

# Do Arctic-nesting birds respond to earlier snowmelt? A multi-species study in north Yukon, Canada

Meagan M. Grabowski · Frank I. Doyle ·  
Donald G. Reid · Dave Mossop · Darielle Talarico

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**Abstract** Climate change has altered the timing of many ecological processes, especially in the Arctic. The initiation of nesting is a key signal of phenological changes in Arctic-nesting birds, and is possibly connected to the circumpolar trend of earlier snowmelt. We collected data on lay dates of 7 bird species, representing shorebirds, passerines, a bird of prey, and seabirds, nesting on Herschel Island, Yukon, Canada, in the years 1984–1986 and 2007–2009. Snowmelt was significantly earlier in the 2007–2009 period. Shorebirds and passerines showed trends to earlier lay dates in conjunction with earlier snowmelt; the other species did not. The strength of response in lay date was correlated with the general categories of foods known to be used by study species. However, six species showed a longer time interval between snowmelt and egg-laying in early compared to late springs, suggesting the need for further monitoring of how robust their responses to snowmelt are in the future.

**Keywords** Arctic · Phenology · Avian · Snowmelt · Herschel Island

## Introduction

With relatively rapid current warming in Arctic latitudes, understanding whether and how animals are responding to this change is of the utmost importance for their management and our adaptation (Walther et al. 2002; Rehfisch and Crick 2003; Høye et al. 2007; AMAP 2011). One key change is the pattern of earlier spring snowmelt in the northern hemisphere (Brown and Robinson 2011). Over the entire record from 1872 to 2009, snow cover duration has decreased in the northern hemisphere, especially at high latitudes, as a result of both later onset and, in particular, earlier snowmelt (Brown 2000; Brown et al. 2007, 2010). These patterns appear causally related to warming temperatures (Serreze et al. 2009; Brown et al. 2010). The general trends of Arctic warming and earlier snowmelt may be influencing the behavior of Arctic-breeding animals, including timing of reproduction, with potential consequences for population viability (Berteaux et al. 2004; Høye et al. 2007; Møller et al. 2008; Smith et al. 2010; Gilg et al. 2012).

Many birds are somewhat flexible in their breeding phenology, especially earlier or delayed nest initiation in response to timing of snowmelt (Crick 2004; Martin and Wiebe 2004; Meltofte et al. 2008; Smith et al. 2010; Pereyra 2011). Arctic-nesting birds generally require snow-free, exposed ground, cavity entrances or bushes, on or in which to nest, making snowmelt a necessary condition for nest initiation (Moe et al. 2009). Snowmelt timing, in turn, is correlated with the timing of the annual emergence of arthropod prey (Høye and Forchhammer 2008; Tulp and Schekkerman 2008). Tundra arthropods are essential food for many birds producing eggs after migration, and for nestlings and fledglings of many species during their rapid growth (Meltofte et al. 2008). It is most advantageous for

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M. M. Grabowski · D. G. Reid (✉)  
Wildlife Conservation Society Canada, Whitehorse, YT, Canada  
e-mail: dreid@wcs.org

F. I. Doyle  
Wildlife Dynamics Consulting, Smithers, BC, Canada

D. Mossop  
Yukon College Research Centre, Whitehorse, YT, Canada

D. Talarico  
Tipping Point Strategies, Whitehorse, YT, Canada

these species to match the periods of nestling and juvenile growth with the period of peak arthropod abundance, so that young birds can maximize their food intake (McKinnon et al. 2012). Arthropod phenology is strongly influenced by spring and early-summer temperatures so will likely advance with earlier snowmelt (Bolduc et al. 2013). Consequently, we wonder, which Arctic-nesting bird species are modifying their timing of nesting in response to changing snowmelt?

Patterns of snowmelt may influence species-specific responses to spring conditions. There are also potential trade-offs during migration affecting timing on the nesting grounds, such as the quality or availability of migration stopover sites (Lehikoinen et al. 2006; Rainio et al. 2006). Timing of arrival at the breeding grounds produces trade-offs between territory or mate availability if the birds arrive too late and risk of starvation if the birds arrive too early (Cotton 2003). In addition, individual species or species groups may be influenced by other factors such as: prey type, nest-site selection, and nutrition breeding strategy (income vs. capital breeders). For example, species with more flexibility when it comes to nest-site selection may have a biological advantage over those which have high nest-site fidelity (Martin and Wiebe 2004).

