, Buckles EL, Gulland F, *et al*. An immunogenetic basis for the high prevalence of urogenital cancer in a free-ranging population of California sea lions (Zalophus californianus). Immunogenetics, 2005; 56:846-848. (https://doi:10.1007/s00251-004-0757-z)
10. Bradshaw WE, Holzapfel CM. Evolution of animal photoperiodism. Annu. Rev. Ecol. Evol. Syst, 2007; 38:1-25. (https://doi.org/10.1146/annurev.ecolsys.37.091305.110115)
11. Buckles EL, Lowenstine LJ, Funke C, Vittore RK, Wong HN, St Leger JA, *et al*. Otarine Herpesvirus-1, not papillomavirus, is associated with endemic tumours in California sea lions (Zalophus californianus). Journal of comparative pathology. 2006; 135(4):183-189. (https://doi:10.1016/j.jcpa.2006.06.007)
12. Cheung WWL, Sarmiento JL, Dunne J, Frölicher TL, Lam VWY, Palomares MLD, *et al*. Shrinking of fishes exacerbates impacts of global ocean changes on marine ecosystems. Nat. Clim. Chang, 2013; 3:254-258. (https://doi.org/10.1038/nclimate1691)
13. Conover DO, Duffy TA, Hice LA. The covariance between genetic and environmental influences across ecological gradients: reassessing the evolutionary significance of countergradient and cogradient variation. Ann. N. Y. Acad. Sci, 2009; 1168:100-29. (https://doi.org/10.1111/j.1749-6632.2009.04575.x)
14. Cyr NE, Earle K, Tam C, Romero LM. The effect of chronic psychological stress on corticosterone, plasma metabolites, and immune responsiveness in European starlings. Gen. Comp. Endocrinol, 2007; 154:59-66. (https://doi:10.1016/j.ygcen.2007.06.016)
15. Deem SL, Kaersh WB, Weisman W. Putting theory into practice: wildlife health in conservation. Conserv. Biol, 2001; 15:1224-1233. (https://doi:10.1046/j.1523-1739.2001.00336.x)
16. Díaz S, Settele J, Brondízio E, Ngo HT, Guèze M, Agard Trinidad J, *et al*. Summary for Policymakers of the Global Assessment Report on Biodiversity and Ecosystem Services of the Intergovernmental Science-policy Platform on Biodiversity and Ecosystem Services. Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, Bonn, Germany, 2019.
17. Easterling DR, Meehl GA, Parmesan C, Changnon SA, Karl TR, Mearns LO, *et al*. Climate extremes: observations, modeling, and impacts. Science, 2000; 289:2068-2074. (https://doi:10.1126/science.289.5487.2068)
18. Eastman LM, Morelli TL, Rowe KC, Conroy CJ, Moritz C. Size increase in high elevation ground squirrels over the last century. Glob. Chang. Biol. 2012; 18: 1499–1508. (https://doi.org/10.1111/j.1365-2486.2012.02644.x)
19. Fair JM, Hansen ES, Ricklefs RE. Growth, developmental stability and immune response in juvenile Japanese quails (Coturnix coturnix japonica). Proc. Biol. Sci, 1999; 266:1735-1742. (https://doi:10.1098/rspb.1999.0840)
20. Foden WB, Young BE. IUCN SSC Guidelines for Assessing Species Vulnerability to Climate Change (IUCN Species Survival Commission, Cambridge, UK, and Gland, Switzerland), 2016, 59:114.
21. French SS, Fokidis HB, Moore MC. Variation in stress and innate immunity in the tree lizard (Urosaurus ornatus) across an urban-rural gradient. J Comp. Physiol. B, 2008; 178:997-1005.
22. Gardner JL, Peters A, Kearney MR, Joseph L, Heinsohn R. Declining body size: a third universal response to warming? Trends Ecol. Evol, 2011; 26:285-291. (https://doi.org/10.1016/j.tree.2011.03.005)
23. Gulland FM, Trupkiewicz JG, Spraker TR, Lowenstine LJ. Metastatic carcinoma of probable transitional cell origin in 66 free-living California sea lions (Zalophus californianus), 1979 to 1994. J. Wildl. Dis. 1996; 32: 250-258.
