THE INFLUENCE OF WEATHER AND HUMAN DISTURBANCE ON THE REPRODUCTIVE SUCCESS OF CHIMNEY SWIFTS IN ST. ADOLPHE, MANITOBA, 2007-2013 AND 2014-2022

Barbara E. Stewart and Robert E. A. Stewart
Sila Consultants
1218 Marchand Road
Howden, MB R5A 1J6
sila.stewart@gmail.com

Introduction

The Chimney Swift (*Chaetura pelagica*) belongs to the guild of aerial insectivores (Figure 1).[1] Declines in prey abundance and the loss of nest sites through the lining, capping, or demolishing of old masonry chimneys have contributed to the significant decline of Chimney Swift populations throughout Canada.[1,2] It is protected as a Species at Risk (Threatened) in Canada and Manitoba.[3-6]

Chimney Swift reproduction has been studied in St. Adolphe, MB (2007-2009 and 2010-2013).[7,8] Here we present additional data (2014-2022) and use long-term data (2007-2022) to analyze reproductive trends and examine site-specific breeding success.

We identified anthropogenic disturbances as one of many factors affecting reproductive success.[9] Prey abundance and aerial insectivore nestling survival are known to vary in species-specific ways with weather.[10-17] Prey availability varies predictably with time of day and season but unfavorable weather is disruptive. Weather parameters interact with each other and with biotic factors in urban and agricultural landscapes.[10,16,18-20] While we were unable to assess interactions among abiotic and biotic factors, we investigated the effect of weather and inferred seasonal prey abundance variation possibly correlated with nest failures.

Methods

Five Chimney Swift nest sites on four buildings in St. Adolphe, MB (~10 km south of Winnipeg) have been monitored with the same protocol since 2007.[7,8] The time of nest site entry and exit events was recorded to the nearest second. The interval between an exit and an entry is the between-visit duration. The interval between an entry and an exit is the turnaround duration, which does not distinguish between an exchange between parents and the departure of the bird that just arrived. The speed, direction, flight characteristics of approach and departure, association with other Chimney Swifts near the nest site, and the number of Chimney Swifts seen in the air were also recorded.

Local weather conditions, including Environment and Climate Change Canada (ECCC) air quality advisories for wildfire smoke, which can affect the behaviour of aerial insects, were noted although subsequent analysis relied on weather station data.[21] Also, anthropogenic disturbances e.g., building construction and rooftop activity, were documented.[9]

Monitoring effort varied among years. Monitoring sessions usually lasted 60-90 min but ranged from 15-180 min as sampling was adapted as needed. An effort was made to monitor at least two nest sites consecutively on any given day. The comparable data enabled an assessment of the effect of weather and human disturbance on nest site use and reproductive success.

Spring nest site occupation was verified and primary breeding attempts by Chimney Swift pairs were tracked to conclusion. All secondary breeding attempts failed and were not included in data analysis. The phenology, or dates for the onset of each nesting stage, was established by interpreting the sequence and frequency of entries and exits.[7,8] Nest building (Figure 2) continues through egg laying and incubation until hatching.[22,23] Establishing the starting date of incubation based on behavior remains problematic.[8] Since 2019, >50% attendance at the nest site during an observation period >60 min, followed by turnaround times for partner exchanges of <10 min has been used increasingly to identify incubation. Incubation was confirmed by the observation of a classic incubation exchange i.e., an entry followed by an exit within 30-120 sec. Incubation exchanges between partners typically occurred once per hour.[7,8]

We compared breeding phenology from 2007-2013 with that of 2014-2022, limiting analyses to pairs starting primary nest building by 6 June because pairs

FIGURE 1. Adult Chimney Swift flying with twig in beak. Photo credit: Dave Lavigne.

that arrived after 6 June (n=6) were not successful. The precision with which nest stage dates can be established depends on the length of the sampling (monitoring) interval. We used only estimated dates, for which the sampling interval was <5 d, and calculated the median date for each nesting stage.

A breeding cycle for Chimney Swifts at St. Adolphe takes at least nine weeks.[8] With only a short breeding season at this northern latitude (~mid-May to late August), a shift of even a few days for nesting stages may be biologically significant without being statistically different. Therefore, we calculated medians for each variable (e.g., hatching day) and explored the data for weather and human disturbance factors affecting even small changes. We also used longitudinal data for pairs of birds to estimate the time between various nesting stages.

Breeding success was defined as a nesting attempt culminating in at least one fledgling, identified on the basis of 'novice' flight characteristics and intact wing margins at a time when adults are moulting.[23] Reproductive success was measured by the number of fledglings

FIGURE 2. Chimney Swift nest. Small diameter twigs are held together by sticky saliva secreted from adult salivary glands. Nests are 8.9-10.8 cm wide and 2.5-3.1 cm high; the cup shaped portion, which holds eggs, extends 4.8-7.5 cm from the vertical wall.[23] Photo credit: Rob Stewart.

and presented as two different rates: 1) the standard fledglings per number of eggs laid or number of eggs hatched; and 2) to evaluate site performance (see below), the number of fledglings per site. This distinction was required because egg counts were available for only two of the five sites. Nest failure was defined by lack of activity at a site during three consecutive daytime monitoring sessions >60 min made over two days. Chimney cleanout traps at Brodeur Bros. and Main St. were inspected to observe fallen nests, eggs/eggshells, and carcasses for the determination of clutch size and reproductive rates (hatching and fledging).

Helpers are immature or non-breeding adult Chimney Swifts which assist with nesting activities.[24] In our study, the presence of a helper was confirmed by three consecutive entries or exits by Chimney Swifts at a nest site prior to fledging. The possible presence of a helper can be behaviourally nuanced. It may be indicated by the observation of a unique entry style, a pattern and sequence of entries/exits indicating a pair plus another bird are onsite, and an increased rate of attendance compared to other nest sites, at a similar nesting stage, and monitored on the same day.[7,8] Confirmed and possible helpers were noted.

Nest site performance (2007-2022) was ranked using the following parameters: order of first occupancy in the spring; number of breeding attempts; number (%) of successful breeding attempts; number of fledglings produced based on visual or physical evidence; and number of consecutive years with successful breeding. Physical evidence of fledging comes from counts of eggshells and carcasses in the chimney cleanout trap.

Each nest site was ranked (1=best, 5=worst) separately for each nest site parameter. These ranks were then summed to generate an overall nest site performance rank. We measured the height of each chimney from ground level using a range-finder with inclinometer (Leupold RX-1600i) but did not assign a rank based on height.

Starting in 2011, local weather data became available for analysis related to nest failures.[8] Late arriving breeders are known to be unsuccessful so we limited this current analysis to only those pairs present at nest sites by 6 June.[8] There were 24 nest failures documented in 2011-2022 that satisfied the arrival date criterion and were accurately dated. Six others were excluded as they failed during gaps in monitoring and could not be accurately dated.

The availability of insects for avian aerial feeders is linked to weather.[11,13,14,16,18,25] In the absence of data on insects at St. Adolphe we used weather data as a proxy for prey availability. We defined a 'weather day' as the daylength (sunrise to sunset) in which Chimney Swifts can forage. In July at St. Adolphe, sunrise is between 05:00 and 06:00 h and sunset between 21:00 and 22:00 h. Hourly weather data represent the preceding hour, e.g., 06:00 data are for 05:00-06:00 h. We limited our analysis to daytime hours: 06:00-22:00 h.[13,19]

We examined weather data preceding known nest failure dates to detect correlates. The number of these weather days examined varied with the precision of the estimated date of failure. If the nest failure date was known, we examined three weather days: the day of failure and the two preceding days. If nest failure was estimated to occur on one of two days, we examined four weather days: failure day estimates one and two, plus the two preceding days. Similarly, if nest failure was estimated to occur on one of three consecutive days, we examined five weather days.

Manitoba Agriculture maintains a weather station located 2.7 km north of St. Adolphe (Station ID 243).[26] We received weather data as Excel files from Manitoba Agriculture. From this data set we used hourly average air temperatures and wind speeds, maximum hourly wind speeds, and hourly rainfall for weather each day.

The number of aerial insects declines when air temperatures are too low or too high.[13,15,16,25] We used lower and upper air temperature thresholds of <18.5° C and > 32° C (reduced prey) and <15.5° C and >34° C (severely reduced prey) for this study. These thresholds were based on those used to define cold snaps that correlated with nestling mortality of Tree Swallows (*Tachycineta bicolor*) at Ithaca, New York due to low prey availability.[15,16] In Louisiana, aerial insect abundance at 32.2° C and 33.9° C were the same as when the temperature was 18.5° C and 15.5° C respectively.[25] Chimney Swifts increased the between-visit feeding intervals at temperatures between 33.1° C and 36° C and again at temperatures over 36° C.[27] The 90th percentile of July maximum temperatures in Winnipeg is about 32° C, suggesting higher temperatures can be considered extreme.[28] In our study period, there were no July temperatures over 36° C.

