An Analysis of Northern Saw-whet owl Banding Data to Determine if Peak Fall Migration Dates in Alberta have Shifted in the last Two Decades

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Abstract

Detailed information on migration patterns and behaviors of northern saw-whet owls is lacking. Despite the abundance of owl banding data in North America, there are limited studies that have the potential to show changes over time, and there is no readily available literature on potential migration date shifts in northern saw-whet owls. Studies from around the world have shown that global warming has affected most biological and ecological processes including wildlife and their population distributions, physiology, and life history, so it can be inferred that there could be changes in northern saw-whet owl migration patterns. The purpose of this study is to analyze fall migration information for northern saw-whet owls in Alberta using existing banding data from two banding stations (Beaverhill Bird Observatory and Lesser Slave Lake Bird Observatory) to investigate if there has been a shift in peak migration dates between 2002 and 2022. This information was compared to local climate data during the study period. Although not statistically significant, the linear regression results show that there has been a delay in peak migration of one day per decade at BBO, and two days per decade at LSLBO. Temperature analysis show statistically significant results at both banding stations in the short and long-term. It is possible that rises in temperature have led to a delay in migration for northern saw-whet owls; however, other factors must be considered and can be studied in future research projects.

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An Analysis of Northern Saw-Whet Owl Banding Data to Determine if Peak Fall Migration Dates in Alberta Have Shifted in the Last Two Decades

Northern saw-whet owls (*Aegolius acadicus*) are small nocturnal owls (approximately the size of an American robin [*Turdus migratorius*]) that are found year-round in forests of central and southern Canada, the north quarter of the USA, and throughout the Rocky Mountains (Cornell, 2019). While some northern saw-whet owls remain on their breeding grounds all year, others make short or long-distance movements to overwintering areas in the central USA (Cornell, 2019; Holroyd & Woods, 1975; Figure 1). Detailed information on migration patterns and behaviors of this nocturnal owl is lacking (Cornell, 2019; DeRuyck et al., 2012; Priestley et al., 2010). The first documented evidence of fall migration in northern saw-whet owls was by Taverner and Swales (1911), in Ontario. Some researchers have provided evidence of migration patterns and peak migration dates in Canada (Weir et al., 1980), and there are several studies published that use long-term banding data collected in the northeastern United States, documenting migration patterns (peak dates), behaviours, and demographics (Brinker et al., 1997; Beckett & Proudfoot, 2011; Holroyd & Woods, 1975; Whalen & Watts, 2002). Limited studies exist for western Canada (DeRuyck et al., 2012; Priestley & Priestley, 2005; Priestley et al., 2010). Across North America there are over 100 owl banding stations in place as an effort to better understand migration patterns of this species (Cornell, 2019).

Figure 1

Geographic Range of Northern Saw-whet Owls
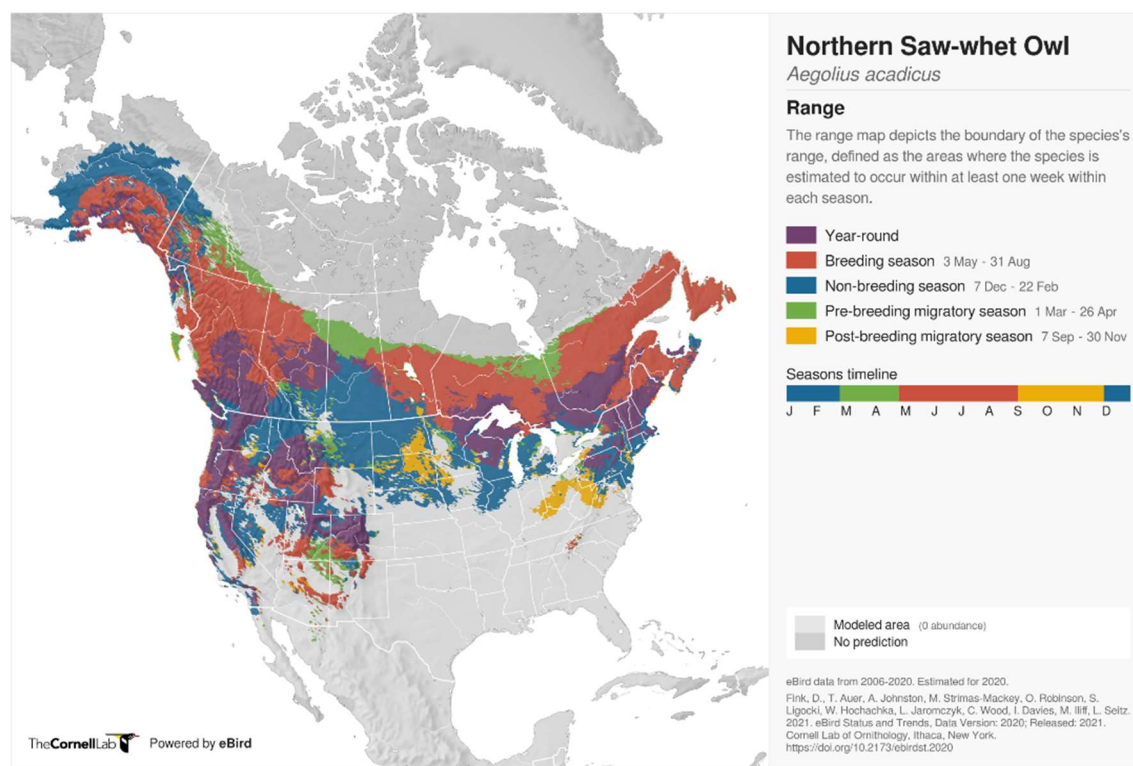
Note: From eBird data, Fink et al. (2021).

It has been well researched that temperatures have increased globally in the atmosphere, oceans, and over land, and they will continue to increase (IPCC, 2021). Studies from around the world have shown that anthropogenic global warming has affected most biological and ecological processes including wildlife and their population distributions, physiology, and life history (Diaz et al., 2019; Parmesan, 2006; Scheffers et. al., 2016). There are many historical references of scientists documenting changes in range of lepidoptera and avifauna (Parmesan, 2006; Scheffers et. al., 2016). Recorded temperature increases have contributed to large scale impacts on biodiversity, including species distribution, phenology, population dynamics, community structure and ecosystem function (Diaz et al., 2019; IPBES, 2019; Pearce-Higgins et al., 2015). Several studies on songbirds have shown that temperate birds' geographic ranges are

moving northwards, and spring arrival dates are getting earlier (DeLeon et al., 2011; De Victor et al., 2008; La Sorte and Thompson, 2007; Rushing et al., 2020).

Despite there being an abundance of owl banding data in North America, there are limited studies that span over one decade that have the potential to show changes over time, and there are no readily available literature on potential migration date shifts or range shifts in northern saw-whet owls. However, since shifts are happening for a variety of other species, it can be inferred that this focal species could be experiencing the same patterns. As of November 2022, there are two unpublished papers that look at this exact topic for northern saw-whet owls. There was an online presentation by Nature Alberta (Nature Alberta, 2022) that explained the summary of these results. Those results will be incorporated and discussed below.

