

Disentangling the migration phases during the non-breeding period reveals uneven carry-over effects to the subsequent breeding in a diving seabird

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Organisms that reproduce in mid- to high-latitude environments face the constraint of marked seasonality in the local availability of their food resource, which may cause detrimental conditions over the non-breeding season. Migratory animals are unique in offsetting this adverse situation by seasonally travelling extensive distances at the surface of the Earth to temporarily exploit other, favourable habitats located away from their breeding grounds. However, this strategy exposes migratory animals to carrying-over the impacts of potentially poor winter habitat suitability, to their subsequent breeding timing and performance.

Many seabird species exhibit such marked seasonal movements, connecting separated marine habitats across their annual cycle. However, for these movements taking place at sea, it has been challenging to study them finely and to link the breeding timing and outputs observed ashore, to any specific feeding phase of the birds along their journey.

Recent progress in animal tracking now allow surveying the at-sea ecology of seabirds on a year-round basis. To investigate the link between at-sea ecology of the birds during the non-breeding period and their following breeding timing and performance, we tracked Rhinoceros auklets (*Cerorhinca monocerata*, Alcidae) during their non-breeding period over 4 successive years from Teuri Island, Hokkaido, Japan (Japan Sea) using light-based geolocation loggers (n=48 datasets in total). This pluri-annual survey provided us the opportunity of a natural experiment to test for the effects of interannual variability in feeding conditions on the birds' migratory and breeding patterns. We used a "broken-stick" model to segment staging versus commuting phases within the individual tracks at sea. Besides, continuous colony-based monitoring allowed detailing the annual breeding timing and output of the birds.

We reveal that the dates of breeding onset in spring were significantly linked to the previous winter stopover and pre-laying periods' duration. On the contrary, later dates of post-breeding departure in autumn had no significant effect on the following breeding timing, and the duration of migrating phases were little variable across years. Moreover, trophic niche inferred from isotopic signature of blood collected in the early breeding season suggested that feeding at a lower trophic level during pre-laying phase correlated with later breeding onset dates. Finally, we confirm that the laid eggs were significantly smaller on average during years of later breeding.

We conclude that foraging conditions at sea during these two phases (and only these: winter and pre-laying) of the non-breeding period may generate cumulative carry-over effects to the subsequent reproductive period in this migratory seabird, both in terms of timing and performance. However, our study also suggests that extrinsic invariable cues such as celestial circannual rhythms might allow the birds to reset their migratory timing, what would limit the possible drift in migration timing across seasons.