Rain and winds can also negatively affect the availability of aerial insects, but we found no published numeric thresholds as we did for temperature. We used the ECCC protocol to report wind gusts greater than 30 kph as a threshold for 'windy'.[29] We tabulated the number of daytime hours when weather factors met the criteria, and, as the number of weather days examined varied, we expressed the results as the percent of daytime hours examined i.e., the percent of potential feeding hours examined. The presence of wildfire smoke was based on air quality advisories from ECCC. Having identified environmental data potentially associated with nest failures, we examined behaviour records for examples of behavioral changes associated with the posited reduced feeding.

Results

Fewer Chimney Swift nest sites were occupied in 2007-2013 (28 breeding attempts over seven years at five sites) than in 2014-2022 (43 breeding attempts over nine years at five sites, Table 1).[8] They were also occupied earlier in 2007-2013 than in 2014-2022 (median dates 18 and 21 May, respectively; Table 2, Figure 3).

Pairs that were ultimately successful in 2014-2022 (Tables 1, 3) typically arrived at

a nest site together or within a day of each other, and usually started nest building immediately. The mean interval between arrival and nest building was 1.9 d in 2007-13 and 0.0 d in 2014-22. The long lag in the first period is due to the protracted start at the Church in 2008. This was the only nesting data point for 2008 and we have no weather data to further assess this case. The mean would be 0.9 d if this pair were excluded (Table 2).

Using entry/exit data to estimate the onset of incubation, the median start of incubation was six days earlier in 2014-2022 than in 2007-2013 (Table 2, Figure 3) and using paired data, the duration of incubation was virtually identical (17 d, Table 2). Corresponding to the earlier start of incubation, all nesting stages were slightly earlier in 2014-2022 than 2007-2013 and the durations of most nesting stages were similar until departure (Table 2). The long period of feeding brooded nestlings at the Church in 2013 (11 d; typically 6-7 d) inflated the overall mean but is thought to be due to inconclusive monitoring. In 2014-2022, both successful and failed parents have left almost a week earlier (successful 6 d and failed 5 d earlier). The time between fledging and departure was 6 d shorter in 2014-2022.

In 2007-2009, pre-migratory groups of local birds were evident while between 2010-2013 they formed only in years with good feeding rates.[7,8] For 2014-2022, no pre-migratory groupings of local birds were seen as Chimney Swifts regularly dispersed from St. Adolphe earlier in the season. For example, concurrent monitoring of all five sites on 2 August 2018 showed all five were being used as roosts but the maximum number of Chimney Swifts counted (12) was less than expected (five pairs and four known fledglings).

The date of first fledging at one site usually marked the start of departures of unsuccessful breeders which previously had roosted in their nest sites. The median date on which successful nesting sites were last used was later in 2007-2013 (22 August, n=6, range 13 August-3 September) than in 2014-2022 (14 August, n=11, range 2-24 August). This was different than reported elsewhere because this analysis is limited to successful sites only.[8]

For corrected data from 2007-2013, the breeding success rate was lower (39%, range 20-60%) than in 2014-2022 (44%, range 20-80%; Tables 1, 3, 4 and 5). The successful fledging at SE Club Amical in 2018 was not only the first recorded success at this site but also the earliest recorded fledging date in St. Adolphe.

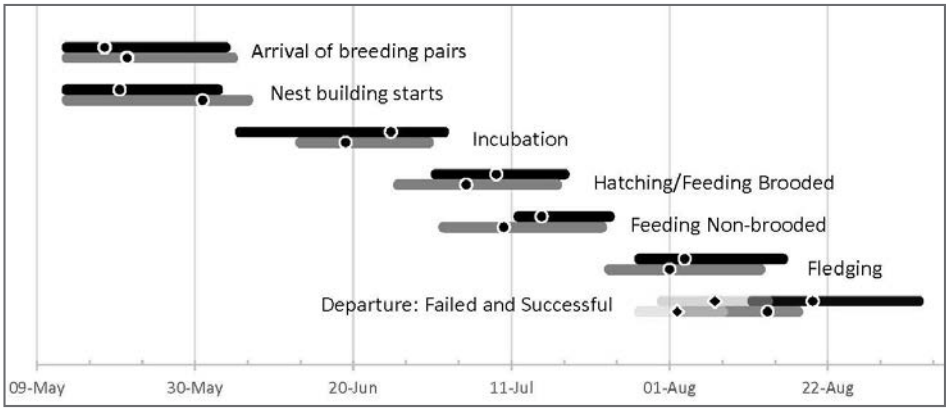

FIGURE 3. Phenology of breeding Chimney Swifts at five nest sites in St. Adolphe, MB. For each nesting stage, the range of dates (bars) and medians (●) are shown for 2007-2013 (upper, darker bar) and 2014-2022 (lower, lighter bar) for breeding pairs starting their primary nest building by 6 June with a sampling interval <5 d. Departure dates are shown for breeders that failed (median ◆; lighter bar, left) and for successful breeders (median ●; darker bar, right). Departure date ranges of failed and successful birds overlap.

There were 16 pairs of visual/physical fledgling counts. Fifteen pairs agreed or differed by a count of one bird more in physical evidence, e.g., one vs. two, two vs. three. At Main St. in 2021, there was physical evidence of five fledglings although the visual estimate was one. The rank assigned to Number of Fledglings was not affected by these data. Fewer fledglings were produced in 2007-2013 than in 2014-2022 (Table 3) although the median number of young produced per successful nest was two for each period.[8]

In 2007-2013, for primary nesting attempts initiated by a pair <4 June, nest failures (n=12) took place at three different nesting stages: incubation (33%); feeding brooded juveniles (25%); and feeding non-brooded juveniles (42%).[8] For 2014-2022, established pairs nest building by 6 June failed (n=24) at only two different stages: feeding brooded juveniles (46%) and feeding non-brooded juveniles (54%).

Some sites were more successful in consecutive years than others and we returned to the 2007-2013 data to examine these patterns. The highest number of consecutive successful breeding attempts at any nest site was four and one site was never successful two years in a row (Table 4). There were four consecutive unsuccessful breeding attempts at NE Club Amical (2018-2021) and three at SE Club Amical (2014-2017).

All the nest chimneys are brick and four of five rise from inside airconditioned buildings. The fifth, the Church chimney, is attached to two walls on the north side of the building where the below-roofline part is well shaded except to the northeast quadrat. The Church is not cooled in summer. The Church site had the best site performance rank in both reporting periods (Table 4). Other sites varied in rank but not by more than one position. Overall, Brodeur Bros. had the poorest site performance rank; it was not used every year, was often selected last by spring arriving Chimney Swifts, and had the lowest breeding success rates. Chimney height above ground ranged from 9.1-14.2 m and all but one extended into basements (Table 4).

Reproductive rates of Chimney Swifts at Brodeur Bros. and Main St., where nesting residue can be observed in the cleanouts, varied between the two reporting periods (Table 5). At Brodeur Bros., the clutch size range remained nearly the same and while the percent of eggs hatching increased there were large declines in the number fledging; breeding attempts which were successful fell (Table 5).

At Main St., clutch size became more variable, the percentage of eggs hatching and fledging rates relative to eggs laid increased, and the number of fledglings relative to the number of eggs hatched decreased. Breeding success at this site doubled between the reporting periods (Table 5). Reproductive success (number of fledglings) from all sites increased between the two periods, attributable primarily to large increases at the Church (Table 4).

The absolute and relative number

TABLE 1. Phenology at five Chimney Swift nest sites in St. Adolphe, MB, 2014-2022. Dates for the onset of nesting stages are for primary breeding attempts. Empty fields reflect missing data. Arrival dates and nest building by single birds are noted. Last known use at site=daytime (D; entries/exits) or roosting (R; roosting entries); number of birds (n).