24. Gustafsson L, Nordling D, Andersson MS, Sheldon BC, Qvarnstrom A. Infectious diseases, reproductive effort and

the cost of reproduction in birds. Phil. Trans. R. Soc. Lond. B, 1994; 346:323-331. (https://doi:10.1098/rstb.1994.0149)

25. Hanssen SA, Folstad I, Erikstad KE. Reduced immunocompetence and cost of reproduction in common eiders. Oecologia, 2003; 136:457-464. (https://doi:10.1007/s00442-003-1282-8)
26. Havens KE. Cyanobacteria blooms: effects on aquatic ecosystems. Adv. Exp. Med. Biol, 2008; 619:733-747. (https://doi:10.1007/978-0-387-75865-7_33)
27. Houston AI, McNamara JM, Barta Z, Klasing KC. The effect of energy reserves and food availability on optimal immune defence. Proc. R. Soc. B, 2007; 274:2835-2842. (https://doi:10.1098/rspb.2007.0934)
28. Husband AJ, Bryden WL. Nutrition, stress and immune activation. Proc. Nutr. Soc. Austr, 1996; 20:60-70.
29. Ilmonen P, Taarna T, Hasselquist D. Experimentally activated immune defence in female pied flycatchers results in reduced breeding success. Proc. R. Soc. B. 2000; 267:665-670. (https://doi:10.1098/rspb.2000.1053)
30. Jones KE, Patel NG, Levy MA, Storeygard A, Balk D, Gittleman JL, *et al*. Global trends in emerging infectious diseases. Nature, 2008; 451:990-993. (https://doi:10.1038/nature06536)
31. Katona P, Katona-Apte J. The interaction between nutrition and infection. Clin. Infect. Dis, 2008; 46:1582-1588. (https://doi:10.1086/587658)
32. Kovach RP, Dunham JB, Al-Chokhachy R, Snyder CD, Letcher BH, Young JA, *et al*. An integrated framework for ecological drought across riverscapes of North America. Bioscience, 2019; 69:418-431. (https://doi.org/10.1093/biosci/biz040)
33. Lany NK, Ayres MP, Stange EE, Sillett TS, Rodenhouse NL, Holmes RT, *et al*. Breeding timed to maximize reproductive success for a migratory songbird: the importance of phenological asynchrony. Oikos, 2016; 125:656-666. (https://doi.org/10.1111/oik.02412)
34. Lehikoinen A, Lindén A, Karlsson M, Andersson A, Crewe TL, Dunn EH, *et al*. Phenology of the avian spring migratory passage in Europe and North America: asymmetric advancement in time and increase in duration. Ecol. Indic, 2019; 101:985-991. (https://doi.org/10.1016/j.ecolind.2019.01.083)
35. MacLeod CD, Santos MB, Reid RJ, Scott BE, Pierce GJ. Linking sandeel consumption and the likelihood of starvation in harbour porpoises in the Scottish North Sea: could climate change mean more starving porpoises? Biol. Lett, 2007; 3:185-188. (https://doi:10.1098/rsbl.2006.0588)
36. Martin LB. Stress and immunity in wild vertebrates: timing is everything. Gen. Comp. Endocrinol, 2009; 163:70-76.
37. Martin TE, Moller AP, Merino S, Clobert J. Does clutch size evolve in response to parasites and immunocompetence? Proc. Natl Acad. Sci. USA, 2001; 98:2071-2076. (https://doi:10.1073/pnas.98.4.2071)
38. Matthews RJ, Jagger C, Hancock RM. Does socio-economic advantage lead to a longer, healthier old age? *Soc. Sci. Med*, 2006; 62:2489-2499. (https://doi:10.1016/j.socscimed.2005.11.019)
39. McCann EL, Johnson NS, Pangle KL. Corresponding long-term shifts in stream temperature and invasive fish migration. Can. J Fish. Aquat. Sci, 2017; 778:1-7. (https://doi.org/10.1139/cjfas-2017-0195)
40. Nagy JD, Victor EM, Cropper, JH. Why don't all whales have cancer? A novel hypothesis resolving Peto's paradox. Integr. Comp. Biol. 2007, 2007, 1-12.