Owl Banding

Owl banding occurs on a large scale in North America to gain knowledge on breeding and migration behaviours, populations, and overwinter locations. Owls are captured at night in mist-nets (long, tall, badminton-type nets) set-up in the forest at a banding station. Owls are lured in by researchers playing a recording of a calling northern saw-whet owl, and owls get caught in the nets. Researchers untangle owls and place a unique identifier band on their leg before taking measurements and releasing them (Appendix). Individually marked birds allow for studies of dispersal, migration, behavior, social structure, life span, survival rate, reproductive success, and population growth through recapture (Priestley et al., 2010).

Research Questions and Objectives

This research paper will explore the details of the migrations of northern saw-whet owls in Alberta. Research has shown that many individuals of this species make seasonal movements, but there are still some unknowns regarding movement patterns and trends (DeRuyck et al.,

2012; C. Priestley & L. Priestley, 2005). Research and detailed information on migration behaviors of northern saw-whet owls in western Canada is deficient due to their secretive and nocturnal habits (Cornell, 2019; DeRuyck et al., 2012; C. Priestley & L. Priestley, 2005; Priestley et al., 2010).

The purpose of this quantitative study is to analyze fall migration data for northern saw-whet owls in Alberta using existing banding data and investigate if there has been a shift in peak migration dates between 2002 and 2022 (and by how much). If there is a shift in peak migration dates, this information could be compared to climate data changes during the study period. Specifically, the study will examine:

1. What are the peak dates of fall migration (overall, and yearly) of northern saw-whet owls recorded at Lesser Slave Lake (LSLBO) and Beaverhill Bird Observatory (BBO) banding stations in Alberta?

    a. Has there been a year-to-year shift since 2002/ 2004 at each station? Is there a significant difference between peak migration in 2002/ 2004 and in 2022 at each station?

    b. Has there been a shift in mean annual average temperatures, locally, at each banding station that may contribute to any changes in migration dates?

The null hypothesis would be that there is no difference in peak migration date between years at each site. The alternative hypothesis would be that there is a difference in peak migration dates of northern saw-whet owls moving to their wintering grounds. I hypothesize that there will be a shift in fall migration dates in 2022 to be later in the season when compared to peak dates in 2002 and 2004. I hypothesize that there will be a significant difference in the temperatures at the study sites and that they will have increased over time.

Importance

Northern saw-whet owls are an important aspect of ecosystem function as they help control rodent populations (they exclusively eat small mammals, especially voles [Holt and Leroux, 1996]), and they can be an indicator of biodiversity and healthy ecosystems (Noss, 1990). Northern saw-whet owl occurrence, monitoring, and conservation can be related to Aichi Targets 1, 5, 14 & 19, and United Nations Sustainable Development Goals (UN SDGs) 3, 13 & 15 (UNDESA, 2022; CBD, 2022); these goals and targets are relevant both locally, and globally. Globally, the current rate of biodiversity loss is at a tipping point; regional and local changes to biodiversity can have extensive damaging effects on ecosystem functions and cycles in the biosphere (Rockstrom et al., 2009).

Although an understudied component of the ecological impacts of climate change, autumn events are important ecologically and evolutionarily (Gallinat, 2015). Information on when northern saw-whet owls migrate may provide more tangible details on their range, habitat preferences, and migration patterns and trends, which can assist wildlife professionals and managers in identifying areas for protection, therefore maintaining biodiversity. Loss of suitable habitat from natural (e.g., wildfires, insect outbreaks) and anthropogenic (e.g., climate change, timber harvest) sources can threaten owl populations (DeRuyck, 2012). Determining if migration dates are changing can help managers and biologists better understand potential effects of climate change on northern saw-whet owls and aid in implementing mitigations. The objective of this research is to determine if seasonal temperature changes may be affecting migration behaviors of northern saw-whet owls.

Literature Review

Breeding Biology and General Migration

In Alberta, egg laying commences in late February or early March and as late as mid-June with an average egg laying date of 12 April (Priestley, 2008). In Oregon, northern saw-whet owls have been detected nesting as early as 1 March and as late as the end of June (Marks et al., 2015). Northern saw-whet owls are found in forested (mainly deciduous) habitats with minimal grass and shrub cover, and in areas with vegetated linear features (Domahidi et al., 2019).

In the first documented report on northern saw-whet owl migration, Taverner and Swales (1911) state that it was generally considered common knowledge that northern saw-whet owls are resident within their range; however, after investigation, they concluded that northern saw-whet owls migrate in large groups, and to great distances. Supporting this conclusion, several studies in northeastern USA and Ontario were able to confirm and contribute similar findings that indicate northern saw-whet owls do migrate south in the fall in large numbers (Confer et al., 2014; Holroyd & Woods, 1975; Weir et al., 1980). However, not all individuals will migrate as documented by researchers in Illinois where 11 of 13 northern saw-whet owls with radio transmitters, overwintered within their study area (Avara et al., 2022). The authors concluded that northern saw-whet owls both overwinter in and migrate through Illinois (Avara et al., 2022). Additionally, Priestley et al. (2010) found evidence to suggest that some northern saw-whet owls overwinter in Alberta and Saskatchewan; However, greater than 70% of owls in their study showed evidence of migration. They concluded that northern saw-whet owls in Alberta are partial migrants (Priestley et al., 2010).

Migration Dates

Migration dates for northern saw-whet owls span from early September to late November. Date range and peak dates of migration are different depending on location (latitude) (**Error! Reference source not found.**). In central Alberta, it was discovered that 95% of all captures were between September 9 and November 4, and after comparing results to other datasets, the authors ascertained that fall migration peaks occurred earlier for more northern latitudes (Priestley and Priestley, 2005). In Manitoba, DeRuyck et al. (2012) discovered that migration dates spanned from September 23 to October 25 with the median peak date of October 8 (**Error! Reference source not found.**). The dates of migration (duration and peak) did not vary significantly from year to year (over 9 years) (DeRuyck et al., 2012). In Ontario, migration dates over a three-year period were consistent across years with most owls captured in mid-October, and 75% of all owls being captured by the third week of October (Weir et al., 1980).