Year (hours obs.)	Site	Arrival Date	Nest Building	Incubation	Feeding Brooded	Feeding Non-brooded	Fledge Date	Last Known Use D, R (n)
2014 (81)	SE Club Amical	30 May-2 June	<11 June		4-9 July; **FAILED 11-12 July**			18 August R (2)
	NE Club Amical	≤21 May	<11 June		13-15 July		11 August	18 August R (2)
	Brodeur Bros.	26-29 May			By 3 July		30 July	14 August R (3)
	Church	22-25 May			By 2 July; **FAILED >3-21 July**			22 July R (2)
	Main St.	≤21 May			≥10 July; **FAILED 10-21 July**			3 August R (2)
2015 (75)	SE Club Amical	20 May single night use	None initiated					N/A
	NE Club Amical	21-24 May	>9 June		6 July	12 July; **FAILED 17-24 JULY**		16 July D (2)
	Brodeur Bros.	21-24 May	~9 June		15 July; **FAILED 16 JULY**			25 July D (1)
	Church	≤20 May	4-5 June		30 June	7 July	1 August	16 August R (5)
	Main St.	≤20 May	1 June		3-6 July; **FAILED 7-12 JULY**			6 July D (2)
2016 (146)	SE Club Amical	7-14 June	7-14 June		10 July	16 July; **FAILED 18-19 July**		24 August R (1)
	NE Club Amical	17-19 May	17-19 May		4 July	9-10 July; **FAILED 16 July**		24 August R (1)
	Brodeur Bros.	*30 May-2 June*, *n*=1; 7-13 June, *n*=2	30 May-2 June		10 July; **FAILED 15 July**			27 July R (1)
	Church	17-28 May	17-28 May		3 July	9 July	30 July	17 August R (3)
	Main St.	*17-29 May*, *n*=1; 15-21 June, n=2	*30 May-2 June n=1*		14 July		12 August	17 August R (2)
2017 (75)	SE Club Amical	By 31 May	≤31 May		3-5 July; **FAILED 10 July**			8 August R (3)
	NE Club Amical	By 31 May	≤31 May		5-6 July	10 July	1 August	8 August R (2)
	Brodeur Bros.	Unoccupied all season						N/A
	Church	By 31 May	1-2 June		3-5 July	8-10 July	31 July	17 August R (4)
	Main St.	By 31 May	≤1 June		4-6 July	9-13 July	2 August	13 August R (4)
2018 (104)	SE Club Amical	20-25 May	20-25 May		25-27 June	Unk.; helper onsite	24 July	2 August R (2)
	NE Club Amical	20-21 May	20-21 May		≥28 June; **FAILED 29 June-1 July**			6 August D (2)
	Brodeur Bros.	*26-31 May*, *n*=1; 4 June, *n*=2	4 June		≥28 June; **FAILED 28 June-1 July**			31 July R (2)
	Church	16 May	16 May		1 July	6 July; **FAILED 16-18 July**		2 August R (2)
	Main St.	*21-24 May*, *n*=1; 4 June, *n*=2	21-24 May		27-30 June	2-3 July	28 July	2 August R (4)
2019 (156)	SE Club Amical	20 May	20 May	20-22 June	29 June-1 July	Unk.; heavy smoke & decreasing attendance during transition	25 July	10 August D (1)
	NE Club Amical	23 May	23 May	17 June	29-30 June	5 July; **FAILED 11-12 July**		31 July D (1; juvenile, likely from SE site)
	Brodeur Bros.	21 May	21 May	30 June	10 July; **FAILED 15-16 July**			16 July D (1)
	Church	13 May	13 May	13 June	27-28 June	3 July; **FAILED 17-18 July**		16 July D (1)
	Main St.	23 May	23 May	21 June	9 July	15 July	5-7 August	14 August D (1)
2020 (132)	SE Club Amical	19-22 May	19-22 May	19 June	9 July	15 July; **FAILED 20-21 July**		20 July D (1)
	NE Club Amical	23-27 May	23-27 May	19 June	9 July	15 July; **FAILED 27 July**		26 July D (2)
	Brodeur Bros.	18-22 May	18-22 May	17 June	3 July	9 July; **FAILED 13-14 July**		5 August R (1)
	Church	18-22 May	18-22 May	17 June	4 July	10 July	2-3 August	23 August R (2)**
	Main St.	18 May owner's report	≤1 June	19 June	10 July	Unk.; **FAILED 17-20 July**		16 July D (2)
2021 (124)	SE Club Amical	First of year observations in St. Adolphe: 14 May, *n*=3; 15 May, *n*=6; 19 May, *n*=8; no day use at any site until 27 May	27 May	18 June	7 July	13 July; **FAILED 14 July**		25 July D (1)
	NE Club Amical		31 May	18 June	6 July	12 July; **FAILED 17 July**		16 July D (1)
	Brodeur Bros.		31 May	17 June	3 July; **FAILED 7 July**			6 August D (1)
	Church		31 May	17 June	5 July	10 July	31 July	15 August R (1; likely migrant)
	Main St.		3 June	19 June	7 July	12 July	3 August	4 August D (2)
2022† (117)	SE Club Amical	Other observers reported Chimney Swifts in St. Adolphe 12 May, *n*=3 and 25 May, *n*=5	4 June	18-20 June	16 July	21 July	13 August	16 August D (3)
	NE Club Amical		4 June	21-22 June	1 July	8 July	29 July	16 August D (1)
	Brodeur Bros.		4-5 June	20-23 June	11 July; **FAILED 13-14 July**			12 July (2)
	Church		6 June	24-26 June	15 July	22 July	11 August	12 August D (1)
	Main St.		5-6 June	28 June-1 July	17 July	23 July	13 August	13 August D (2)

** At the Church aerial group sizes on 8-12 August were two adults and two juveniles. There was heavy rain during the day on 14 August (30.8 mm) and the average daytime temperature was 16.4°C. No Chimney Swifts were seen 15-17 August. The two birds seen on 23 August were likely migrants.

† In 2022, Red River flood waters prevented us monitoring until 1 June.

of helpers increased between the two periods and, more often, helpers were present at successful breeding attempts (Table 3). The success rate of attempts with a helper were indistinguishable between periods, due to small sample sizes, and across all years the success rate with a helper was 70%.

For each nest failure, the most prevalent weather parameter was considered the most likely proximal cause (Table 6). Two failures, both at Brodeur Bros. (Lines 1 and 8 in Table 6), showed no strong weather effects but were associated with visits of non-parent adult birds. The September 2011 examination of the Brodeur Bros. cleanout revealed unhatched eggs and no nest while in 2015, unhatched eggs, hatched eggs, and no nest were observed. Another failed attempt, at the Church (Line 2 in Table 6) also seemed uncorrelated with weather, although most of the hours <18.5° C were also <15.5° C, and the young were within 3-5 days of expected fledging. Of the remaining 21 failures, 17 were associated with daytime hours when air temperature was <18.5° C. The proportion of daytime hours in which winds exceeded 30 kph showed no obvious relation to nest failures (0% in 19 of 24 cases, 1.6-10% in 5 of 24; unpubl. data).

There were 21 successful breeding attempts that shared the weather events with the 24 failed attempts (2011-2022; Tables 1, 3, and 6). Six of these successes were at different nesting stages than the failures when the failures occurred. Weather/chick age interactions cannot be ruled out but we have too few data to assess the nesting stage or chick age as covariates with weather. When successes overlapped at least one failure at the same nesting stage (n=15), helpers were present at 11 nests (73%) and the other four were at prime nesting sites (Church n=2, Main St. n=2).

Nest building often started the day the birds arrived in St. Adolphe (Table 1) but was delayed in cold weather. In 2021, Chimney Swifts arrived by 14 May, but no nest building was detected until 27 May (five monitoring days 15-27 May). Although the average daytime air temperature for 15-31 May inclusive was 15.4° C, the maximum hourly daytime air temperatures fell on 20 May to 10.2° C, rose briefly on 24 May to 27.5° C, then fell again to <15° C until midday on 28 May. In the first few hours of daylight on 27 May temperatures were below freezing.

TABLE 2. Phenology (dates) of nesting stages of Chimney Swifts at St. Adolphe, MB, in 2007-2013 and 2014-2022. Median dates were calculated using data for birds which nested by 6 June and for which the sampling interval was <5 d. Paired data are a subset for which dates were available for both stages. Paired data are considered a better estimator of duration than is a comparison of medians.

NESTING STAGE	2007-2013	2014-2022	COMMENTS
Arrival	18 May *(n=14)*	21 May *(n=15)*	
Nest building	20 May *(n=12)*	31 May *(n=27)*	2022 nesting delayed by weather. Excluding 2022, $\bar{X}$=24 May *(n=22)*
Arrival to nest building ($\bar{X}$, d) (paired data)	1.9 *(n=9)*	0.0 *(n=14)*	Church was late nesting in 2008. Excluding 2008: $\bar{X}$=0.9 *(n=8)*
Incubation	25 June *(n=17)*	19 June *(n=20)*	
Hatch	9 July *(n=15)*	5 July *(n=31)*	
Incubation to hatching ($\bar{X}$, d) (paired data)	16.6 *(n=11)*	17.0, *(n=20)*	
Non-brooded	15 July *(n=12)*	10 July *(n=23)*	
Hatching to non-brooded ($\bar{X}$, d) (paired data)	6.2 *(n=10)*	5.7 *(n=23)*	Lengthy period (11 d) of feeding brooded young at the Church 2013 affected the mean. Excluding these: $\bar{X}$=5.7 *(n=9)*
Fledge	3 August *(n=10)*	1 August *(n=16)*	
Non-brooded to fledging ($\bar{X}$, d) (paired data)	20.6 *(n=9)*	22.2 *(n=14)*	
Depart successes	20 August *(n=7)*	14 August *(n=8)*	
Fledging to departure ($\bar{X}$, d) (paired data)	17.7 *(n=7)*	11.9 *(n=8)*	
Depart failures	7 August *(n=5)*	2 August *(n=5)*	

Low temperatures were also associated with reduced feeding rates. On 20 July 2020, the average daytime temperature was 20.2° C, but it had been <18.5° C between 21:00 h the night before and 09:00 h on the 20th with an overnight low of 10.4° C. At 10:55-12:10 h, non-brooded young at SE Club Amical were being fed at a rate of one visit per hour compared to an expected rate of four per hour.

