Environmental conditions influence the breeding and migratory patterns of many avian species and may have particularly dramatic effects on long-distance migrants that breed at northern latitudes. Environment, however, is only one of the ecological variables affecting avian phenology, and recent work shows that migration tactics may be strongly affected by changes in predator populations. We used long-term data from 1978 to 2000 to examine the interactions between snowmelt in western Alaska in relation to the breeding or migration phenologies of small shorebirds and their raptor predators. Although the sandpipers' time of arrival at Alaskan breeding sites corresponded with mean snowmelt, late snowmelts did delay breeding. These delays, however, did not persist to southward migration through British Columbia, likely due to the birds' ability to compensate for variance in the length of the breeding season. Raptor phenology at an early stopover site in British Columbia was strongly related to snowmelt, so that in years of early snowmelt falcons appeared earlier during the sandpipers' southbound migration. These differential effects indicate that earlier snowmelt due to climate change may alter the ecological dynamics of the predator–prey system.

An annual migration to distant breeding sites is a common strategy among many taxonomic groups, as it allows animals to raise their offspring in highly-seasonal areas that may not support life year-round. Many ecological factors influence migratory behaviors (Alerstam et al. 2003), including abiotic factors such as climate (Crick 2004) and photoperiod (Quinn and Adams 1996; Coppack and Pulido 2004), as well as

## Timing of snowmelt in breeding regions

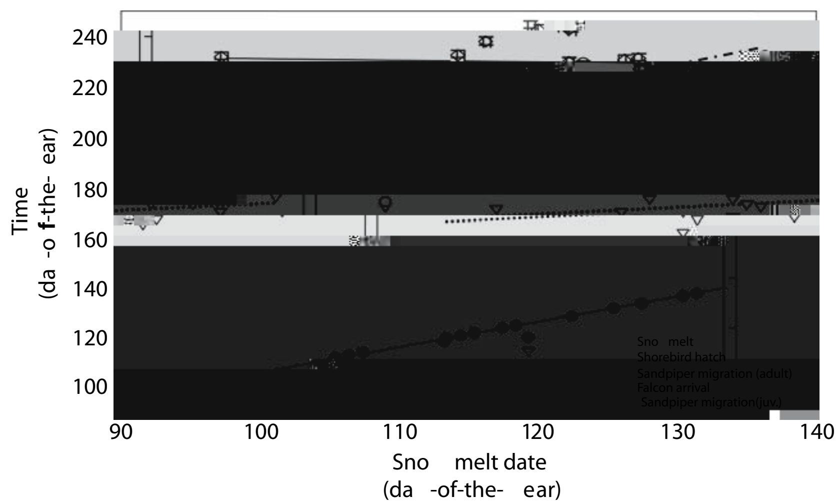
We derived an annual regional snowmelt index date from weather records (c.f. Foster 1989) available at three sites spanning the breeding range of [illegible] in Alaska (see Holmes 1972). Daily ter beginning in the late summer and plateau in autumn (see Fig. 1 in Lank et al. 2003). The onset of this sharp increase appears to vary greatly between years. To estimate the timing of this onset, we derived a peregrine arrival timing index based on the surveys made between July 1 and October 31 (123 days) in the years 1986–2000 (~1,100 surveys), during which about 1,250 sightings were made. We estimated falcon abundance by combining sightings made over 3-day intervals, to smooth out day-to-day variation in presence. We then defined falcon arrival timing as the interval in which the number of falcons present at Reifel Island reached 50% of the maximum for that year.

## Statistical analysis

We report results using Pearson product-moment correlations, and means ± 95% confidence intervals. Sample sizes vary among our analyses because not all years are represented in all four datasets.

From 1978 to 2000, mean snowmelt occurred in western-coastal Alaska on day-of-the-year 120 (± 4.4 days), but varied among years by 43 days. Over the same time period, the mean hatch date for small shorebirds was about 1.5 months later, on day 174 (± 4.7 days). Overall, the hatch of small shorebirds took place earlier in years with earlier snowmelt ( = 0.60, < 0.01, = 17), and results were similar when the snowmelt data of Babcock et al. (2002) were included and 1998 was excluded (see Materials and methods) ( = 0.7, = 0.01, = 16). More specifically, the timing of hatch was not related to snowmelt ( = 0.0, = 11) in years when snowmelt occurred prior to sandpiper arrival (day-of-the-year 125; see Discussion). However, hatch was significantly delayed in years when snowmelt took place after day 125 ( = 0.77, < 0.05, = 7), changing by 0.64 days ( = 0.77, < 0.05, = 7) for each day that snowmelt was delayed.

The mean timing of southward passage of adult in the Strait of Georgia was day 198.3 (± 3.1 days) and occurred on average 25.7 ± 6.5 days after the index hatch date. Migratory timing showed no correlation with either snowmelt or hatch (both > 0.5), likely because the timing of migration was the least variable of the factors that we considered. In fact, sandpiper passage timing varied by only 19 days, less than half the range recorded among years for snowmelt (Fig. 1). The consistency in migratory timing means that the observed interval between hatch and migratory passage dates shortened by 1.05 days for each day that hatch was delayed ( = –0.77, < 0.01, = 9). Juvenile showed similar patterns to adults, with a mean southward migratory passage on day-of-the-year 229.6 (± 2.3 days) and varying among years by




Annual variation in the phenology of and is shown between northern nesting sites and a migratory stopover in British Columbia from 1978 to 2000. Regional snowmelt ( ) is plotted against itself to form a 1:1 reference line, with points jittered to reveal any overlapping data. Above the reference line, the timing of hatch for small shorebirds in western Alaska is (to)-259.on(m72ETBT8.4682 0t7 1ng 102.7838 Tm[(black)-252.2(circles)] TJE23e,)718.ETBT8.4682 0 9.965(ran72.9(

only 20 days (Fig. 1

condition during the southward migration could elucidate some of these questions.

In contrast with the sandpipers, the timing of falcon arrival on stopover sites during southward migration shows a strong and consistent relationship with snowmelt. For [illegible] breeding in northern and western Canada and Alaska, snow cover is likely to play a strong role in the timing of food availability, and perhaps the longer incubation and parental care provided by breeding falcons limits the flexibility timing of their breeding season among years with varying snowmelt timing. Although we are uncertain what proportion of the falcons sighted in southwestern British Columbia are from Canadian or Alaskan populations, we hypothesize that large-scale climate factors such as position of the Aleutian Low affect the timing of snowmelt similarly for both predators (i.e., falcons) and prey (i.e., sandpipers) breeding at the northern latitudes.

Several recent studies have evaluated trends in the timing of breeding and migration with respect to changing climate (e.g., Crick et al. 1997; Stevenson and Bryant 2000; Both and Visser 2001; Jenni and Kéry 2003) or predator landscapes (e.g., Ydenberg et al. 2004). The data reported here suggest that advances in the date of snowmelt caused by climate change may produce species-specific effects on the migratory timing of some species of birds. In this case, the predatory