In this study, we investigated the initiation of nesting in 7 Arctic bird species representing four life history groups (passerine, shorebird, bird of prey, and seabirds) at Qikiqtaruk-Herschel Island Territorial Park, north Yukon Territory, Canada. First, we determined whether the Yukon/Alaska North Slope region is indeed experiencing a trend to earlier snowmelt, similar to the rest of the northern hemisphere. Second, we tested the hypothesis that individual bird species are changing their mean laying date in response to changes in the timing of snowmelt, by comparing data from 1984–1986 to 2007–2009.

## Materials and methods

### Study area

Herschel Island (69°34.2'N, 138°54.1'W), Qikiqtaruk in Inuvialuktun, is a 110 km<sup>2</sup> island in the Beaufort Sea about 1 km off the north coast of the Yukon Territory, Canada. It is a traditional residence for Inuvialuit peoples, was a whaling station in the late 1800s, and became a Territorial Park in 1987. It is also an important breeding ground for many Arctic-nesting species (Salter et al. 1980), including the only colony of Black Guillemots in the western Canadian Arctic (Sinclair et al. 2003).

Herschel Island is a low Arctic site, in bioclimatic subzone D, being primarily erect dwarf shrub tundra (Walker et al. 2005). We studied nesting birds in all the common

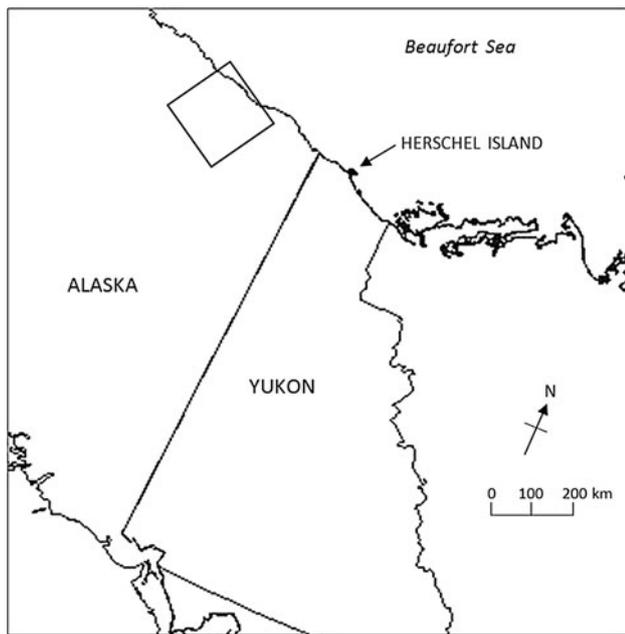
tundra habitats on the eastern 25 km<sup>2</sup> of the island. Most of the study area is a relatively well-drained upland plateau covered with either a tussock meadow of cottongrass (*Eriophorum vaginatum*) and moss or a heath of Arctic willow (*Salix arctica*), mountain avens (*Dryas integrifolia*), and various graminoids (notably *Arctagrostis latifolia*) and forbs. Stream valleys intersect the plateau. On sloping valley sides, the heath community becomes increasingly lush with extensive cover of Arctic lupine (*Lupinus arcticus*), saxifrages (*Saxifraga* spp.), and other forbs. Wet meadows of grasses, sedges, and *Salix pulchra* line the small streams. The edges of the plateau often fall steeply to the ocean or lowland areas in cliffy mud and clay slopes held together by permafrost. These areas are poorly vegetated but are dominated by Arctic willow, wormwood (*Artemisia* spp.), legumes (*Leguminosae*), and grasses. A large alluvial fan, vegetated with grasses (e.g., *Alopecurus alpinus*), sedges (e.g., *Carex aquatilis*) and *Salix richardsonii*, reaches the ocean, and is fringed with a sand and gravel beach community dominated by wild rye grass (*Elymus arenarius*), *Stellaria humifosa*, and some tidal ponds.