High temperatures alone, or in conjunction with high winds, reduced incubation exchange and feeding rates. Incubating adults at both NE and SE Club Amical sites were exchanging once per 90 min (expected 1/h) when a heat advisory was in effect on 3 July 2020. Average air temperature from 11:00-20:00 h was 31.0° C and winds were light (wind speed average 7.5 kph, gusts average 14.7 kph). A heat and wind warning for 7 July 2018 was reflected in an average air temperature of 30.4° C, average windspeed of 31.8 kph and average gusts of 48.5 kph from 13:00-19:00 h. Feeding rates at both the Church and Main St. were reduced: Church 1/h; Main St. 2 exits, no exchange in 60 min; the expected rate for non-brooded young is 3-4/h.

There were few observations made in heavy rain. May 2022 was the rainiest May for which we have data and may have been related to an apparent lag of up to 26 days between the first sighting of a Chimney Swift in St. Adolphe on 12 May and nest building 4-6 June. Between 13 and 31 May, 123 mm of rain fell (12-year average 60.0 mm) but it was also cold (average air temperature 12.1° C).

Chimney Swift behaviour in the presence of wildfire smoke was variable. We distinguished between upper-air smoke (when there was no Air Quality Health Index advisory but when we could estimate the percent of the sky that was smoke), and low-level smoke (when an advisory was issued because humans would be in the smoke). With upper-air smoke covering 50% of the sky on 24 July 2010, (~20° C at 10:25 h; no precipitation; moderate wind), the non-brooded feeding rate at Brodeur Bros. was 3/h, slightly less than the expected rate of 4/h. Feeding conditions may have been good as evidenced by observations of many low feeding Chimney Swifts, Purple Martins (*Progne subis*) and Barn Swallows (*Hirundo rustica*). Similar behaviour was recorded with 100% smoke cover on 4 July 2015 (~28° C at 14:40 h; no precipitation; strong breeze); the brooded Church juveniles were fed at the expected rate of 2/h and both Chimney Swifts and Purple Martins fed near the ground. In low-level smoke on 6-7 July 2019, in association with air quality advisories, we recorded reduced feeding rates of non-brooded young at both Club Amical sites: 6 July - NE Club Amical 2/h, SE Club Amical 1/h; 7 July - NE Club Amical 1/h, SE Club Amical 2/h (expected 4/h). When

extremely low and dense wildfire smoke triggered air quality advisories on 16-17 August 2018 no aerial insectivores, indeed very few birds at all, were seen flying locally.

Discussion

Analysis

Methods of monitoring and assessing nesting phenology remained constant through the years with one refinement in 2019.[7,8] We attempted to improve the ability to detect incubation by using any one of three criteria: the amount of time spent at the nest site, turn-around times between partners and partner exchange rates.[8,9] There was no difference in the duration of incubation between periods and we underestimated the expected minimum duration of incubation (18 d) by 2 d.[8,22,23] We cannot determine if this difference reflects a shorter incubation period in Manitoba or an inability to precisely detect the start of incubation. Notwithstanding this imprecision, our criteria remain useful for establishing that incubation is in progress. Intensive monitoring is necessary to establish when hatching and the transition to feeding non-brooded juveniles occur; estimated fledging dates can then be calculated.

We limited our weather analysis to daytime hours when Chimney Swifts would be expected to be feeding. Longer term, or even daily, averages of weather variables were not informative. They included hours when the birds were in the chimney and protected from low temperatures, high winds, and all but the heaviest of rains, which can wet the inside walls of chimneys.[30] Even daytime averages can mask episodic events such as sudden downpours, which when averaged over 24 hours may not appear extreme. Most of the daytime hourly temperatures below 18.5° C in our study occurred in the first few hours after sunrise when the adults and young should have been ending their ~9-hour overnight fast. Chimney Swifts feed intensively in the early daylight hours and Tree Swallows are thought to be impacted by reduced prey availability as soon as abundance starts to drop.[16,17] We consider hourly data to be most applicable to assessing impacts.

In the absence of Manitoba data, we relied on information from other areas to establish temperature thresholds that

TABLE 3. Chimney Swift nesting outcomes at five St. Adolphe chimneys, 2014-2022. Helper attendance was confirmed (H) or likely (H?). Estimated fledging success is based on observations of birds entering and exiting the chimney (SE, NE Club Amical and Church) and physical evidence in cleanout traps (Brodeur Bros. and Main St.).

YEAR	SITE	BREEDING ATTEMPT	SUCCESSFUL	FLEDGE DATE	ESTIMATED. NO. FLEDGLINGS				
					VISUAL	PHYSICAL EVIDENCE			BEST EST.
						Clutch size	No. hatch	No. fledge	
2014	SE Club Amical	yes	no						
	NE Club Amical	yes	yes	11 August	2				2
	Brodeur Bros.	yes	yes (H)	30 July	1	4	4	1	1
	Church	yes	no						
	Main St.	yes	no		0	6	6	0	
	Summary	5	2						3
2015	SE Club Amical	no							
	NE Club Amical	yes	no						
	Brodeur Bros.	yes	no (H)		0	5	1	0	
	Church	yes	yes	1 August	5				5
	Main St.	yes	no		0	6	6	0	
	Summary	4	1						5
2016	SE Club Amical	yes	no (H)						
	NE Club Amical	yes	no						
	Brodeur Bros.	yes	no		0	5	4	0	
	Church	yes	yes (H?)	30 July	6				6
	Main St.	yes	yes (H?)	12 August	2	2	2	2	2
	Summary	5	2						8
2017	SE Club Amical	yes	no						
	NE Club Amical	yes	yes (H)	1 August	1				1
	Brodeur Bros.	no							
	Church	yes	yes	31 July	2				2
	Main St.	yes	yes	2 August	2	3	3	3	3
	Summary	4	3						6
2018	SE Club Amical	yes	yes (H)	24 July	2				2
	NE Club Amical	yes	no						
	Brodeur Bros.	yes	no		0	3	3	0	
	Church	yes	no						
	Main St.	yes	yes	28 July	2	8	7	2	2
	Summary	5	2						4
2019	SE Club Amical	yes	yes (H)	25 July	2				2
	NE Club Amical	yes	no						
	Brodeur Bros.	yes	no		0	4	4	0	
	Church	yes	no						
	Main St.	yes	yes (H)	5-7 August	2-3	4	4	4	4
	Summary	5	2						6
2020	SE Club Amical	yes	no						
	NE Club Amical	yes	no (H)						
	Brodeur Bros.	yes	no		0	7	7	0	
	Church	yes	yes	2-3 August	2				2
	Main St.	yes	no (H?)		0	5	5	0	
	Summary	5	1						2
2021	SE Club Amical	yes	no						
	NE Club Amical	yes	no						
	Brodeur Bros.	yes	no		0	8	6	0	
	Church	yes	yes (H)	31 July	2				2
	Main St.	yes	yes (H?)	3 August	1	5	5	5	5
	Summary	5	2						7
2022	SE Club Amical	yes	yes (H)	13 August	2-3				3
	NE Club Amical	yes	yes	29 July	2				2
	Brodeur Bros.	yes	no			5	5	0	
	Church	yes	yes (H?)	11 August	5				5
	Main St.	yes	yes	13 August	1-2	3	3	3	3
	Summary	5	4						13
	2014-2022	43	19 successful, 24 failed 10 attempts with confirmed helper: 7 successful; 3 failed 5 attempts with likely helper: 4 successful; 1 failed						54

TABLE 4. Relative performance of five Chimney Swift nest sites in St. Adolphe, MB, 2007-2013 and 2014-2022. All sites were available for use each year. Each parameter (order of first occupancy; number of breeding attempts; number (%) of successful breeding attempts; number of fledglings produced based on visual (V) or physical (P) evidence; and number of consecutive years with successful breeding attempts) was assigned a rank (1-5, best to worst) which were summed to provide an overall rank for each site in each period. Chimney above-ground heights: SE Club Amical 9.6 m; NE Club Amical 10.9 m; Brodeur Bros. 7.0 m; Church 14.2 m; Main St. 9.1 m.