41. Norris K, Evans MR. Ecological immunology: life history trade-offs and immune defense in birds. Behav. Ecol, 2000; 11:19-26. (https://doi:10.1093/beheco/11.1.19)
42. Ozgul A, Childs DZ, Oli MK, Armitage KB, Blumstein DT, Olson LE, *et al*. Coupled dynamics of body mass and population growth in response to environmental change. Nature, 2010; 466:482-485. (https://doi.org/10.1038/nature09210)
43. Patz JA, Olson SH, Uejio CK, Gibbs HK. Disease emergence from global climate and land use change. Med. Clin. North Am, 2008; 92:1473-1491. (https://doi:10.1016/j.mcna.2008.07.007)
44. Paul VJ. Global warming and cyanobacterial harmful algal blooms. Adv. Exp. Med. Biol, 2008; 619:239-257.
45. Post E. Implications of earlier sea ice melt for phenological cascades in arctic marine food webs. Food Webs, 2017; 13:60-66. (https://doi.org/10.1016/j.fooweb.2016.11.002)
46. Reusch TB, Wood TE. Molecular ecology of global change. Mol. Ecol, 2007; 16:3973-3992. (https://doi:10.1111/j.1365-294X.2007.03454.x)
47. Romero, L.M. Seasonal changes in plasma glucocorticoid concentrations in free-living vertebrates. Gen. Comp. Endocrinol, 2002; 128:1-24.
48. Rudolf VHW. The role of seasonal timing and phenological shifts for species coexistence. Ecol. Lett, 2019; 22:1324-1338. (https://doi.org/10.1111/ele.13277)
49. Selgrade MK. Immunotoxicity: the risk is real. Toxicol. Sci, 2007; 100:328-332. (https://doi:10.1093/toxsci/kfm244)
50. Sheldon BC, Verhulst S. Ecological immunology: costly parasite defenses and trade-offs in evolutionary ecology. Trends Ecol. Evol, 1996; 11:317-321. (https://doi:10.1016/0169-5347(96)10039-2)
51. Smith KF, Acevedo-Whitehouse K, Pedersen AB. The role of infectious diseases on biodiversity. Anim. Conserv, 2009; 21:1-12.
52. Smith VH. Eutrophication of freshwater and coastal marine ecosystems: a global problem. Environ. Sci. Pollut. Res. Int, 2003; 10:126-139. (https://doi:10.1065/espr2002.12.142)
53. Sonne C, Dietz R, Born EW, Riget FF, Leifsson PS, Bechshoft TO, *et al*. Spatial and temporal variation in size of polar bear (*Ursus maritimus*) sexual organs and its use in pollution and climate change studies. Sci. Total Environ, 2007; 387:237-246.
54. Staudinger MD, Mills KE, Stamieszkin K, Record NR, Hudak CA, Allyn A, *et al*. It's about time: a synthesis of changing phenology in the Gulf of Maine ecosystem. Fish. Oceanogr. 2019; 28(5):532-566. (https://doi.org/10.1111/fog.12429)
55. Sundby S, Drinkwater KF, Kjesbu OS. The North Atlantic spring-bloom system-where the changing climate meets the winter dark. Front. Mar. Sci, 2016; 3:28.
56. Thomas CD, Cameron A, Green RE, Bakkenes M, Beaumont LJ, Collingham YC, *et al*. Extinction risk from climate change. Nature. 2004; 427(6970):145-148. (https://doi:10.1038/nature02121)

57. Tibbetts J. Driven to extremes: health effects of climate change. Environ. Health Perspect, 2007; 115:A196-A203.
58. Visser ME, Gienapp P. Evolutionary and demographic consequences of phonological mismatches. Nat. Ecol. Evol, 2019; 3:879-885.
59. Wann GT, Aldridge CL, Seglund AE, Oyler-McCance SJ, Kondratieff BC, Braun CE, *et al*. Mismatches between breeding phenology and resource abundance of resident alpine ptarmigan negatively affect chick survival. Ecol. Evol. 2019; 9(12):200-7212. (https://doi.org/10.1002/ece3.5290)
60. Wasmund N, Nausch G, Gerth M, Busch S, Burmeister C, Hansen R, *et al*. Extension of the growing season of phytoplankton in the western Baltic Sea in response to climate change. Mar. Ecol. Prog. Ser, 2019; 622:1-16. (https://doi.org/10.3354/meps12994)
61. Weeks BC, Willard DE, Ellis AA, Witynski ML, Winger BM. Shared morphological consequences of global warming in North American migratory birds. Ecol. Lett. 2019; 23(2):316-325. (https://doi.org/10.1101/610329)
62. Zimova M, Mills LS, Nowak JJ. High fitness costs of climate change induced camouflage mismatch in a seasonally colour moulting mammal. Ecol. Lett, 2016; 19:299-307. (https://doi.org/10.1111/ele.12568)
63. Zuk M, Johnsen T. Social environment and immunity in male red jungle fowl. Behav. Ecol, 2000; 11:146-153. (https://doi:10.1093/beheco/11.2.146)