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Climate Change Responses

COMMENTARY Open Access

Climate change impacts on animal migration

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Commentary

This is the first in a regular series of mini-review which highlight outstanding recently published papers that shed new light on biological responses to climate change. We chose migration as the topic for the first mini review because its global geographical scale makes migrating individuals particularly vulnerable to climate change, and at the same time, the process of migration has fundamental impacts on ecological processes and biodiversity.

Movement is an integral part of the ecology of many animals, and it can affect individual fitness and population persistence by enabling foraging and predation, behavioural interactions, and migration [1]. Migration, in particular, affects biodiversity at regional and global scales, and migratory animals affect ecosystem processes. Animals use predictable environmental cues for the timing and navigation of migration. A change in these cues will affect the phenology and extent of migration. Arrival date and hatching date are phenological markers in migrating birds, for example, that can be strongly affected by global warming. These dynamics have been incorporated into a mathematical model recently [2]. Higher temperatures cause earlier appearance of the insect prey of hatchling birds, which exerts pressure on birds to breed earlier so that hatchling development coincides with peak prey abundance. Advanced breeding is dependent on the arrival time of the adults at the breeding site, as well as the delay between arrival and the start of breeding. These traits can change synchronously or asynchronously, and a mismatch between prey abundance and hatching can cause population declines. The mathematical model [2] explores the dynamics of these interactions and their evolutionary trajectories, and it can explain patterns observed in European flycatchers. Conversely, departure from their non-breeding grounds in Africa also appears to occur earlier for at least some Palearctic migratory birds [3]. Hence, there is a global shift in departure and arrival times that affects migratory bird movement and local abundance as a result of climate warming.

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Phenological shifts in migration of endothermic birds are linked to the abundance of their ectothermic prey. Although endotherms are also directly affected by changes in temperature, which affects their metabolic demands for thermoregulation, these direct effects are more pronounced in ectotherms. The body temperature and hence physiology of ectotherms such as invertebrates and fish is closely tied to environmental temperatures. Climate warming will therefore influence metabolism and other physiological processes directly in ectotherms, and this can have pronounced effects on movement and migration.

The proximate mechanisms that enable movement are the physiological functions that provide energy to the muscles and the muscles themselves that transform chemical energy (ATP) to work. All physiological processes are influenced by temperature, to varying degrees and usually optimal physiological rates are achieved within a relatively narrow temperature range. At extreme low or high temperatures, cessation of physiological functions leads to mortality [4]. But even at more benign temperatures that nonetheless diverge from the optimal range, decreases in physiological performance increase ecological failure by impairing movement [5]. Hence, changing environmental temperatures, including changes resulting from anthropogenic global warming, impact migration and other ecological processes via the thermal sensitivity of physiological processes.

A new theoretical model now suggests that in Chinook salmon, metabolic constraints exacerbate the effect of temperature on the metabolic costs of migration [6]. Salmon often migrate hundreds of kilometres from their natal riverine areas to the ocean and return to their natal areas for spawning. Salmon prefer relatively cool water, and increasing water temperatures compromise their cardiovascular and metabolic physiology [5]. If fish did not have to replenish metabolic substrates (in particular glycogen) during their migration, the effects of warm water could be mitigated by swimming through warm sections of river rapidly. However, the need to replenish substrates by resting in tranquil warm water increases migration times and therefore exposure to warm waters [6]. Replenishment of substrates and increased exposure to warm water reduce the metabolic scope, that is the energy available for migration, because metabolic maintenance costs increase in warmer water. These effects are amplified because cardiovascular efficiency is compromised as temperatures increase beyond optimal ranges, thereby further reducing metabolic scope. These physiological dynamics mean that climate warming along the North American west coast has already affected salmon migration [5, 6]. The examples from salmon emphasise that predictions of future effects of climate change require detailed physiological studies.