YEARS	SITE	ORDER OF OCCUPANCY RANK†	BREEDING ATTEMPTS (RANK)	NO. (%) SUCCESSFUL BREEDING ATTEMPTS (RANK)	ESTIMATED NO. OF FLEDGLINGS (V OR P) BY YEAR (RANK)	CONSECUTIVE SUCCESSES (RANK)	SITE RANK
2007-2013 (7 years)	SE Club Amical	5	3* (4)	0 (0%) (4)	0 (V) (5)	0 (4)	5 (Σ=22)
	NE Club Amical	2	7 (1)	4 (58%) (1)	8 (V; 3, 2, 1, 2) (2)	1 (3)	2 (Σ=9)
	Brodeur Bros.	4	5 (3)	1 (20%) (3)	2 (P; 2) (4)	1 (3)	4 (Σ=17)
	Church	1	7 (1)	4 (57%) (1)	6 (V; 2, 1, 1, 2) (3)	3 (1)	1 (Σ=7)
	Main St.	3	6† (2)	2† (33%) (2)	9† (P; 4, 5) (1)	2 (2)	3 (Σ=10)
All Sites			**28***	**11 (39%);**	**25****		
2014-2022 (9 years)	SE Club Amical	4	8 (2)	3 (38%) (2)	7 (V; 2, 2, 3) (3)	2 (3)	4 (Σ=14)
	NE Club Amical	2	9 (1)	3 (33%) (2)	5 (V; 2, 1, 2) (4)	1 (4)	3 (Σ=13)
	Brodeur Bros.	5	8 (2)	1 (13%) (3)	1 (P; 1) (5)	1 (4)	5 (Σ=19)
	Church	1	9 (1)	6 (67%) (1)	22 (V; 5, 6, 2, 2, 2, 5) (1)	3 (2)	1 (Σ=6)
	Main St.	3	9 (1)	6 (67%) (1)	19 (P; 2, 3, 4, 5, 2, 3) (2)	4 (1)	2 (Σ=8)
All Sites			**43**	**19 (44%)**	**54**		
OVERALL 2007-2022	SE Club Amical	4	11 (4)	3 (27%) (4)	7 (V) (3)	2 (3)	4 (Σ=18)
	NE Club Amical	2	16 (1)	7 (44%) (3)	13 (V) (2)	1 (4)	3 (Σ=12)
	Brodeur Bros.	5	13 (3)	2 (15%) (5)	3 (P) (4)	1 (4)	5 (Σ=21)
	Church	1	16 (1)	10 (63%) (1)	28 (V) (1)	3 (2)	1 (Σ=6)
	Main St.	3	15† (2)	8† (53%) (2)	28 (P) (1)	4 (1)	2 (Σ=9)
All Sites			**71**	**30 (42%)**	**79**		

* Modified from Stewart and Stewart 2013 – for this current analysis, we consider only primary breeding attempt by pairs of Chimney Swifts nest building by 6 June
** n=25 best estimate of no. fledglings in Stewart and Stewart, 2013, Table 2
† No data in 2007.

TABLE 5. Chimney Swift reproductive rates at Brodeur Bros. and Main St. nest sites in St. Adolphe, MB, in 2007-2013 and 2014-2022, based on observations of physical evidence in chimney cleanout traps. Sample sizes (n) are listed for clutch size, total number of eggs hatched/total number of eggs laid, and total number of fledglings for each consecutive year in each reporting period; N/A (not applicable) indicates that no nesting attempt was made.

	BRODEUR BROS.		MAIN ST	
	2007-2013 (7 YEARS)	2014-2022 (9 YEARS)	2007-2013 (7 YEARS)	2014-2022 (9 YEARS)
Breeding Attempts (n)	5	8	7	9
Successful Breeding Attempts (n)	1	1	2	6
Successful Breeding Attempts (%)	20	12.5	33.3 (2/6)	66.7
Clutch Size Range (n)	3-7	3-8	5-6	2-8
Median Clutch Size (n)	4	5	5	5
Total No. Eggs Laid (n)	18	41	21	42
Total No. Hatched Eggs (n)	6	34	18*	41
Eggs Hatched/Eggs Laid (%)	33.3	82.9	85.7*	97.6
Total Fledglings (n)	2	1	9	19
Fledged/Eggs Laid (%)	11.1	2.4	42.8	45.2
Fledged/Eggs Hatched (%)	33.3	2.9	50.0*	46.3

*Corrects Stewart & Stewart 2013 values of n=16; 76%

would reflect prey availability. The lower thresholds of about 15.5° C and 18.5° C appear to apply to various more northern areas (New York, Illinois, Quebec).[13,15-17,19] The selection of the upper thresholds, however, was established from one study in Louisiana where insect abundance was similar at upper and lower thresholds.[25] Data for Chimney Swifts in Illinois used upper temperature brackets of 30.1-33.0° C and 33.1-36.0° C that were too broad to generate a threshold value.[17] At St. Adolphe, nest failures that were correlated with heat (32° C and 34° C) were also associated with several hours over 30° C. Local research would be required to determine if this is a more appropriate threshold than was used.

High and low temperatures, extreme rain events, high winds and smoke can all negatively affect the availability of aerial insects and are expected to become more frequent based on climate change models.[31] A comprehensive and overall assessment on different scales is necessary to understand the complexities of how weather affects Chimney Swift reproduction. For example, May 2022 was the wettest and windiest May in 11 years of weather data but, despite a delay in the start of nest building, a record number of successful breeding attempts took place that year.

Phenology

All nest sites in St. Adolphe remained accessible throughout the two study periods, so fluctuations in site occupancy reflected preferences of breeding pairs in choosing nest sites. Not all nest sites were occupied each year between 2014-2022, but there was a higher overall occupancy rate compared to 2007-2013. SE Club Amical and Brodeur Bros. were first seen to house Chimney Swifts in 2009.[8] They

were also the only two sites to remain unoccupied between 2014 and 2022. It is not known if their lack of use in 2007-2008 reflects a pattern of use/disuse or if they were newly occupied in 2009. It is not known what an unoccupied nest site means in relation to the Chimney Swift population at large. At least sometimes in St. Adolphe, when a site was unoccupied, there was a helper at another site.

The median nest building date was later in 2014-2022 than 2007-2013, largely attributable to a late start in 2022 when all pairs began nesting on 4-6 June. The regression of nest building date as a function of year showed a significant increase (later nest building) from 2007 to 2022 ($P=0.02$, $R^2=0.37$, $n=39$), driven completely by the 2022 data. Without the 2022 data, the regression was not significant ($P=0.32$, $R^2=0.03$, $n=33$). In 2022, the average temperature in May after the birds arrived (12 May) was 12.2° C with 130.3 mm of rain. Comparable temperatures were recorded in 2019 (average temperature 12.6° C) but in other years ranged from 13.9-19.0° C and only 13.8 mm of rain fell after the birds arrived in 2019. Additionally, Red River flood waters peaked at St. Adolphe on 13 May 2022, approximately 3.2 m above normal river levels and were still about 1.9 m above normal on 4 June.[32,33] We consider insufficient prey due to the cold wet weather and submerged insect-producing land the most likely cause of delayed nest building in 2022.

In general, after nest building, nesting stages progressed a few days earlier in recent years compared to 2007-2013. Both successful and unsuccessful birds left St. Adolphe earlier (5-6 d) in 2014-2022. The regression of departure date by year for successful birds was significant ($P=0.009$, $R^2=0.42$, $n=15$). The regression for failed nesters was not significant ($P=0.18$, $R^2=0.21$, $n=10$) although they too left about 5 d earlier (Table 2). The pre-migratory assemblages (<19 birds) at the Church between 2007-2013 were local family groups (adults and fledglings) plus a few migrants.[7,8] No pre-migratory groupings of Chimney Swifts formed in St. Adolphe between 2014-2022. We suggest that the earlier departure and lack of pre-migratory groups indicate prey availability levels were too low to support the birds staying.

Overall breeding success at St. Adolphe nest sites was similar between 2007-2013 and 2014-2022. Generally, only one or two nests produced fledglings each year, although reproductive success was higher in 2017 (three of four attempts) and 2022 (four of five attempts). In 2022, departure dates were also later than any others in the 2014-2022 period and personal observations indicated mosquitoes remained abundant in bothersome numbers well into August.

There was an apparent difference in the timing of nest failures, but sample sizes were small. In 2007-2013, some nests failed at the incubation stage but later all failures were when young were being fed. Survival of eggs may depend more on the condition of the parents when they arrive at the breeding area than on local resources. Some failures were associated with high temperatures (Table 6) which may be more stressful for incubating parents than for feeding parents.

Reproductive rates are based on the number of eggs laid, number of eggs hatched, and number of surviving offspring which fledge. That information can only be derived from observing cleanout trap material. Reproductive rates at Brodeur Bros. fell while at Main St. they increased between 2007-2013 and 2014-2022. A higher proportion of eggs hatched at both sites, but the number of hatchlings which survived to fledge declined significantly at Brodeur Bros. while the rate declined marginally at Main St. There was no increase in nest slippage events at Brodeur Bros., so the lack of food appears to be a primary issue. Of the two sites, the Main St. chimney is preferred by the Chimney Swifts. We interpret reproductive rate changes as evidence of lower prey availability late in the breeding season having a disproportionate effect on pairs which occupy less than optimal nest sites.

Factors associated with nesting outcomes

Reproductive success depends on the interaction of parental abilities to meet basic requirements (nest construction and feeding) and to compete when the necessities such as nesting structures (chimneys) are limited. While suitable chimneys may not be limiting at a broad scale they can be scarce locally.[34] We consider the six nest sites a limiting resource in St. Adolphe. However, prey abundance is also considered a limiting resource for songbirds during the nesting season and weather affects prey abundance, thence aerial insectivore reproductive success.[10-17,35,36] Human altered landscapes and agricultural practices also affect prey abundance and bird survival.[13,37] The ability of Chimney Swifts to locate adequate food and compete successfully for suitable nest sites are key parental assets.