Table 1

Summary of Migration Dates for Northern Saw-whet Owls in the Literature

Location	Year	Migration Conclusions	Author
Alberta	2002-2003	Peak 2-5 Oct	C. Priestley & L. Priestley (2005)
Vancouver Island	2002-2009	Peak 2-8 Oct	Nightingale (2009)
Delta Marsh, Manitoba	2000-2008	5th percentile: 23-Sept Peak: 8-Oct 95th Percentile: 25-Oct Consistent among years	DeRuyck et al. (2012)
Oregon	1999-2000	73% of owls were captured between 1-31 Oct	Frye & Gerhardt (2003)
Montana	2001-2006	Peaked between mid-September and early October	Frye (2012)
Ontario	1976-1978	Peak mid-Oct	Weir et al. (1980)
Idaho	1999-2004	Peak 8-Oct	Stock et al. (2006)
Idaho	1998-2001	Peak 5-25 Oct	Hamilton (2002)
Northeastern USA	1955-1969	Michigan, Massachusetts peak mid-Oct; Wisconsin, New Jersey peak mid to late Oct;	Holroyd & Woods (1975)

		Ontario, New York, Iowa, Maryland peak late Oct; Ohio peak late Oct to early Nov	
Cape May, New Jersey	1980-1988	Peak 7-Nov 90% of captures are between 16-Oct and 19-Nov	Duffy & Kerlinger (1992)
Nebraska	2019-2021	Peak early November	Brenner & Jorgensen (2021)
Alabama	2007-2016	Peak 13-Nov Most captures between 2 and 27-Nov	Soehren et al. (2019)

Note: Rows are arranged in approximate order of latitude from north to south

In the first large migration study in the northeastern USA, Holroyd & Woods (1975) determined that mean fall migration dates were between mid-October to early November, but spanned from September 1 to November 30, with migration starting earlier at the sites that are further north (**Error! Reference source not found.**). This is corroborated with another large study in eastern USA (Beckett & Proudfoot, 2011) which also concluded that migration started earlier in more northern latitudes; this supports the theory that northern saw-whet owls migrate south for winter. Another earlier study in northeastern USA determined a date range of October 3 – November 10 (Davis, 1966). In Montana, Frye (2012) discovered that capture rates peaked between mid-September and early October. Frye & Gerhardt (2003) conducted studies in Oregon and found that 73% of owls were caught between October 1 -31.

In 2022, BBO analyzed their data to get detailed information on the timing of northern saw-whet owl migration. They analyzed early, peak, and late migration dates to see if there have been any shifts since 2002. The conclusions are not yet published but they were presented in a webinar hosted by Nature Alberta (2022). BBO determined that 98% of captures were between September 12 and November 8, owls are starting to migrate one day earlier than historically, peak migration date is getting later since 2002, and the end dates of migration have remained consistent (Nature Alberta, 2022). In another unpublished 2022 study in collaboration with BBO, Graduate student Myrthe Van Brempt looked at banding data from the northeastern USA

between 1990 and 2020 and found that the date of peak migration has been delayed by one day per decade (Nature Alberta, 2022). Additionally, it was noted that migration season is getting longer over time (starting earlier and extending later) (Nature Alberta, 2022).

Capture rates on different days or at different sites during fall migration banding may be affected by weather (e.g., wind speed and direction, precipitation, temperature), habitat type, moon phase, moon visibility (i.e., clear sky or overcast), and prey availability within the habitat (Kanda et al., 2016; Murphy, 2016). It has been shown that increased lunar illumination results in a decrease in the probability of capture of northern saw-whet owls during autumn migration (Bedard and Whiteman, 2018; Kanda et al., 2016; Murphy, 2016).

Migration Shifts Potentially Related to Climate Change

Human impact has undeniably warmed the earth's oceans, land, and atmosphere, and each of the last four decades has been warmer than the previous (IPCC, 2021). Additionally, climate zones have shifted poleward, there has been a global retreat of glaciers, and northern hemisphere spring snow cover has decreased (IPCC, 2021). Global temperature increases are expected to continue (IPCC, 2021). Climate changes have been noted to cause poleward and upward advancement of the treeline, altered geographic ranges of arctic species (including polar bear [*Ursus maritimus*] and caribou [*Rangifer tarandus*]), and changes in migration patterns of many species including anadromous fish (Purvis et al., 2019), as well as phenological changes in African wild dogs (*Lycaon pictus*) where they have delayed birthing dates by up to seven days per decade in response to warming (Abrahms et al., 2022).

Indigenous Peoples and Local Communities (IPLC) in Eurasia and North America have reported changing animal population trends, and changing migration patterns, due to climate change (Purvis et al., 2019). There is strong evidence across an assortment of bird taxa favoring

early migration and breeding activity, and a general expectation of increased selection for early migrations due to climate change (Charmantier and Gienapp, 2013). Studies have shown that an increase in winter temperatures allow southern species to become relatively more common, and northern species to become less abundant, and experience range contractions, which is consistent with the theory that as the world warms, there will be a poleward shift of species ranges (Elmhagen et al., 2015; McCarty, 2001; Valiela and Bowen, 2003).

Songbirds have been studied frequently as they are easy to survey, and DeLeon et al., (2011) concluded that 76% of the 93 species analyzed had an earlier spring arrival date on the breeding grounds, and the average was 0.10 days/ year earlier for a total of 4.2 days earlier over 42 years. Results also presented a negative temperature slope indicating that migrants are arriving earlier with increasing temperatures (De Leon et al., 2011). In the Gulf of Mexico, it was noted that early spring migration dates (first 5% of birds moving) for songbirds had an advancement of 1.6 days per decade over a 20-year period, but the date of peak migration had not changed (Horton et al., 2018). It has been observed that northern songbirds have northward shifts in range, and they are slow to adjust to the shifts in temperature (DeVictor et al., 2008; Rushing et al., 2020).

Changes of timing of autumn migration are more variable and they are less well understood than spring migration (Lehikoinen at el., 2004). Some species are migrating south earlier, and others postponed their autumn migration (Lehikoinen at el., 2004). Several studies in Europe have indicated that fall migration departure dates are getting later by 0.3-1.4 days per year with waterfowl showing the greatest delay (Gilyazov and Sparks, 2002; Sparks and Mason, 2001 in Lehikoinen at el., 2004). However, a few species departed earlier on fall migration over time (Gilyazov and Sparks, 2002). Amateur ornithologists constantly register records of delayed

autumn migration or rare first winter observations for different areas, which strongly suggest that delayed fall migration may be a climate response (Lehikoinenal et al., 2004).

Although climate change or warming temperatures can be a factor in alterations to migration patterns, other characteristics (land use changes, winds, staging area conditions, higher trophic level interactions, prey availability) have been shown to contribute to migration fluctuations (Charmantier and Gienapp, 2013; Elmhagen et al., 2015).

Methods

A quantitative approach was taken for this exploratory research project. This research is a non-experimental, descriptive design as there are no variables that are controlled by the researcher, no explanatory variables, and sites/ variables are not randomized (Schwartz, 1998).

Existing owl banding data was obtained by contacting two bird banding stations in Alberta (Lesser Slave Lake Bird Observatory [LSLBO], and Beaverhill Bird Observatory [BBO]), and requesting their raw data from northern saw-whet owl banding. Data sharing agreements are in place with both locations. Data from LSLBO included all data from 2004-2022 (19 years), and the BBO data included 2002-2021 (20 years).

Data at LSLBO and BBO banding stations has been collected annually in the fall for northern saw-whet owls since 2004 (Campsall & Perkins, 2021) and 1997 (BBO, n.d.), respectively, following standard protocols. Many parameters are measured and recorded (Appendix); however, only some will be used for this research. Key data used for this research project includes effort, date captured and total counts. Data prior to 2002 at BBO will not be used, as standardized methods started in 2002.

