Abstract

Movements of long-distance migratory birds are frequently well timed and routed in order to maximise individual fitness. However, individual timing of events or environmental conditions experienced have a potential to carry over into subsequent annual cycle stages and may have delayed fitness consequences. Therefore, knowledge of these seasonal interactions is crucial to identify key periods and regions that limit survival beyond the breeding period and thus to fully understand population dynamics of migratory species. Despite current evidence for seasonal interactions, there is no detailed knowledge of the complex of relationships within the full annual cycle, differences between sexes and populations or impact of environmental conditions during moult in one species.

To unveil this system of seasonal interactions within the annual cycle, we directly tracked 103 great reed warblers (*Acrocephalus arundinaceus*) using light-level geolocators from five breeding sites across the breeding range to obtain information on timing and positions of annual cycle events. We then combined this information with various remotely sensed habitat condition metrics and stable isotopic composition of feathers from the non-breeding grounds to identify and quantify carry-over effects within the full annual cycle.

Our results supported the previously suggested domino effect between timing of consecutive events within migratory phases and buffering capacity of the non-breeding period preventing events to carry over between migratory periods. Contrary to our predictions, we did not identify any strong or moderate effect of habitat quality experienced during the whole non-breeding period but, interestingly, variability of vegetation condition during moult affected both spring migration course and timing of breeding site arrival. Moreover, the carry-over effects appeared to be strongest in the southernmost breeding population compared to central and north European population and did not differ between males and females. Our results provide a first full picture of carry-over effects within the annual cycle in the species and we recommend integrating these results into detailed population models that could better explain species population dynamics.

We also suggest future studies to focus on the effect of inter-specific interaction on the non-breeding grounds on the subsequent annual cycle stages. Finally, as the number of tracking studies is steadily growing, we suggest summarising the current knowledge on seasonal interactions across species and populations in a quantitative review to unveil more general trends.