Breeding Chimney Swifts in St. Adolphe demonstrated site preferences by routinely occupying some sites ahead of others during spring arrival. Chimney Swifts live about four years and marked-recaptured breeding birds are known to return to the same nest site over several years.[22,23] Therefore it is likely that some individuals returned in consecutive years over shorter periods. Our study documented that some nest chimneys were preferred over others, likely due to one or more physical attributes.[30]

While our method for measuring chimney height accurately estimated a Chimney Swift tower known to be 3.8 m tall, it lacks the precision to distinguish between chimneys of similar height. This is largely due to the recording of angles to the nearest degree. For example, if upper angles recorded for the chimney at Main St. were 14.4° instead of the reported 14°, and that at SE Club Amical were 15.5° instead of 16°, the measured chimney heights would be identical. Nonetheless, instrument error cannot account for the difference between the Church (14.4 m) and Brodeur Bros (7.0 m) which were the first and last ranked chimneys respectively or between Brodeur Bros and the next shortest chimney, Main St.

We found a chimney height threshold of about 9 m (~30'; Main St) above ground was associated with repeated successful breeding. Chimney height (above ground or above the roofline) has been identified as an important factor for nest and roost site selection in some but not all studies.[30,34,38] Total chimney depth, which also includes below ground portions, should be considered in evaluating height influences on nesting outcomes. All sites except Brodeur Bros. include chimney space below ground, so the difference in usable vertical space (depth) is greater than the reported above ground height. In Manitoba, purpose-built Chimney Swift towers >10.4 m were successful in attracting Chimney Swifts but 3.8 m towers were not.[39]

Short chimneys may render nests prone to slipping if heavy rains wet the inside walls.[40] Nest slippage may be implicated in the 2021 failure at Brodeur Bros. (Line 21 in Table 6) and nests were detected in autumn cleanout inspections at Main St. (2012) and Brodeur Bros. (2013). However, it is not known when in the season the nests fell. Chimney Swifts may nest in the part of the chimney below ground (BES, unpubl. data), so below ground chimney depth may be important for nest attachment. Tall chimneys may confer some yet to be determined beneficial attribute e.g., air flow dynamics. It remains that less successful sites still serve as sources of possible helpers and as a safe resting spot for fledglings as they develop flight proficiency.

Pre-migratory roosts at the Church chimney were consistent with early forming assemblages of Chimney Swifts where family groups join local and other migrants at larger roosts which had been used season-long or only later in migration.[7,38] Tall chimneys which are clear of adjacent foliage are used by large groups of roosting Chimney Swifts.[38] The Church was the tallest chimney but the canopy of a large adjacent tree prevented swirling pre-roost flight behaviour typical of large numbers of Chimney Swifts.

Not all failures were associated with weather events. Aggressive chasing flights near or in chimneys were observed between breeding and other non-helper adults. These were not seen with the arrival of a helper.[24] Such hostile visits often end with the visitor destroying eggs or killing young (M. Postolan, *in litt.*). At least two observed nest failures were associated with hostile incursions at Brodeur Bros.; the inability to repulse intruders may be linked to the parents' inability to secure a better nest site.

Three failures were associated with roof repairs at two sites (Club Amical in 2016 and Brodeur Bros. in 2019).[9] There were concurrent weather-related stressors (Lines 10, 11 and 16 in Table 6). In 2016, it was cool and rainy before rooftop activity

TABLE 6. Environmental events in days preceding observed Chimney Swift nest failures (n=24) in St. Adolphe, MB, 2011-2022. The precision of failure dates depended on the monitoring interval and only failures known within 72 h of the last monitoring session are shown. Weather days are the number of days for which weather was examined (see text). Nesting stages: incubation (I), feeding brooded young (B), and feeding non-brooded young (N-B). Results are presented as the proportion (%) of daylight hours in which hourly averages met the criteria of temperature and wind speed. Daytime rain is reported as total and maximum 1-hour rainfall, and the number of hours over which that rain fell. Proximal putative causes of nest failure are in **bold** denoting the event with the largest duration.

LINE	SITE (NAMES TRUNCATED TO SAVE SPACE)	DATE	WEATHER DAYS	NESTING STAGE	AGE OF CHICKS (D)	HOURS <15.5° C	HOURS <18.5° C	HOURS >32° C	HOURS >34° C	RAIN TOTAL (MM)	RAIN HOURLY MAX	HOURS WITH RAIN	COMMENTS
1	Brodeur 2011	16 July	3	I	Day 22 I	2.1%	10.4%	0.0%	0.0%	0.4	0.2	4.2%	12 July: **non-parent adult**
2	Church 2011	2 August	3	N-B	25	4.2%	**6.3%**	0.0%	0.0%	1.2	1.2	2.1%	
3	Main 2011	19 July	3	I/B	Day 19 I; 0-1	2.1%	4.2%	**22.9%**	0.0%	0.0	0.0	0.0%	25h >30°C over 3 d
4	SE Club 2012	12-13 July	4	I	Day 16-19 I	1.6%	4.7%	**9.4%**	1.6%	0.2	0.2	1.6%	20 h >30°C over 4 d
5	NE Club 2012	31 July	3	N-B	17	0.0%	8.3%	**12.5%**	6.3%	8.4	8.4	2.1%	13 h >30°C over 2 d
6	Church 2012	9-10 July	4	B	3-7	6.3%	**9.4%**	0.0%	0.0%	6.4	6.2	3.1%	9 h >30°C over 2 d
7	SE Club 2014	11-12 July	4	B	3-9	7.8%	**20.3%**	0.0%	0.0%	1.0	1.0	1.6%	
8	Brodeur 2015	16 July	3	B	2	0.0%	4.2%	0.0%	0.0%	1.9	0.9	8.3%	16 July: **non-parent adult**
9	Brodeur 2016	15 July	3	B	6	10.4%	**43.8%**	0.0%	0.0%	3.4	1.3	18.8%	15 July: smoke
10	NE Club 2016	16 July	3	N-B	13	14.6%	**25.0%**	0.0%	0.0%	1.8	1.1	6.3%	11-12, 14 July: rooftop activity
11	SE Club 2016	18-19 July	4	N-B	9-10	10.9%	**20.3%**	0.0%	0.0%	5.3	3.2	7.8%	11-12, 14 July: rooftop activity
12	SE Club 2017	10 July	3	N-B	6-8	8.3%	**18.8%**	0.0%	0.0%	0.0	0.0	0.0%	all but 1 morning of chicks' life <18.5°C from 06:00 to 08:00 h
13	NE Club 2018	29 June -1 July	5	B	2-4	5.0%	**18.8%**	0.0%	0.0%	**22.4**	**16.3**	5.0%	
14	Church 2018	16-18 July	5	N-B	16-18	11.3%	**26.3%**	0.0%	0.0%	0.0	0.0	0.0%	16-17 July: overnight low 7.0°C
15	NE Club 2019	11-12 July	4	N-B	12-14	1.6%	**17.2%**	0.0%	0.0%	**41.7**	**18.6**	**15.6%**	9-10 July: rain every hour from 16:00 to 08:00 h
16	Brodeur 2019	16 July	3	B	6-7	1.6%	4.7%	0.0%	0.0%	**32.0**	**14.9**	**10.9%**	14 July: rained all day, 15 July: rooftop activity
17	Church 2019	17-18 July	4	N-B	20-22	3.1%	**12.5%**	0.0%	0.0%	**20.5**	**12.1**	**6.3%**	9-17 July (inclusive): 103.3 mm rain
18	Brodeur 2020	13-14 July	4	N-B	11-12	4.7%	**15.6%**	0.0%	0.0%	**12.1**	**2.2**	**12.5%**	13 July: rain all day; 14 July rain after sunset
19	SE Club 2020	July 20-21	4	N-B	12-13	12.5%	**26.6%**	0.0%	0.0%	1.6	0.9	7.8%	19-20 July: overnight low 10.4°C
20	NE Club 2020	27 July	3	N-B	19	8.3%	**14.6%**	4.2%	0.0%	0.0	0.0	0.0%	
21	Brodeur 2021	7 July	3	B	5	37.5%	**50.0%**	0.0%	0.0%	0	0	0.0%	5-7 July: 37.5% of hours <15.5°C; <18.5°C for 37 h (22:00 h on 5 July to 10:00 h on 7 July); 5-6 July: smoke
22	SE Club 2021	14 July	3	N-B	8	8.3%	**14.6%**	0%	0%	1.2	0.5	4.2%	11 July: >32°C for 6 h, 1 h >34°C; 12-13 July: smoke
23	NE Club 2021	17 July	3	N-B	12	0.0%	**12.5%**	0.0%	0.0%	0.0	0.0	0.0%	16 July: smoke
24	Brodeur 2022	13-14 July	4	B	4	3.1%	**17.2%**	0.0%	0.0%	20.3	11.6	12.5%	11 July: (hatching day) temperature 06:00-10:00 h <18.5°C; 19.6 mm rain

and in 2019 it rained for two of three days preceding rooftop work. Parents may be able to compensate for disrupted feeding by more intensive foraging when the weather improves.[10] Compensatory feeding may not be possible, however, if new or additional factors interfere with feeding. Best practices would be to allow the birds a refractory period after inclement weather before conducting essential rooftop work; non-essential repairs should be deferred.[9]

Most nest failures were associated with weather events known to reduce prey availability. Almost 130 years ago it was noted that low temperatures reduced food availability.[40] The driving weather factors, however, vary with location and species. Insufficient food could lead to chick starvation rather than hypothermia since occupied chimneys have relatively stable internal temperatures compared to ambient temperatures.[30] During the nesting season, non-breeding adults and immature birds at roost sites may delay morning exit or return during the daytime to seek refuge during inclement weather but this energy saving tactic may lower nesting success for Chimney Swifts feeding young.[17]

After site selection, the most common factor associated with breeding success in St. Adolphe was the presence of a helper. In terms of feeding young when food is less available, the importance of helpers is hard to overstate. Indeed, the only two successes at Brodeur Bros., the lowest ranked chimney, were when a helper was present (Table 3).[8] Relatively higher feeding rates were often observed when a helper was present. For example, consecutive monitoring sessions were held at two sites where non-brooded juveniles were being fed on 17 July 2021. The feeding rate at the Church was 8/h with a helper present and the feeding rate at Main St. was 4/h where no helper was present. Similarly, on 29 July 2021 the feeding rate at the Church was 6/h with a helper present and the feeding rate at Main St. was 3/h with no helper present.