Raw data was reviewed for quality, and a subset of data was selected based on limitations of the data (e.g., most current data available, data collected using current protocols). Data that

was collected prior to using an audio lure was not used, as well as any other data indicated by the data sharing agreement to be excluded. Owls that were previously banded (recaptures) were not used in this data analysis.

Study Area

LSLBO monitoring sites are in the Lesser Slave Lake Provincial Park within the boreal forest of north-central Alberta (approximately 55°25'33"N, 114°49'28"W) (Figure 2). BBO monitoring sites are within the Beaverhill Lake Natural Area in central Alberta (approximately 53°22'1.60"N, 112°32'29.86"W) (Figure 2). The north-south distance between the two sites is approximately 235km.

Figure 2

Northern Saw-whet Owl Study Area in Alberta
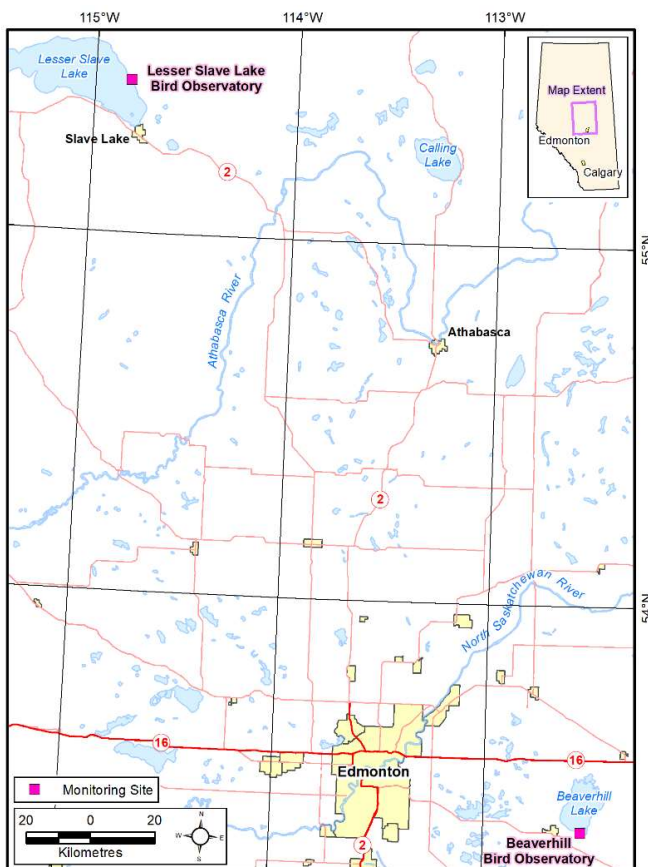
Capture Effort and Capture Rate

Both LSLBO and BBO provided data where four mist-nets were used in combination with a male northern saw-whet owl call playback in the first 4 hours after sunset. Capture data for northern saw-whet owls at BBO was filtered for the dates where 98% of captures occurred (Sept 12 to Nov 8). Raw data from LSLBO was supplied and the dates in which 98% of the owls were captured was calculated to eliminate the extreme outlier dates for migration (to be comparable to BBO). To do this, the seasonal capture for all years is summed (grand total of owls captured) and multiplied by 0.01 and 0.99 to get the start and end dates of migration where 98% of owls will pass through (September 1 to October 29), during the 19-year period. Outlier captures of northern saw-whet owls at the extreme beginning and end of migration could be resident (non-migratory) owls.

Net-hours (effort) were calculated by the total hours of owl call playback per night multiplied by the number of nets used per night. One standard mist net operated for one hour with call playback is a "net-hour" (Ralph et al., 1993). Variation in net-hours can be attributed to closing nets early due to bad weather, and nights where the banding station was closed.

Capture rate is used to compare between years or between sites since it is a standardized number which controls for effort (number of nets used, total number of hours spent mist netting). Using capture rates rather than absolute captures assumes that effort each year was equal. Capture rate was calculated as owls/100 net-hours (owls captured divided by playback net-hours, times 100). Once capture rate per day was calculated, then an annual capture rate was calculated by summing the net-hours and the total captures and dividing the annual total capture by net-hours times 100. Differences between sites in vegetation structure, net placement, and weather

disturbance may have strong effects on capture rates, so caution is needed when interpreting capture rates between sites.

Peak migration date (50% passage) per year

To calculate seasonal peak migration date for each banding station, the methods of Priestley and Priestley (2005) were followed. To calculate the mean capture date, daily capture totals were summed to make a seasonal capture total, then the seasonal capture total is divided by two (half the seasonal total). Daily capture totals are added in chronological order until the sum was at or just larger than half the seasonal total. The mean capture date was the date on which the midpoint capture total was reached. Descriptive statistics and a linear regression analysis were completed on the data set using excel data analysis tool pack.

Temperature Changes Over Time

Historical weather data for towns close to each site (Tofield for BBO, and Slave Lake for LSLBO) was downloaded from Climate Atlas (Climate Atlas, 2022). Annual mean temperatures were used to determine if there has been a trend in temperature changes for the region. A linear regression analysis was completed on the data set using excel data analysis tool pack.

Results

Capture Effort and Capture Rates

Total capture effort for both sites was calculated and BBO's effort was higher than LSLBO, and both sites appear to have a slight increasing trend over the study period. Capture rates are standardized (effort year to year [or night to night] has been controlled for) and used to compare captures across years, or across different sites.

Capture rates fluctuated over the years and showed relatively stable rates for LSLBO and a trend of increasing capture rates for BBO **(Figure 3)**. Capture rates spanned from a low of 7 owls per 100 net-hours at LSLBO in 2013, to a high of 48 owls per 100 net-hours at BBO in 2015. In 2004, both sites started out with an average of just over 20 owls/100 net-hours, and in 2022 LSLBO remained about the same and BBO is showing an average trend of just over 30 owls/100 net-hours.