Herschel Island is experiencing a number of changes associated with a warming climate including more extensive retrogressive thaw slumps, a deeper active layer accompanying permafrost thaw, proliferation of some graminoids and legumes, and more extensive and taller growth of willows (Kennedy et al. 2001; Lantuit and Pollard 2008; Burn and Zhang 2009; Myers-Smith et al. 2011).

### Snowmelt

To investigate the hypothesis that the timing of snowmelt has advanced on the Yukon North Slope, we searched for remotely sensed data sets quantifying spring snow cover in both our time periods (1980s and 2000s). The National Oceanographic and Atmospheric Administration (NOAA) Climate Data Record Northern Hemisphere weekly satellite snow chart data set, described by Robinson et al. (1993) and maintained by Rutgers University Global Snow Lab, was the best available data set. Based on visual interpretation by trained meteorologists of Very High Resolution Radiometer (VHRR, launched in 1972) imagery, these data are interpolated records of the date at which 50 % of the snow cover has melted (termed “snow-off date”) across entire 190 × 190 km tiles (Robinson et al. 1993; Brown and Robinson 2011). The NOAA data set does not include a tile covering our study area, so we used the closest tile that also covered relatively flat coastal tundra, and this was about 300 km west (centered on the middle Kavik River, Alaska at 69°15'N, 146°48'W) (Fig. 1).

We lacked field data on timing of snowmelt in the 1980s. In the 2000s, we estimated snow cover daily on a portion of the eastern end of the island from a hilltop



**Fig. 1** Map showing the study site, Herschel Island, Yukon Territory, located in the Beaufort Sea. The *black square* in north Alaska is the location of the NOAA tile with remotely sensed satellite data used to estimate snow-off dates in this study (see Methods)

vantage point. These data provide a test of the relevance of the NOAA tile data to the general pattern and timing of snowmelt on Herschel Island.

#### Bird nesting phenology

To test the hypothesis that lay date is related to timing of snowmelt, we quantified the phenology of nesting during two time periods at least 20 years apart: 1984, 1985 and 1986, and subsequently in 2007, 2008 and 2009. Some of our data from the 1980s were summarized in an unpublished report (Talarico and Mossop 1986), but that report did not include all nests, and here we have included all nests sampled in those years. We collected the 2007–2009 data during an International Polar Year study (Gauthier and Berteaux 2011).

During both time periods, nests were primarily located by general searches of all habitats on foot, and backtracking flushed birds to nests. Crews were in the field continuously from late May through mid-July. Most nests were located after birds had started laying, and often when clutches were complete. Each nest was re-visited, at 2-day intervals, until the nest failed or hatching was complete. The focus of our study was lay date, which we calculated by backdating from hatch date using incubation periods published in Poole (2005) and Ehrlich et al. (1988). Backdated, nest-specific lay dates represent the date of laying of the first egg. For published incubation periods, presented in ranges, we used the midpoint length. When the

midpoint of an incubation period was a decimal of a day, we rounded to the earlier day.

Of a total of 523 nests, from 11 species, found in all study years, we could determine lay date for 230. However, we found few nests for some species in one or other time period, and had to exclude species with less than one nest in at least 2 years of each time period. This reduced our sample to seven species and 196 nests for the statistical analysis (Table 1). Of the four species dropped, Horned Lark nests were rarely found in either time period, but American Pipit, Savannah Sparrow and Common Redpoll nests were more commonly encountered in the 2000s.

We investigated the potential effect of time period (1980s compared to 2000s) and species on lay date using a two-way factorial ANOVA with time period and species as factors, followed by post hoc Tukey tests on pairwise comparison within species between time periods. The assumption of normality was met for all species judging by histograms of lay dates and by Shapiro–Wilks tests (all species  $P > 0.1$ ). The assumption of homogeneity of variance was met for all species except Long-tailed Jaeger, judging by spread of residuals against group means and by Levene tests (all species  $P > 0.2$ , except Long-tailed Jaeger,  $P < 0.01$ ). We removed Long-tailed Jaeger from this analysis. We tested the hypothesis that each species' mean lay date advances with earlier snowmelt using least-squares regression. All statistical analyses were performed in R (R Development Core Team 2011).