Helpers may contribute to higher energetic input directly to juveniles and they may prevent energy depletion in foraging parental birds. A higher proportion of helpers and higher success rates of breeding attempts associated with helpers was seen in 2014-2022 compared to 2007-2013. Helpers attended each nest site at least once during 2014-2022 (Table 3).

Helpers may move among sites. Several pairs of observations made on consecutive days recorded three adults at site A and two at site B, then the reverse pattern. We have also observed the arrival of a helper at a site 1-2 d after another site in town failed. Helpers also appear in the third week of June as new birds, late migrants, or redispersing birds arrive in St. Adolphe.[8] Helpers in St. Adolphe may therefore be adults which were recently unsuccessful breeders, non-breeding adults or juveniles. Gender of helpers we observed could not be determined but males can outnumber females.[24]

Warmer springs associated with climate change have been linked to earlier arrival of some migrants and have been identified as a hazard due to more variable spring weather.[10] The median first arrival of Chimney Swifts remained 13 May with a greater range of dates in 2014-2022. Nonetheless, breeding began slightly earlier and carried through to fledging which was in early August in both periods. Diminished food availability may have caused swifts to leave St. Adolphe earlier in recent years and precluded the formation of pre-migratory flocks.

Mosquito abatement programs, increased insecticide use, and changes in insect habitat availability may be implicated in these shifts. Using Google Earth, we calculated that urban expansion and construction of a flood-protection dike in south St. Adolphe peaked in 2016. That year 90 ha of agricultural land was bulldozed, leaving a net loss of about 29 ha by 2022. On the north side of St. Adolphe, a residential area built between 2010 and 2017 removed about 25 ha of agricultural land and woodlots. Both areas were <1 km from the farthest nest site.

Future Research

Our study provided a long-term perspective of the effect of weather on breeding activities and reproductive success. It is unknown if our results can be extrapolated to other areas of Manitoba and North America. The cluster of recent purpose-built towers and existing chimneys on buildings at the Selkirk Mental Health Centre (SMHC), Selkirk, MB, represents an opportunity for comparative studies with St. Adolphe nest sites.[41] The latest known fledging date in Manitoba is 6-8 September 2022 at SMHC tower T4.[41] The latest date of successful fledging in St. Adolphe is 16 August 2010 at Brodeur Bros.[8] The last observed Chimney Swifts in Manitoba have been recorded regularly in Selkirk (11 September 2020; 12 September 2021) compared to 2 September 2008 in St. Adolphe.[8,42,43]

Future research on the influences of local weather and climate change, insect population dynamics and agricultural practices on breeding Chimney Swifts is needed. A full assessment of the physical attributes of the St. Adolphe nest sites including chimney depth and air flow would inform management decisions to improve breeding outcomes. The development of engaging citizen science projects and obtaining meaningful support to implement the Chimney Swift recovery strategy and management plan are important next steps.[44,45]

Some nest failures were associated with multiple environmental events occurring sequentially or concurrently. Anthropogenic disturbances can cumulatively exacerbate weather stressors but can be managed in the future. Our study supports regulators who are developing a recovery strategy that identifies disturbances and formulates best practices for limiting the impacts of those disturbances in Chimney Swift habitat and at nest sites.[45]

Conclusions

We detected minor shifts in nesting phenology up to and including fledging. We attribute earlier departures from St. Adolphe in 2014-2022 to a shift in the seasonal reduction of prey availability. Cold, wet weather coincided with most nest failures although hostile intruding Chimney Swifts and human disturbance were also implicated in nest failures. Successful nesting attempts were associated with nest site quality and the presence of helpers.

All nest sites, including those with relatively poor ranks, are important to the resident flock and merit continued protection. Nest sites with poor breeding success are nonetheless valuable sources of potential breeders and helpers and provide refuge for fledglings as they develop flight competency.

The creation of new habitat, through erecting purpose-built structures and refurbishing/reopening other candidate chimneys, needs evaluation. Part of that

process should include an assessment of local habitat management to ensure a secure food supply is available.[46]

Acknowledgements

We appreciate the continued support of St. Adolphe nest site landlords, tenants, and homeowners: RM of Ritchot, Paroisse St. Adolphe; St. Adolphe Childcare Centre; and S. and A. Leclerc. Weather data were provided by the Manitoba Agriculture Weather Program as part of Manitoba Agriculture with welcome assistance in interpretation from A. Sass, Agricultural Meteorology Specialist, and T. Ojo, Agricultural Modeller Specialist. We thank the Manitoba Chimney Swift Initiative Steering Committee and those who helped improve the manuscript: C. Artuso; R. Bazin; T. Poole; J. Tuckwell; and W. Wake. Thank you also to the dedicated observers who assisted in monitoring: L. Cocks; R. Cocks; F. Machovec; J. Machovec; L. Parker; A. Shave; and T. Poole. We appreciate the thoughtful review provided by Jim Duncan, the editorial support of Annie McLeod and the assistance of the *Blue Jay* publication staff.

1. COSEWIC (2018) *COSEWIC Assessment and Status Report on the Chimney Swift* (Chaetura pelagica) *in Canada 2018*. Ottawa: Committee on the Status of Endangered Wildlife in Canada, vii +49 pp. Accessed 28 February 2023. https://www.canada.ca/en/environment-climae-change/services/species-risk-public-registry.html

2. Stewart REA, Poole TF, Artuso C, Stewart BE (2017) Loss and preservation of Chimney Swift habitat in Manitoba, 2007-2016. *Blue Jay* 75(2):11-15. https://www.mbchimneyswift.com/Documents/lossandpreservation.pdf

3. *Species at Risk Act*. 2002. S.C. 2002, c. 29. *Species at Risk Act*. Government of Canada, Ottawa, Ontario, Canada. Accessed 11 November 2022. https://laws.justice.gc.ca/PDF/S-15.3.pdf

4. SARA (*Species at Risk Act*) Registry (2021) Species summary: Chimney Swift (Chaetura pelagica). Government of Canada, Ottawa, Ontario, Canada. Accessed 23 December 2022. https://species-registry.canada.ca/index-en.html#/species/951-650

5. Government of Manitoba (2016) Species and Ecosystem at Risk. Government of Manitoba, Winnipeg, Manitoba. Accessed 8 February 2023. https://www.gov.mb.ca/nrnd/fish-wildlife/wildlife/ecosystems/index.html

6. Government of Manitoba *The Endangered Species and Ecosystems Act*. 10 (1). *The Endangered Species and Ecosystems Act*., Winnipeg, Manitoba, Canada. Accessed 2 November 2022. https://web2.gov.mb.ca/laws/statutes/ccsm/_pdf.php?cap=e111

7. Stewart BE, Stewart REA (2010) Nest site use and breeding success of Chimney Swifts in St. Adolphe, MB, 2007-2009. *Blue Jay* 68(3):124-132. https://www.mbchimneyswift.com/Documents/bluejay2013.pdf

8. Stewart BE, Stewart REA (2013) Nest site use, breeding success, and reproductive rates of Chimney Swifts in St. Adolphe, MB, 2010-2013. *Blue Jay* 71(4):166-182. https://www.mbchimneyswift.com/Documents/bluejay2010.pdf

9. Poole TF, Stewart BE, Stewart REA (2022) Impact of anthropogenic disturbance on nesting Chimney Swift (*Chaetura pelagica*) including best practices for conservation. *Canadian Field- Naturalist* 136(4):364-373. https://doi.org/10.22621/cfn.v136i4.2963

10. Cox AR, Robertson RJ, Lendvai AZ, Everitt K, Bonier F (2019) Rainy springs linked to poor nestling growth in a declining avian aerial insectivore (*Tachycineta bicolor*). Proc. R. Soc. B 286 20190018. Accessed 28 February 2023. http://dx.doi.org/10.1098/rspb.2019.0018

11. Cucco M, Malacarne G (1996) Reproduction of the pallid swift (*Apus pallidus*) in relation to weather and aerial insect abundance. *Italian Journal of Zoology* 63(3):247-253. https://www.tandfonline.com/doi/pdf/10.1080/11250009609356141