Figure 3

Annual Capture Rate Over Time at LSLBO and BBO
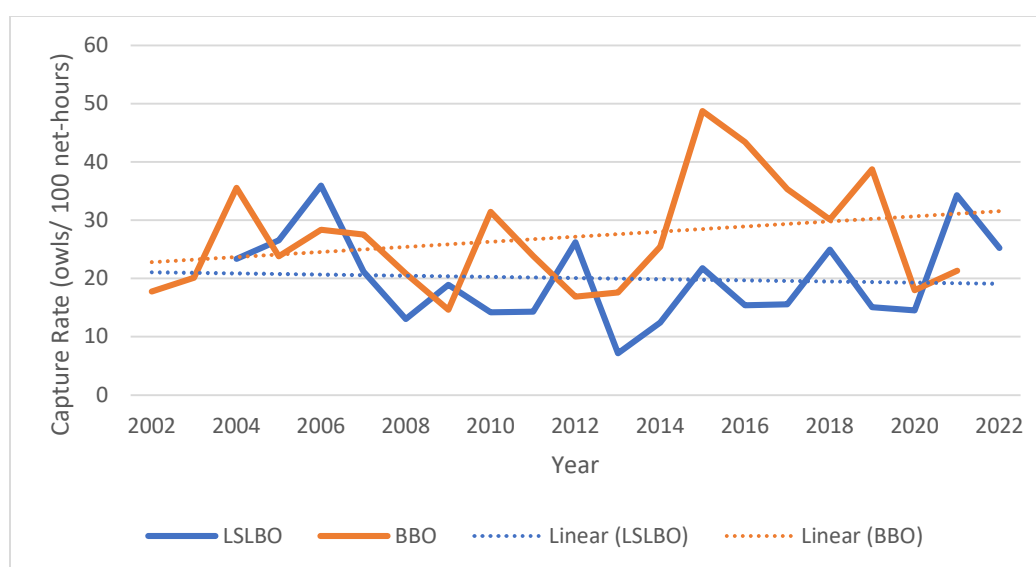
Peak migration date (50% passage) per year

At LSLBO peak fall migration has ranged from September 16 to September 29, and over all the years, the mean peak date is approximately September 24 (Table 2). In 2004 peak migration was approximately on September 22, and the trend is now displaying September 26 (Figure 4). This indicates a delay in peak fall migration departure by four days (two days per decade). The linear regression showed that both the correlation coefficient (Multiple R) and the goodness of fit tests (R^2) were weak, and the p-value is greater than 0.05 (Table 2). The analysis

from the linear regression shows that the results are not statistically significant, and therefore the null hypothesis is not rejected.

Table 2.

Descriptive Statistics and Linear Regression Analysis for Peak Migration at LSLBO and BBO

Statistics	LSLBO	BBO
Overall Mean Date ± SE	24-Sep ± 1 day	9-Oct ± 1 day
Min	16-Sep	3-Oct
Max	29-Sep	19-Oct
Std Dev.	4 days	4 days
95% CL	1.92	1.77
Multiple R	0.363	0.13
R^2	0.131	0.017
Standard Error	3.83	3.86
Slope	0.258	0.083
p Value (0.05)	0.127	0.584

Figure 4

Date of peak fall migration (50% passage date) at LSLBL and BBO
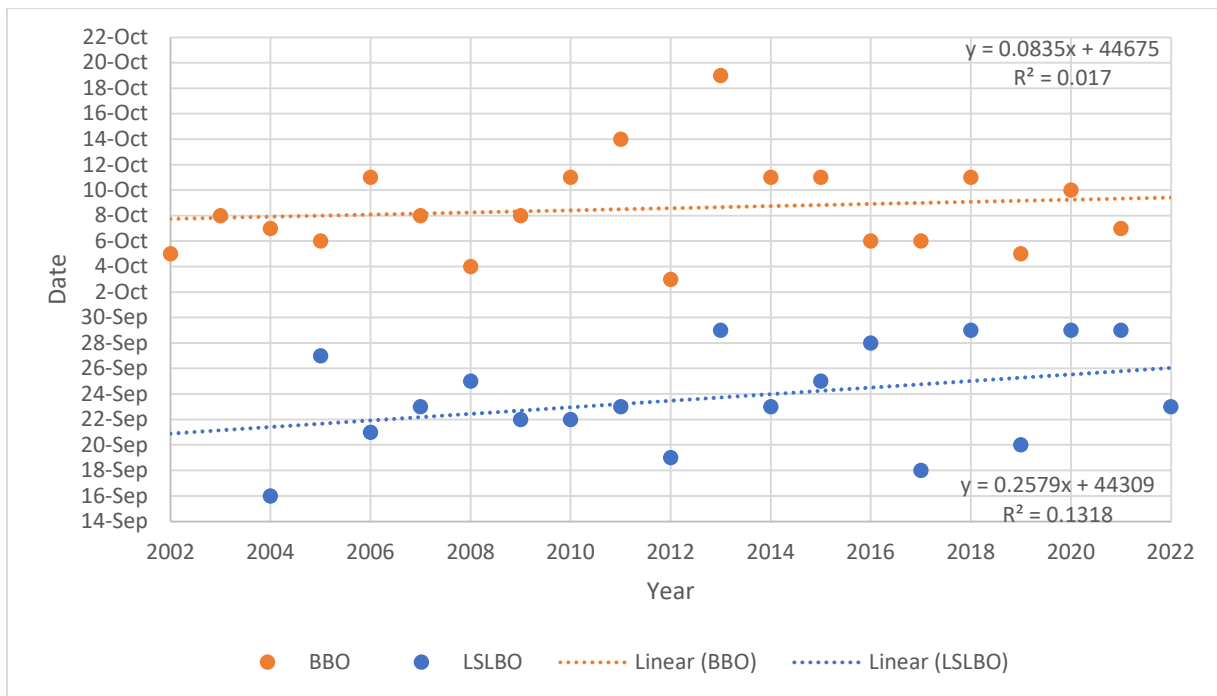
At BBO peak fall migration has ranged from October 3 to October 19, and over all the years, the mean peak date is approximately October 9 (Table 2). Date of peak fall migration at BBO has become later in the season. The trend shows it started at approximately October 8 in 2002 and currently in 2022 it has advanced to October 10 (Figure 4). This shows a delay in peak departure of two days (one day per decade). The linear regression showed a slope that was close to zero, both the correlation coefficient (Multiple R) and the goodness of fit tests (R^2) were weak, and a p-value greater than 0.05 (Table 2). The analysis from the linear regression shows that the results are not statistically significant, and therefore the null hypothesis is not rejected.

The peak migration analysis illustrates that in every year, peak migration at LSLBO was earlier than at BBO (Figure 4), and the overall average date of peak migration is also earlier at LSLBO than BBO. This is consistent with other research stating that banding stations at more northern latitudes have earlier fall departure dates.

Temperature Changes Over Time

Data was available from 1950 to present and average annual mean temperature was plotted for each site (Figure 5). There has been a noticeable trend of an increase in temperatures from 1950 to 2022. LSLBO temperatures have increased from 0.2°C to 3°C in 70 years (0.4°C per decade); and temperatures at BBO have increased from 1.2°C to 3.8°C (0.4°C per decade). Results from the linear regression show that these long-term temperature changes are statistically significant at both sites (Table 3) and therefore the null hypothesis is rejected. The linear regression analysis for both sites revealed the correlation coefficient (Multiple R) and the goodness of fit tests (R^2) were moderate, the Standard Error (SE) had >90% of values along the best fit line, and the p-value was less than 0.01 (Table 3).