## Results

### Snowmelt

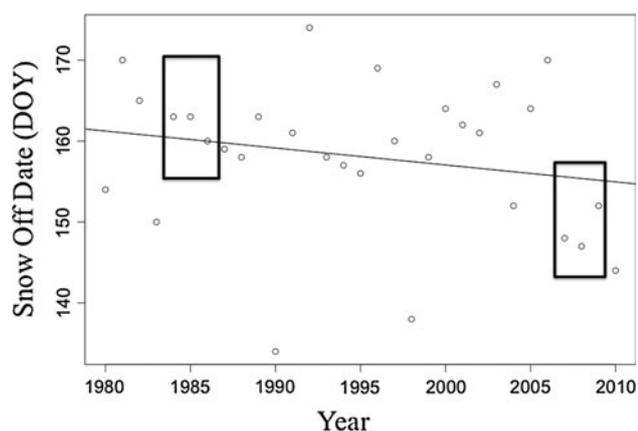
From 1980 to 2010, there was a tendency to earlier snowmelts (snow-off dates) based on the NOAA tile we used to represent Herschel Island (Fig. 2). However, this pattern was statistically insignificant because of a great deal of inter-annual variability in the timing of snowmelt and perhaps a nonlinear pattern. The pattern indicates that snow-off date is advancing at about 2 days per decade. We found a similar trend in a coastal tile to the east of Herschel Island (MacKenzie River delta), but tiles covering the British Mountains to the south did not represent the coastal situation well because of longer lasting snow at high elevations.

The snow-off dates for the 2007–2009 period were significantly earlier than those for 1984–86 ( $F = 50.7$ ,  $df = 1.4$ ,  $P = 0.002$ ), with a difference of 13 days between means of the two periods. Our sampling in the 1980s occurred in relatively late springs, and in 2007–2009 coincided with a set of particularly early springs, but all years were well within the range of snow-off dates in recent history (Fig. 2).

**Table 1** Summary of major life history, diet, and habitat characteristics of study species

Species	Group	Habitat	Nest-site	Strategy	Prey for young
Common Eider ( <i>Somateria mollissima</i> )	Seabird	Coastal/ upland	Ground	Precocial	Marine invertebrates
Baird's Sandpiper ( <i>Calidris bairdii</i> )	Shorebird	Upland	Ground	Semiprecocial	Arthropods—terrestrial
Semipalmated Sandpiper ( <i>Calidris pusilla</i> )	Shorebird	Coastal	Ground	Precocial	Arthropods—terrestrial and aquatic
Rough-legged Hawk ( <i>Buteo lagopus</i> )	Bird of prey	Upland	Platform	Semialtricial	Lemmings
Long-tailed Jaeger ( <i>Stercorarius longicaudus</i> )	Seabird	Upland	Ground	Semiprecocial	Lemmings; arthropods; young birds
Lapland Longspur ( <i>Calcarius lapponicus</i> )	Passerine	Upland	Ground	Altricial	Arthropods—terrestrial
Snow Bunting ( <i>Plectrophenax nivalis</i> )	Passerine	Upland	Cavity	Altricial	Arthropods—terrestrial

Information is from Poole (2005)



**Fig. 2** The timing of snowmelt from 1980 to 2010 based on snow-off date (50 % snowmelt; DOY = Day of Year) on the Kavik River NOAA tile. The line shows a tendency, though statistically insignificant, to earlier snowmelt through time ( $y = -0.21x + 546$ ,  $P = 0.26$ ,  $F = 1.30$ ,  $df = 1.29$ ,  $R^2 = 0.01$ ). The rectangles outline the two periods during which we collected field data on nesting phenology, and between which snow-off date was significantly different

For each year with field data, the estimates of date (DOY) at which 50 % snowmelt was reached on Herschel Island and on the NOAA tile were as follows: 2007 (150/148); 2008 (145/147); and 2009 (155/152). The estimates from the two sites were within 2 or 3 days of each other, with Herschel Island estimates showing later melt in 2 years and earlier melt in 2008. The direction of change between years in timing of melt was the same for Herschel Island and the Kavik River NOAA tile. Snow had completely melted, except for deep drifts, by mid-June (DOY 166), in all years.