Similar to birds, a recent study has shown that the phenology of migration of aphids in the UK has changed as a result of climate change [7]. Seven hundred seventy trap-years of data collected over the past 50 years showed that over 55 species of aphids started flying progressively earlier in the year, and most species showed increasing duration of their flying season. The severity of the previous winter was the best predictor for the onset of the subsequent flying season, and the number of days above 16 °C predicted flying behaviour later in the year [7]. Correlations of phenological changes with climate change are essential starting points that need to be followed up with experimental approaches to determine the cause-and-effect relationships between climate change and animal responses [8]. The strength of the salmon studies [5, 6] is that at least some of the mechanistic bases for the climate-dependent change in migration pattern have been identified. Hence, it is possible to determine the thermal sensitivity of, for example, cardiovascular function and metabolism experimentally, and use these data to predict the effects of future or regional climate change.

In addition to shifts in phenology of migrating animals, some species have reduced their migratory behaviour or even formed sedentary populations as a result of anthropogenic changes to the environment [9, 10]. A new study now shows that changes in migratory behaviour also alter the incidence of infectious disease and its transmission [11]. Migration can reduce the incidence of disease because individuals leave contaminated habitats periodically, individuals are more separated from each other during migration, and infected individuals are likely to succumb to demanding long-distance movement. Monarch butterflies in the US have drastically changed their migratory behaviour in recent years as a result of habitat alterations, and the incidence of sedentary, non-migratory populations is increasing. Non-migratory populations have a significantly greater rate of infection by the protozoan *Ophryocystis elektroscirrha* compared to migratory populations. Infected butterflies have significantly reduced lifespan [11]. Changes in animal movement and migration as a result of habitat modification and climate change may therefore alter lifetime fitness of individuals in addition to biodiversity and ecosystem processes at regional and global scales.

Competing interests
The authors declare that they have no competing interests.

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References
1. Nathan R, Getz WM, Revilla E, Holyoak M, Kadmon R, Saltz D, Smouse PE (2008) A movement ecology paradigm for unifying organismal movement research. Proc Natl Acad Sci 105:19052–9.
2. Kristensen NP, Johansson J, Ripa J, Jonzen N (2015) Phenology of two interdependent traits in migratory birds in response to climate change. Proc R Soc B 282:20150288.
3. Bussière EMS, Underhill LG, Altwegg R (2015) Patterns of bird migration phenology in South Africa suggest northern hemisphere climate as the most consistent driver of change. Global Change Biol 21:2179–90.
4. Tattersall GJ, Sinclair BJ, Withers PC, FIields PA, Seebacher F, Cooper CE, Maloney SK (2012) Coping with thermal challenges: physiological adaptations to environmental temperatures. Comprehensive Physiol 2:2151–202.
5. Eliason EJ, Clark TD, Hague MJ, Hanson LM, Gallagher ZS, Jeffries KM, Gale MK, Patterson DA, Hinch SG, Farrell AP (2011) Differences in thermal tolerance among sockeye salmon populations. Science 332:109–12.
6. Martin BT, Nisbet RM, Pike A, Michel CJ, Danner EM (2015) Sport science for salmon and other species: ecological consequences of metabolic power constraints. Ecol Lett 18:535–44.
7. Bell JR, Alderson L, Izera D, Kruger T, Parker S, Pickup J, Shortall CR, Taylor MS, Verrier P, Harrington R (2015) Long-term phenological trends, species accumulation rates, aphid traits and climate: five decades of change in migrating aphids. J Anim Ecol 84:21–34.
8. Seebacher F, Franklin CE (2012) Determining environmental causes of biological effects: the need for a mechanistic physiological dimension in conservation biology. Phil Trans R Soc B 367:1607–14.
9. Fiedler W, Bairlein F, Köppen U (2004) Using large-scale data from ringed birds for the investigation of effects of climate change on migrating birds: pitfalls and prospects. Adv Ecol Res 35:49–67.
10. Evans KL, Newton J, Gaston KJ, Sharp SP, McGowan A, Hatchwell BJ (2012) Colonisation of urban environments is associated with reduced migratory behaviour, facilitating divergence from ancestral populations. Oikos 121:634–40.
11. Satterfield DA, Maerz JC, Altizer S (2015) Loss of migratory behaviour increases infection risk for a butterfly host. Proc R Soc B 282:20141734.