Figure 5

Long-term Annual Average Temperature Changes since 1950 at LSLBO and BBO
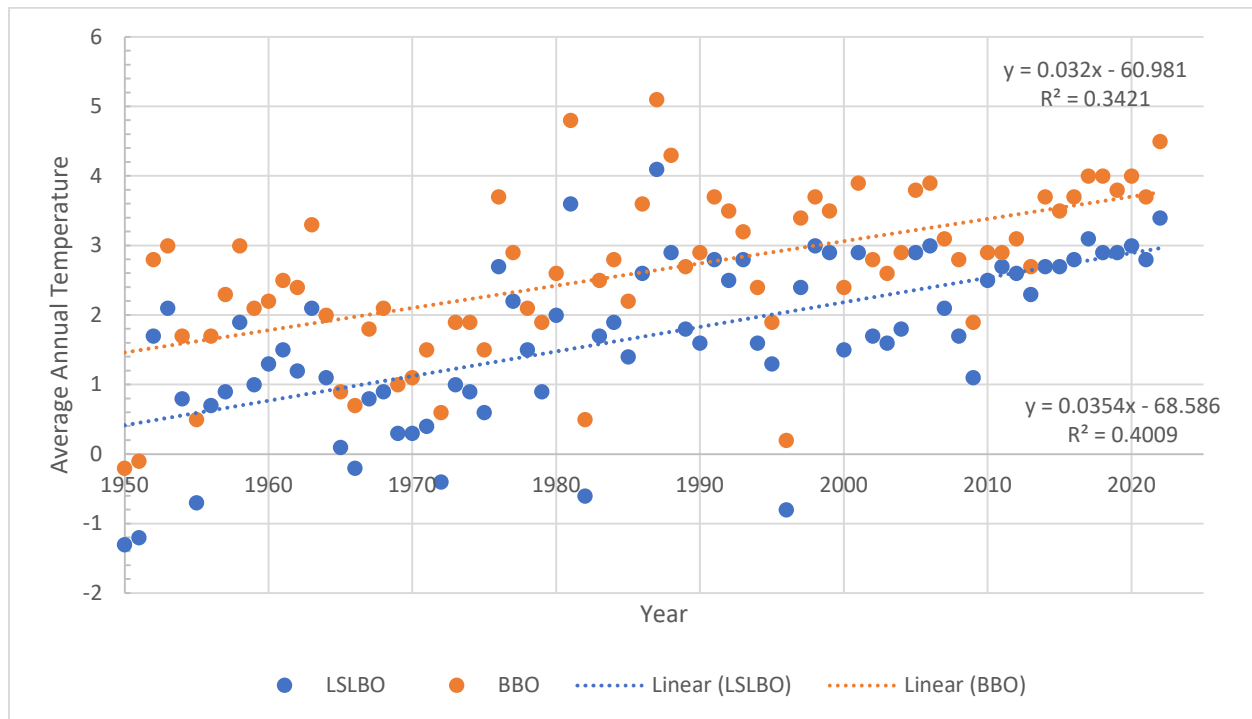
Table 3.

Linear Regression Analysis for Long-term (1950-2022) Temperature Changes

Statistics	LSLBO	BBO
Multiple R	0.633	0.585
R^2	0.401	0.342
SE	0.924	0.949
Slope	0.035	0.032
p Value (0.05)	<0.01	<0.01

In the shorter term (Figure 6), looking at temperature data from 2000 to 2022, LSLBO

had an increase of 0.06°C per year (0.6°C per decade), and BBO had an increase of 0.05°C per

year (0.5°C per decade). In the last two decades, warming has been more rapid than in the last 7

decades. A linear regression was performed, and results show that the short-term temperature

changes are statistically significant at both sites, and therefore the null hypothesis is rejected. The

linear regression analysis for both sites established that the correlation coefficient (Multiple R) and the goodness of fit tests (R^2) were moderate, the Standard Error (SE) had approximately 50% of values along the best fit line, and the p-value was less than 0.01 (Table 4).

Figure 6

Short-term Annual Average Temperature Changes (2000 – 2022)
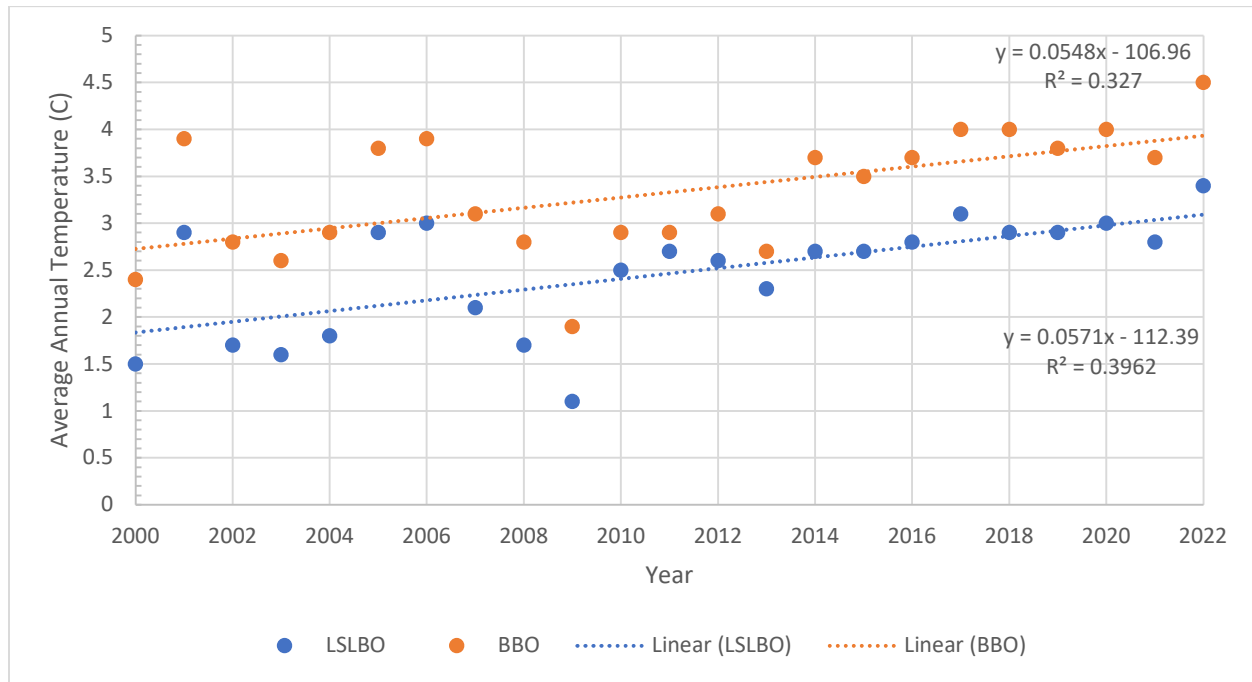
Table 4.

Linear Regression Analysis for Short-term (2000-2022) Temperature Changes

Statistics	LSLBO	BBO
Multiple R	0.629	0.572
R^2	0.396	0.327
SE	0.489	0.546
Slope	0.057	0.054
p Value (0.05)	<0.01	<0.01

In both short-term and long-term temperature graphs (Figure 5 and Figure 6), average temperatures at LSLBO are lower than at BBO, which is expected as LSLBO is at a higher latitude.