#### Lay dates

Time period ( $F = 12.87$ ,  $df = 1$ ,  $P < 0.001$ ) and species ( $F = 17.22$ ,  $df = 5$ ,  $P < 0.001$ ) were significant factors affecting the pattern of lay dates in the two-way ANOVA.

In years with earlier snowmelts (2000s), birds generally tended to lay earlier. Also, the timing of lay dates differed significantly among species, with some being consistently earlier than others. There was also a significant interaction effect of species and time period ( $F = 4.34$ ,  $df = 5$ ,  $P < 0.001$ ), indicating that different species responded in different ways to the changes in snowmelt between the two time periods.

Tukey test results explore the species-specific changes in lay date between time periods. Only the Baird's Sandpiper showed a statistically significant advancement of mean lay date in the warmer 2000s (12 days,  $P < 0.01$ ). Three other species advanced their mean lay dates, but the data were not statistically significant: Snow Bunting (11 days,  $P = 0.27$ ); Lapland Longspur (7 days,  $P = 0.10$ ); and Semipalmated Sandpiper (6 days,  $P = 0.49$ ). One species showed very little response (Rough-legged Hawk: 2 days,  $P = 0.99$ ), and one species tended to delay laying in the years with earlier snowmelt (Common Eider: 7 days,  $P = 0.76$ ).

Across the sample of years studied, the shorebirds and passerines showed a tendency to earlier lay date with earlier snow-off date (Table 2, Fig. 3). This was statistically significant in three of the shorebird and passerine species but not so in the Snow Bunting. However, only 15–46 % of the variation in lay date was explained by snow-off date (Table 2).

Although six of seven species showed a tendency to advancement of lay date with earlier melt, none was able to fully keep up with the earlier melt, judging by the slopes ( $<1$ ) of the trend lines (Table 2). The shorebirds and passerines were most responsive, advancing lay date by about 4–8 days for 10 days advancement in melt. The bird of prey and one seabird were only able to respond by about 1 day, and the other seabird showed a delay in lay date of about 3 days for every 10 days of earlier melt. The bird of prey (Rough-Legged Hawk) consistently laid eggs earlier than other species (Fig. 3). This species laid well before

**Table 2** Trend lines, and associated statistical parameters, describing the relationship between lay date (DOY) and snow-off date (DOY) for the seven species across both time periods (1984–1986 and 2007–2009) on Herschel Island, Yukon

Species	<i>F</i>	<i>df</i>	<i>P</i>	<i>R</i> <sup>2</sup>	Trend line
<i>Somateria mollissima</i>	1.15	1,13	0.30	0.08	$y = -0.31x + 219.0$
<b><i>Calidris bairdii</i></b>	25.19	1,29	<0.01	0.46	$y = 0.84x + 34.4$
<b><i>Calidris pusilla</i></b>	13.79	1,29	<0.01	0.32	$y = 0.44x + 95.5$
<i>Buteo lagopus</i>	2.24	1,13	0.16	0.15	$y = 0.13x + 131.1$
<i>Stercorarius longicaudus</i>	0.23	1,13	0.64	0.02	$y = 0.06x + 151.0$
<b><i>Calcarius lapponicus</i></b>	13.65	1,77	< 0.01	0.15	$y = 0.62x + 68.7$
<i>Plectrophenax nivalis</i>	3.97	1,7	0.08	0.36	$y = 0.75x + 48.4$

Species with a statistically significant trend line are highlighted in bold

snow-off dates in the 1980s but appeared unable to maintain this relationship in the period with earlier snowmelt (2000s).