12. Facey RJ, Vafidis JO, Smith JA, Vaughan IP, Thomas RJ (2020) Contrasting sensitivity of nestling and fledgling Barn Swallow *Hirundo rustica* body mass to local weather conditions. *Ibis* 162(4):1163-1174. https://orca.cardiff.ac.uk/id/eprint/131001/1/IBIS-2019-OP-092-DEC-EIC.pdf

13. Garrett DR, Pelletier F, Garant D, Bélisle M (2022) Interacting effects of cold snaps, rain, and agriculture on the fledging success of a declining aerial insectivore. *Ecological Applications* 32(7):1-16. https://doi.org/10.1002/eap.2645

14. Møller, AP (2013) Long-term trends in wind speed, insect abundance and ecology of an insectivorous bird. *Ecosphere* 4(1):1-11. http://dx.doi.org/10.1890/ES12-00310.1

15. Shipley JR, Twining CW, Taff CC, Vitousek MN, Flack A, Winkler DW (2020) Birds advancing lay dates with warming springs face greater risk of chick mortality. *PNAS* 117(41):25590-25594. https://doi.org/10.1073/pnas.2009864117

16. Winkler DW, Luo MK, Rakhimberdiev E (2013) Temperature effects on food supply and chick mortality in tree swallows (*Tachycineta bicolor*). *Oecologia* 173:129-138. https://doi.org/10.1007/s00442-013-2605-z

17. Zammuto RM, Franks EC, Preston CR (1981) Factors associated with the interval between feeding visits in brood-rearing chimney swifts. *Journal of Field Ornithology* 52(2):134-139. https://www.jstor.org/stable/4512635

18. Cusimano CA, Massa B, Morganti M (2016) Importance of meteorological variables for aeroplankton dispersal in an urban environment. *Italian Journal of Zoology* 83(2):263-269. https://www.tandfonline.com/doi/full/10.1080/11250003.2016.1171915

19. Garrett DR, Lamoureux S, Rioux Paquette S, Pelletier F, Garant D, Bélisle M (2022) Combined effects of cold snaps and agriculture on the growth rates of Tree Swallows (*Tachycineta bicolor*). *Canadian Journal of Zoology* 100(10):630-646. https://doi.org/10.1139/cjz-2021-0210

20. Rioux Paquette S, Garant D, Pelletier F, Bélisle M (2013) Seasonal patterns in Tree Swallow prey (Diptera) abundance are affected by agricultural intensification. *Ecological Applications* 23(1):122-133 https://doi.org/10.1890/12-0068.1

21. Hegedüs RS, Åkesson S, Horváth G (2007) Anomalous celestial polarization caused by forest fire smoke: why do some insects become visually disoriented under smoky skies? *Applied Optics* 46(14):2717-2726. https://doi.org/10.1364/AO.46.002717

22. Steeves TK, Kearney-McGee SB, Rubega MA, Cink CL, Collins CT (2020) Chimney Swift (*Chaetura pelagica*), version 1.0. In: Poole AF (editor) *Birds of the World*. Ithaca, NY: Cornell Lab of Ornithology. Accessed 13 January 2023. https://doi.org/10.2173/bow.chiswi.01

23. Kyle P, Kyle G (2005) *Chimney Swifts: America's Mysterious Birds Above the Fireplace*. College Station: Texas A&M University Press.

24. Dexter, RW (1952) Extra-parental cooperation in the nesting of chimney swifts. *Wilson Bull*. 63(3):133-139.

25. Glick PA (1939) The distribution of insects, spiders, and mites in the air. *U.S. Department of Agriculture Technical Bulletin* No. 673. 151 p. https://naldc.nal.usda.gov/download/CAT86200667/PDF

26. Ojo ER, Manaigre L (2021) The Manitoba Agriculture Mesonet: Technical Overview. Bull. Am. Met. Soc. 1.02(9). 19 pp. Accessed 14 July 2023. https://doi.org/10.1175/BAMS-D-20-0306.1 (The data are also available online https://web43.gov.mb.ca/climate/HourlyReport.aspx)

27. Zammuto RM, Franks EC (1981) Environmental effects on roosting behavior of Chimney Swifts. *Wilson Bull*. 93(1):77-84. https://www.jstor.org/stable/4161428

28. Weather Spark (2023) July weather in Winnipeg Canada. Accessed 13 March 2023. https://weatherspark.com/m/8367/7/Average-Weather-in-July-in-Winnipeg-Canada

29. ECCC (Environment and Climate Change Canada) (2023) Glossary. Accessed 11 March 2023. https://climate.weather.gc.ca/glossary_e.html#s_maxGust

30. le Roux CE, McFarlane Tranquilla LA, Nocera JJ (2019) Ambient temperature preferences of chimney swifts (Chaetura pelagica) for nest site selection. *J. Therm. Bio.* 80:89-93. https://doi.org/10.1016/j.jtherbio.2018.12.017

31. ECCC (Environment and Climate Change Canada) (2022) Extreme events in a changing climate: Canadas top 10 weather stories of 2022. Accessed 14 March 2023. https://www.canada.ca/en/environment-climate-change/news/2022/12/extreme-events-in-a-changing-climate-canadas-top-10-weather-stories-of-2022.html

32. Government of Manitoba (2022) Hydrologic Forecasting and Water Management, Manitoba Transportation & Infrastructure Daily Flood Sheet, Red River May 13. https://www.gov.mb.ca/mit/floodinfo/floodoutlook/forecast_centre/flood_sheets/2022/20220513%20Red%20River%20Flood%20Sheet.pdf

33. Government of Manitoba (2022) Hydrologic Forecasting and Water Management, Manitoba Transportation & Infrastructure Daily Flood Sheet, Red River June 4. https://www.gov.mb.ca/mit/floodinfo/floodoutlook/forecast_centre/flood_sheets/2022/20220604%20Red%20River%20Flood%20Sheet.pdf

34. Fitzgerald TM, van Stam E, Nocera JJ, Badzinski DS (2014) Loss of nesting sites is not a primary factor limiting northern Chimney Swift populations. *Population Ecology* 56:507-512. https://doi.org/10.1007/s10144-014-0433-6

35. Mccarty JP, Winkler DW (1999) Relative importance off [sic] environmental variables in determining the growth off [sic] nestling tree swallows *Tachycineta bicolor. Ibis* 141(2):286–296. https://doi.org/10.1111/j.1474-919X.1999.tb07551.x

36. Grames EM, Montgomery GA, Youngflesh C, Tingley MW, Elphick CS (2023) The effect of insect food availability on songbird reproductive success and chick body condition: evidence from a systematic review and meta-analysis. *Ecology Letters* 00:1-16. https://doi.org/10.1111/ele.14178

37. Grüebler MU, Morand M, Naef-Daenzer B (2008) A predictive model of the density of airborne insects in agricultural environments. *Agriculture, Ecosystems and Environment* 123(1-3):75–80. https://doi.org/10.1016/j.agee.2007.05.001

38. Laughlin AJ, Blake Hudson T, Brewer-Jensen T (2022) Dynamics of an urban Chimney Swift (*Chaetura pelagica*) roost system during autumn migration. Wilson Journal of Ornithology 134(2)269-277. https://doi.org/10.1676/21-00081

39. Firlotte N, Poole TF, Artuso C, Breiter C-JC, Burns LD, Petersen SD, Stewart BE, Stewart REA (2020) The first use of purpose-built artificial Chimney Swift habitat in Manitoba. *Blue Jay* 78(3):30-33. https://www.mbchimneyswift.com/Documents/FirstUseMB.pdf

40. Bendire, C. 1895. Life histories of North American birds, from the parrots to the grackles, with special reference to their breeding habits and eggs. US National Museum. Special Bulletin. (no. 3). 518 pp.

41. Poole TF (2022) Possible effects of placement timing on the use of replacement habitat by Chimney Swifts in Manitoba. *Blue Jay* 80(4):26-32. https://www.mbchimneyswift.com/Documents/bluejay_winter2022.pdf

42. Manitoba Chimney Swift Initiative (2020) The Last of the Swifts. Accessed 30 January 2023. https://www.mbchimneyswift.com/?s=last+seen+September

43. Manitoba Chimney Swift Initiative (2021) That's a Wrap, Folks! Accessed 30 January 2023. https://www.mbchimneyswift.com/thats-a-wrap-folks/

44. Manitoba Chimney Swift Initiative (2023) About the Manitoba Chimney Swift Initiative. Accessed 14 March 2023. https://www.mbchimneyswift.com/

45. ECCC (Environment and Climate Change Canada) (2022) Recovery Strategy for the Chimney Swift (*Chaetura pelagica*) in Canada [Proposed]. *Species at Risk* Recovery Strategy Series, Environment and Climate Change Canada, Ottawa, Ontario, Canada

46. Courtois E, Garant D, Pelletier F, Bélisle M (2021) Nonideal nest box selection by tree swallows breeding in farmlands: Evidence for an ecological trap? *Ecology and Evolution* 11(22):16296-16313. https://doi.org/10.1002/ece3.8323