Discussion

Capture Effort and Capture Rates

Capture effort at both sites has varied over the years and shows a gradual increase. Capture rates during fall migration have fluctuated but exhibited relatively stable rates for LSLBO and a trend of increasing capture rates for BBO. At the beginning of the study period both sites started out with an average of just over 20 owls/100 net-hours, and in 2022 LSLBO remained the same and BBO is showing a current trend of just over 30 owls/100 net-hours. At LSLBO, the same proportion of owls are being captured each year on average. At BBO increasing proportion of captures can likely be attributed to a very successful breeding year in 2015 and subsequent years; however, recent years (2020 & 2021) have shown capture rates similar to what they were in 2002 which is consistent with the cyclical nature of northern saw-whet owl population cycles (Pearce-Meijerink, 2023, pers.comm.).

Capture rates can be affected by the day of the week in which mist-netting is performed with Sundays and Mondays (Saturday and Sunday evenings) capturing more owls, and Tuesday and Friday capturing less owls (Kanda et al., 2016) because of a human caused bias in more captures on weekends due to the availability of staff and volunteers to work on those days (Kanda et al., 2016). Additionally, various weather conditions including temperature, wind speed and direction, and moon phase an affect capture rates (Bedard and Whiteman, 2018; Kanda et al., 2016; Murphy, 2016). These variables were not considered during this research but could be confounding factors. If there is a human perceived difficulty in capturing northern saw-whet

owls on nights with full moon, there could be less effort put in on those nights and therefore a bias towards more captures on darker evenings (Kanda et al., 2016).

Peak migration date (50% passage) per year

This research showed that at LSLBO peak fall migration is currently (2022) four days later than it was in 2004, which is a delay of two days per decade. At BBO peak fall migration was two days later in 2021 than it was in 2002, which is a delay of one day per decade. Although these results are not significant statistically, they may be in the future as more data is collected, assuming a real but weak trend. Furthermore, results such as these could have significant ecological consequences such as synchrony of life history events, changes in moult timing which affects departure dates, ecological mismatches, food availability, and overall potential risks of extinction due to climate change (Gallinat, 2015; Hurlbert and Liang, 2012; Lehikoinenal, 2004).

LSLBO has shown a greater change in peak migration date (two days per decade) than BBO (one day per decade). This could suggest that shifts in fall migration dates due to temperature changes are more pronounced at higher latitude sites. Previous research has shown that fall migration can be delayed in areas of higher latitude (Bitterlin and Van Buskirk, 2014). This is also consistent with the literature stating that sites further north are affected by changes in climate to a greater extent than more southern sites (Gutiérrez et al., 2021; Hansen et al., 2016; La Sorte and Thompson, 2007).

In an analysis completed by BBO it was noted that peak migration date is getting later since 2002 and has been delayed by four days (two days per decade) (Nature Alberta, 2022). BBO's results differ because of a transcription error in the original dataset that they used for their analysis, but it was updated for this investigation; BBO anticipates re-running their analysis. Another unpublished study by Myrthe Van Brempt looked at banding data from the northeastern

USA between 1990 and 2020 and found that the date of peak migration is delayed by one day per decade (Nature Alberta, 2022). There are no other studies on fall migration pattern changes of northern saw-whet owls. The results of this study are consistent with results from Europe on fall migration research on songbirds noting that fall migration departure dates are getting later over time (Gilyazov and Sparks, 2002; Sparks and Mason, 2001 in Lehikoinen at el., 2004; McCarty, 2001).

Earlier spring migration arrival dates for songbirds have been noted in several studies (Charmantier and Gienapp, 2013; DeLeon et al., 2011), and short-distance migrants advanced their arrival date more significantly than long-distance migrants (DeLeon et al., 2011; Gallinat et al., 2015; Hurlbert and Liang, 2012). Northern saw-whet owls have varying migration behaviors indicative of partial migrants such as short to long-distance movements, nomadism, and residency (Priestley et al., 2010). Since northern saw-whet owls have some short-distance migration patterns, it is also possible that their spring arrival dates could have changed over time.

Temperature Changes Over Time

Within the study sites there has been a noticeable trend of an increase in temperatures in the long-term data (1950 to 2022) with both sites having a 0.4°C per decade increase. In the shorter term (2000 to 2022), LSLBO had an increase of 0.6°C per decade, and BBO had an increase of 0.5°C per decade. Globally, it is well understood that human impact has warmed the atmosphere leading to swift changes in the biosphere (IPCC, 2021). Global surface temperature between 2001–2020 was 0.99°C higher than between 1850–1900; and global surface temperature was 1.09°C higher in 2011–2020 than 1850–1900, with larger increases over land (IPCC, 2021). These global temperature trends are comparable to the local temperature datasets analyzed in that

both the global and local temperatures have increased more in the last decade than in the previous 50 years.

The pattern of global increasing temperatures is expected to continue (IPCC, 2021), and therefore the local temperatures are anticipated to increase as well. Global warming of 1.5°C and 2°C are very likely to be exceeded in the 21st century (IPCC, 2021). With local temperatures continuing to warm, it is likely that migration patterns of northern saw-whet owls, and other species will continue to shift with the temperature changes. For some species, longer summer and later autumn may lead to later fall migrations (Lehikoinen et al., 2004).

Earlier spring migration arrival dates for songbirds have been noted in several studies that can be linked to increasing temperatures (Charmantier and Gienapp, 2013; DeLeon et al., 2011; Hurlbert and Liang, 2012). Pearce-Higgins et al. (2015) discovered that late arriving long-distance migrants that have failed to advance their arrival time tended to decline in abundance. Recent warming trends have contributed to changes in bird communities, including increases in resident and short-distance migrants, and decreased populations in long-distance migrants, habitat specialists, and cold adapted species (Pearce-Higgins et al., 2015). Northern saw-whet owls prefer cooler summer temperatures and lower levels of snow precipitation (Domahidi et. al., 2019). Warming temperature trends could affect their breeding habitat and their migration patterns. An analysis on mean autumn temperatures (as opposed to mean annual temperatures) over time at the local banding stations could be completed to determine if fall temperatures are significantly different.

General trends are that temperate birds' geographic ranges are moving northwards, spring arrival dates are getting earlier, and fall departure dates are getting later. Some songbirds tend to be trailing behind the shifts in temperature (DeVictor et al., 2008; Rushing et al., 2020). Certain

researchers recognize that although the data points to climate change, there are other factors that can cause shifts in range such as habitat structure and regional anthropogenic influences (Hitch and Leberge, 2007; La Sorte, 2007).

Conclusion

This study showed that the date of peak fall migration in northern saw-whet owls is becoming later in the season by one to two days per decade in Alberta. These results may not have been statistically significant, but it could have significant ecological impacts, especially as time goes on. Results also showed that the more northern site (LSLBO) had earlier fall migration and had a longer delay of departure than the site that was further south (BBO). Results of temperature analysis demonstrated that there has been a shift in mean annual temperature at each banding station with increasing temperatures since 1950, with a more pronounced increase in recent decades, and these results are significant. The increase in local temperature is consistent with the trend in increasing global temperatures.