## Discussion

### Snowmelt

In the three decade period (1980–2010) bracketing our field observations, we calculated that snowmelt had advanced on the proxy study tile (Kavik River) by about 2.1 days per decade. This corresponds well with an estimate for the Alaska North Slope region of 2.3 days per decade (1965–2000) (Stone et al. 2002). Stone et al. (2002) also reported a fairly wide geographical synchrony in snowmelt. Although our study site is an island, it lies very close to the mainland, experiencing similar weather conditions. From the 1980s to 2007, the extent of sea ice cover in May has decreased the least of any month and essentially not at all in the southern Beaufort Sea (Comiso et al. 2008). It is unlikely that break-up of ocean ice differentially affected melt patterns on the island compared to the mainland because the ocean has remained essentially ice-covered through May and early June in all years (Wendler et al. 2010) with continuous land-fast ice along the coast and around the island. Also, melt on land is largely complete by mid-June, so precedes the ice break-up. Our field records of snowmelt on the island in the 2000s show a similar pattern to the Kavik tile data. Overall, we feel confident that the Kavik Region NOAA tile fairly represents Herschel Island given its similar latitude, lack of mountainous terrain, and proximity to the coast.

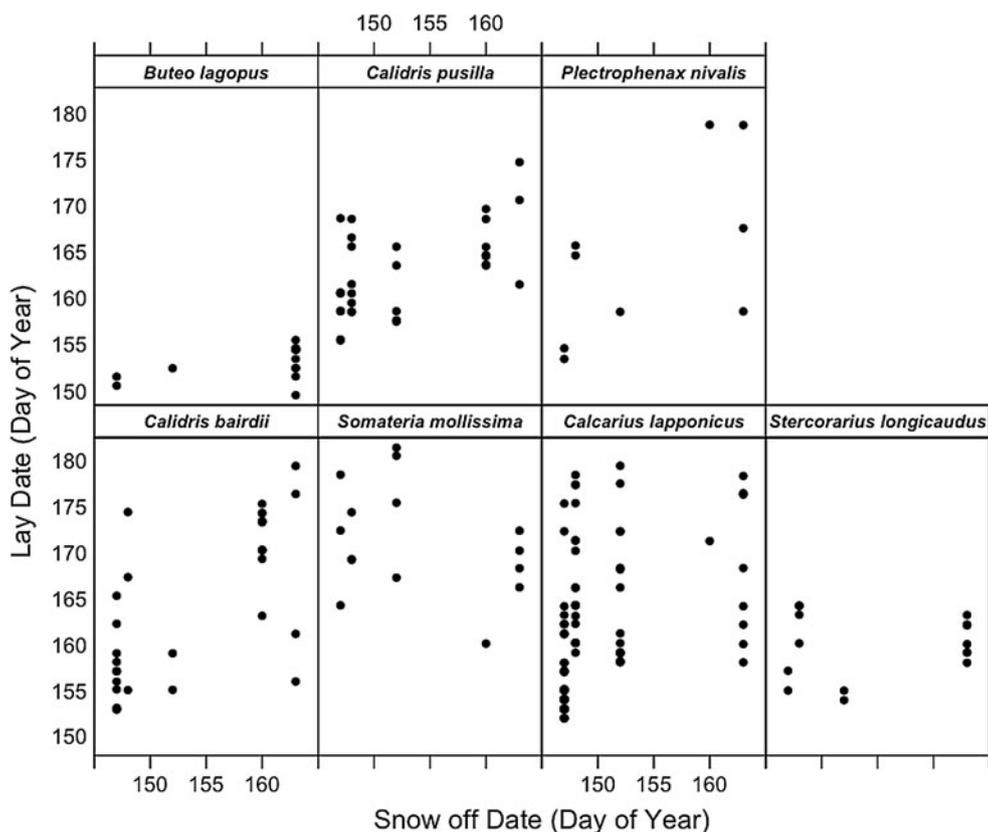
One shortcoming in our analysis is that the geographical and temporal scales of the satellite snow data are large, with coarse resolution compared to the fine scale of bird nesting data. Higher resolution remote sensing techniques for monitoring snowmelt, such as the European Space Agency GlobSnow project and Moderate-resolution Imaging Spectroradiometer (MODIS) snow albedo product (MCD43A) (Derksen and Brown 2011; Wang et al. 2012), are now available but did not cover the earlier of our time periods. Future research would benefit from ground-based validation and use of these new techniques.

