Keeping up with early springs- will migratory goose survive the challenges induced by climate change?

Warming due to climate change is the most rapid in the arctic, a phenomenon known as arctic amplification, hence, spring phenology arises earlier in arctic as compared to temperate regions (Lameris et al., 2017; Layton-Matthews et al., 2020). Goose migration has advanced in recent decades to reach the arctic breeding grounds early, their egg laying, however, has not changed accordingly (Lameris et al., 2018). This causes a mismatch between the arrival and breeding of migratory birds in accordance with spring phenology in arctic, as their wintering grounds in temperate areas have a comparatively lower warming rate (Bauer et al., 2008; Nolet et al., 2020). The aim of this study is to understand the effects of the mismatch between the arrival of geese and early spring onset on the migration and population demographics of arctic breeding geese. The migration of geese has undergone a sudden shift during extreme warming years and there has been a gradual shift of staging sites towards a colder climate zone (Loonen & Schaafsma, unpublished; Van Der Jeugd et al., 2009; Ward et al., 2009). Some goose populations tend to skip staging sites to arrive arctic in accordance with early spring for defending and occupying breeding sites (Lameris et al., 2018; Nolet et al., 2020).

Early spring is advantageous for goose species with both- income as well as capital breeding strategies as the food is abundant and nutritious for pre-nesting birds (Lameris et al., 2019; Layton-Matthews et al., 2021). These nutrients can be used to improve body conditions after migration as well as for egg development (Ely et al., 2007; Hupp et al., 2018). In barnacle geese (*Branta leucopsis*), early spring increased the probability to reproduce for the first time, resulting in many young (2 year old) females to reproduce successfully (Fjelldal et al., 2020). Geese with low body conditions were able to obtain enough resources in the pre-nesting phase to reproduce successfully (Layton-Matthews et al., 2021). Increase in goose population further resulted in an extension of their breeding sites northward due to the availability of food and nesting sites because of warmer climate and less population density (Fjelldal et al., 2020; Tombre et al., 2008; Ward et al., 2009).

The food peak shifts with an early spring, therefore the goslings that hatch from late nests may obtain plant material with deteriorating nutrition value, consequently resulting in adults with lower body condition (Cooch et al., 1991; Nolet et al., 2020). Furthermore, predation pressure on migratory goose have increased in the past decades. Lemmings, an important food source for arctic fox, have been undergoing faltering population cycles, which is a suspected consequence of recent warm winters. This results in an increased predation pressure on migratory geese (Nolet et al., 2013). Additionally, due to an increase in the number of polar bears (*Ursus maritimus*) on islands with breeding geese because of changes in sea ice conditions, there is an increased risk of predation on goose colonies by polar bears (Cooch et al., 1991; Drent & Prop, 2008). Previously absent greater skuas (*Stercorarius skua*) as well as red foxes (*Lupes lupes*) have been observed on Svalbard and Alaska respectively, indicating the range extension of these predators to the arctic due to favorable conditions caused by spring warming (Elmhagen et al., 2017; Fuglei and Ims, 2008; Gallant et al., 2012; Madsen et al., 2019).

In conclusion, early onset of spring results in an increase in goose populations due to increased availability of high nutrition containing food and nesting sites, however, decreased gosling growth rate

as well as increased predation pressure result in a decrease in goose population size. More studies need to be conducted to determine the extent of increase or decrease in goose population size due to early spring. Furthermore, ecological impacts of migratory geese moving northwards to previously unused sites need to be assessed.

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