Ecological significance of a shift in fall migration timing can include asynchrony in autumn interaction within or between species; dietary changes or food availability; allowance of more time to complete moult cycles; and overall risk of extinction (Gallinat, 2015; Hurlbert and Liang, 2012; Lehikoinenal, 2004). Even though the significance of these results may still be disputed, there are implications for conservation and resource management. Climate change could be a threat to northern saw-whet owls and even though a causal link cannot be directly demonstrated at this time, the research indicates that these concerns need to be taken seriously.

Some researchers acknowledge that although the data points to climate change, there are other factors that can cause shifts in range and changes in migration dates (DeVictor et al., 2008; Gallinat et al., 2015; Hitch and Leberge, 2007; La Sorte, 2007). Timing of autumn bird migration

is prompted by temperature but also by other climate components (e.g., precipitation and photoperiod), interactions with other species, habitat structure and dynamics, life-history traits, spring arrival times, migration speed, annual biological cycles, and dispersal limitation (DeVictor et al., 2008; Gallinat et al., 2015). Ecological conditions can affect fitness (i.e., food availability) during the days preceding departure, and moult can be affected by resource availability, which in turn depends on climate variability; moreover, migratory phenology can be affected by quality and quantity of replaced feathers during moult (Gordo, 2007). Northern saw-whet owls moult their feathers in the summer (Slack, 1992), so a poor or delayed moult could affect departure date. Another aspect that has been rarely researched is the factor of evolution versus adaptation (Crozier et al., 2011; Gienapp et al. 2008). It is a possibility that evolutionary processes could explain variation that cannot be explained using the available information about driving environmental factors; If these processes are ignored, it could create bias in analysis of the effects of climate change on migration pattern shifts (Crozier et al., 2011). Multi-variate research would be required to determine which variables could be confounding factors to delayed fall peak migration dates.

Since capture rate can be affected by various weather factors including moon phase and visible moon it is possible that peak migration date could be influenced by the number of days of banding surrounding the new moon and full moon. More captures surrounding new moon could influence the date of peak migration. Capture rates are also affected by the day of the week in which mist-netting is performed, so if operating days were more often on weekends, then capture rates could be higher, and could influence the outcome on the date of peak migration. The factors of moon phase and operating days were not assessed in this research but could be examined to

determine if those variables are influencing the date of peak migration and reveal if those variables are human dimensions.

Climate change is a direct driver that is increasingly exacerbating the impact of other drivers on nature and human well-being (IPBES, 2019), so preservation of the biodiversity of ecosystems and its individual components is paramount. Intact natural ecosystems can regulate local climate regimes and help human population overcome challenges and adapt to climate change (Scheffers et al., 2016). Climate change in combination with habitat loss or alteration, and invasive species can have a detrimental impact on bird populations, status, and distributions (Bateman, 2019; Jenouvrier, 2013; Rushing, 2020).

Northern saw-whet owl peak fall migration dates are getting later in central Alberta. A larger, more comprehensive study should be conducted to determine if this trend is occurring throughout the North American range of the northern saw-whet owl. If dates are shifting regionally, then it is possible that researchers may need to adjust their migration monitoring periods to collect representative data. Spring migration surveys on northern saw-whet owls are lacking; These studies should be completed to determine if spring peak arrival dates have also shifted. Additionally, multivariate studies should be completed to determine if factors other than temperature are affecting peak fall migration dates.

Limitations

The data collected as part of owl banding projects is not randomized, so the degree of control and strength of inference are low (Schwartz, 1998). The purpose of the owl monitoring projects is to collect as much data as possible from a location known to support northern saw-whet owls. Since the data used in this research project is secondary, the author has no control on how the data was collected, recorded, or quality checked. The data collected may be skewed due

to certain protocols used at the time, though thorough efforts were made to ensure data analyzed in this research used consistent protocols. A relatively small sample size is used (two banding stations) in this research to ensure being able to complete the scope in the time frame given; additional research should be conducted on all recent data at all banding stations in Alberta. However, a time frame of 20 years is considered a long-term data set.

This research will not provide a comprehensive overview on the migratory patterns of northern saw-whet owls in their range; rather, it provides descriptive indicators. The geographic region is limited to the areas surrounding the banding station locations and cannot be generalized. This is due to potential external factors affecting the data, and the potential of northern saw-whet owls being partial migrants depending on their natal location and their sex. This research does not provide information on breeding or population status of northern saw-whet owls.

The data analysis is not able to include the days that the banding stations were closed and not collecting data. So, dates of peak migration could be slightly different than if the banding station was open every day during migration.

The author was a member of the Calgary Bird Banding Society and has been involved in volunteer efforts to collect data for a similar project in Calgary. However, there is no bias associated with the data or the analysis, as the researcher remains impartial.

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Appendix

Descriptions of Field Data Entry and Codes for Owl Banding

Table A1.

Parameters Measured/ Recoded during Owl Banding

Field Name	Description
Band Number	The unique number of the federally issued USGS band put on the bird.
Species	The four-letter species alpha code.
Program	The program in which the bird was banded or recaptured (see below).
Banding / Recapture Date	The date the bird was captured in DD-MMM-YEAR format.
Capture Time	The time of the net check that the bird was extracted from the net rounded to the nearest five-minute interval in 24-hour format.
Location	The banding station the bird was captured in (see Protocols and below).
Net	The standardized location of the net the bird was captured in (Protocols).
Coordinates WGS84	Coordinates of the capture location in WGS84 projected decimal degrees with errors $\pm$ 3 to 6 m. Non-standardized locations with higher uncertainty have one decimal digit and errors $\pm$ 10 km.
Age	The numeric age using the calendar/year class aging system (see below).
2016 HA	The current code for how the bird was aged; used since 2016.
HA	The original (often discontinued) how aged code recorded in the field.
HA Description	Brief description of the original how aged code recorded in the field.

Field Name	Description
Sex	The numeric sex code (see below).
2016 HS	The current code for how the bird was sexed; used since 2016.
HS	The original (often discontinued) how sexed code recorded in the field.
HS Description	Brief description of the original how sexed code recorded in the field.
Wing Chord	The unflattened wing length in millimeters (Pyle, 1997).
Wing Wear	Score describing the wear on the primaries (MAPS Manual, 2020)
Muscle	Score describing muscle development around the keel (Protocol, p. #).
Bird Weight	The bird's weight to the nearest tenth of a gram.
Moult Score	If the bird was actively moulting flight feathers, the score describing the progression of the flight feather moult (see Protocols).
Tail Length	The tail length in millimetres (Pyle, 1997).
Comments	Additional comments about the bird's plumage, condition, or other features. Can include additional measurements and if photos were taken. Additional codes may be used, contact the LSLBO for further clarification.

Notes: From LSLBO (Campsall & Perkins, 2021)