### Bird nesting

Our conclusions regarding the effect of earlier snowmelt on lay dates must be interpreted cautiously because we were unable to use snowmelt data specific to Herschel Island, and because our sample of nests varied in size across species and time periods and was quite low for some combinations of species and time period. Our results suggest some broad patterns of response across different bird life histories. More definite results for a number of species will depend on a replicate future study in comparison with our data from 2007 to 2009, and involving snowmelt estimates from the study site (e.g., MODIS) and enhanced nest sampling where possible.

Our results for Arctic-nesting shorebirds reiterate relationships between lay date and snowmelt found previously for this group (Green et al. 1977; Durant et al. 2007; Meltofte et al. 2007, 2008; Smith et al. 2010). Regarding Arctic passerines, Custer and Pitelka (1977) reported that Lapland Longspurs in north Alaska initiated nests very soon after the first snowmelt, and were delayed in nest initiation by relatively late snowmelt. Our results demonstrate a similar flexibility of nest initiation in this species and extend the pattern to Snow Buntings. A few studies have found spring snowmelt to be a predictor of alpine passerine lay date and clutch size (Hendricks 2003; Crick 2004). The lack of response in the Common Eider to timing of snowmelt is consistent with other studies that have linked both nest initiation and productivity to the area of marine ice cover adjacent to the nesting grounds (Love et al. 2010; Chaulk and Mahoney 2012).

The type and availability of food for the young potentially provides the best explanation as to whether a species does or does not respond to snowmelt (Table 1, Fig. 3). Species relying on arthropod foods for altricial young or for precocial fledglings (i.e., shorebirds and passerines) showed the strongest advancements of lay date. Species relying at least in part on lemmings (Rough-legged Hawk and Long-tailed Jaeger) as food for young did not show a strong response to snowmelt. The lone species whose precocial young immediately become part of the marine



**Fig. 3** Patterns of lay date (DOY) in relation to snow-off date (DOY) for the seven species with sufficient nest data in each time period (1984–1986 and 2007–2009) on Herschel Island, Yukon. *Each dot* represents a single nest, and trends are recorded in Table 2

food web (Common Eider) did not show an advancement of lay date with earlier snowmelt.

On arrival at the nesting grounds, adult shorebirds and passerines feed on arthropods which they need for developing eggs (Klaassen et al. 2001; Meltofte et al. 2007). The timing of nest initiation is influenced by this spring-time arthropod availability, as well as snowmelt, at least in Arctic shorebirds, and the two factors are probably integrated by temperature which directly influences both snow and arthropod activity (Meltofte et al. 2007; Høye and Forchhammer 2008). However, we lacked data on arthropod availability in spring, so could not investigate this factor's influence on timing of nesting.

To feed nestlings and precocial young, Arctic shorebirds and passerines also rely on the strong pulse of arthropod life stages that become active and available later in the summer. The majority of the variation in timing of this summer arthropod emergence is explained by weather in the current growing season, in particular mean daily temperatures and accumulated degree-days above freezing (Tulp and Schekkerman 2008; Bolduc et al. 2013), and time since snowmelt (Høye and Forchhammer 2008). To optimize the coincidence of hatch and rapid chick growth with the pulse of arthropod emergence, the birds need to

adjust their lay date to try to follow any change in date of snowmelt and accumulated growing degree-days, and thereby minimize a risk of mismatch with peak arthropod availability later in the summer (Tulp and Schekkerman 2008; McKinnon et al. 2012).

Another factor selecting for flexibility in lay date is the potential for re-nesting if a first clutch fails or if the first clutch fledges and a second can be attempted. The only species that could conceivably re-nest are those with short incubation and hatchling stages, and in which both adults remain on the nesting grounds through the first reproductive attempt. This is true of the passerines and shorebirds we studied though re-nesting is rare in all these species (Hussell and Montgomerie 2002; Moskoff and Montgomerie 2002; Hicklin and Gratto-Trevor 2010; Montgomerie and Lyon 2011). Incubation periods are too long in the larger-bodied species to fit more than one reproductive cycle into the Arctic summer. We did document two successive clutches fledged by one pair of Snow Buntings in 2008.

Our limited data suggest that species preying largely on lemmings and voles to feed young (Rough-legged Hawk and Long-tailed Jaeger) showed little response to earlier snowmelt. These species may not experience strong selection for tracking early melt, or may be unable to

advance their migration timing to match the earlier tundra spring conditions. Being relatively large bodied, both species nest relatively early (especially the Hawk) to fit their breeding cycle into the short Arctic summer. Longer summer seasons, with earlier snowmelts and later onset of autumn snow (Brown 2000; Dye 2002), and no single predictable pulse in prey availability (Krebs et al. 2011), may reduce the selection pressure for early nesting. Regarding patterns of spring migration, the Hawks travel and feed across the boreal forests (Bechard and Swem 2002) where advancement of snowmelt has been 40–50 % slower than in subarctic and tundra regions (Dye 2002), perhaps contributing to a mismatch in migration timing and timing of spring on the nesting grounds. The Jaegers can feed on a variety of terrestrial and marine prey (Wiley and Lee 1998), and appear to follow diverse migration routes, some overland across Alaska and others along the Beaufort coast (Johnson and Herter 1989). Their opportunities to feed along the migration routes and at the nesting ground may not be changing in concert with changes in tundra snowmelt, especially because the extent of marine ice in May and early June has not decreased appreciably in the southern Beaufort Sea since the 1980s (Comiso et al. 2008).

Common Eiders did not change their pattern of laying in response to changing snowmelt, and maintained relatively late lay dates compared to other species. Adults and precocial young rely on marine foods (Goudie et al. 2000), so timing of snowmelt on land has no direct influence on food availability. Common Eider lay dates are influenced by ocean ice cover in spring with more extensive ice cover delaying nest initiation (Chaulk and Mahoney 2012), and also by female body condition on arrival at the nesting grounds (Descamps et al. 2011). In late May and early June, Common Eiders have staged and fed in open water leads to the northeast of Herschel Island since the 1980s (Dickson and Gilchrist 2002), but we do not know of any analysis of temporal trends in the extent of this particular staging site. In general, the extent of sea ice cover since the 1980s in the southern Beaufort Sea has changed very little in spring, being essentially constant in May and only showing a noticeable trend to decreasing extent after mid-June (Comiso et al. 2008). Access to marine feeding areas close to nesting grounds probably did not increase substantially for Common Eiders during the course of our study, and this may be the strongest explanation for a lack of response to an advancing terrestrial spring in this species.

In our low Arctic study site, a subset of shorebirds and passerines showed some ability to adjust lay date in response to earlier snowmelt. However, none of these species was able to fully adjust lay date to changing snowmelt, probably because birds on migration cannot track spring conditions on nesting grounds, and because there is inter-annual variation in food availability when

they reach the nesting grounds. Shorebirds and passerines have shown some ability to respond to earlier spring temperatures along migration routes by advancing their migrations (Anthes 2004; Tøttrup et al. 2010). Smith et al. (2010) found that, although timing of 50 % snowmelt in the central Canadian Arctic varied by up to 3 weeks, timing of arrival in shorebirds varied by only about 1 week and was not well correlated with local conditions. The birds showed limited ability to time their arrival to fit the timing of spring on the tundra. However, they showed considerable flexibility in subsequently matching laying dates to the timing of tundra spring season and the relative abundance of predators (Smith et al. 2010). Such flexibility in arrival and egg-laying in Arctic shorebirds was also reported by Meltofte et al. (2008). It remains to be seen whether these bird groups can continue to respond if snowmelt continues its advancing trend. A clearer picture depends on data on timing of arrival on the nesting grounds and early season arthropod availability, both of which we lacked, along with more detailed mapping of habitat-specific snowmelt patterns.

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