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Tree Swallow (*Tachycineta bicolor*) nest success and nestling growth near oil sands mining operations in northeastern Alberta, Canada

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Abstract: Industrial development and contaminant exposure may affect reproductive success and food quality for birds. Tree Swallows (*Tachycineta bicolor* (Vieillot, 1808)) nesting near oil sands development in northern Alberta (Canada) potentially experience elevated environmental stressors that could influence reproduction. We measured reproductive and growth endpoints in Tree Swallows, predicting reduced reproductive success and nestling growth near oil sands operations compared with reference sites. We also identified the invertebrate prey in the stomach contents of nestlings to understand variability in the diet and its potential effect on growth and survival of nestlings. From 2012 to 2015, clutch initiation varied among years but was not influenced by proximity to oil sands operations. Hatching and fledging success decreased in response to increased precipitation, regardless of location. Measurements of nestling growth reflected the variation associated with nestling sex and possibly asynchronous hatching. The composition of the nestling diet was significantly different; birds near oil sands development consumed Odonata, whereas birds at reference sites consumed Ephemeroptera. Nestlings from all sites consumed relatively high quantities of terrestrial insects. Our results demonstrate that factors such as weather conditions, diet, hatching order, and nestling sex are important when interpreting the potential effects of oil sands development on nest success and nestling growth.

Key words: oil sands, Tree Swallows, *Tachycineta bicolor*, nestling growth, nest success, insect diet, food web, environmental stress.

Résumé : Le développement industriel et l'exposition aux contaminants peuvent avoir une incidence sur le succès de reproduction et la qualité de la nourriture des oiseaux. Les hirondelles bicolores (*Tachycineta bicolor* (Vieillot, 1808)) qui nidifient à proximité d'exploitations de sables bitumineux dans le nord de l'Alberta (Canada) pourraient être exposées à des facteurs de stress ambiants de forte intensité qui pourraient influer sur leur reproduction. Nous avons mesuré des effets sur la reproduction et la croissance chez des hirondelles bicolores, prédisant un succès de reproduction et une croissance des oisillons au nid plus faibles près d'exploitations de sables bitumineux que dans des sites de référence. Nous avons également identifié les proies invertébrées dans les contenus stomacaux d'oisillons au nid afin de comprendre la variabilité de leur régime alimentaire et son incidence possible sur leur croissance et leur survie. De 2012 à 2015, la date de ponte a varié d'une année à l'autre, mais n'était pas influencée par la proximité d'activités d'exploitation de sables bitumineux. Les succès d'éclosion et d'envol diminuaient en réponse à la hausse des précipitations, peu importe le site. Les mesures de la croissance des oisillons au nid reflétaient des variations associées au sexe des oisillons et possiblement à leur éclosion asynchrone. La composition du régime alimentaire des oisillons au nid variait de manière significative; les oiseaux à proximité d'exploitations de sables bitumineux consommaient des odonates, alors que les oiseaux dans les sites de référence consommaient des éphéméroptères. Les oisillons au nid dans tous les sites consommaient des quantités relativement grandes d'insectes terrestres. Nos résultats démontrent qu'il importe de tenir compte de facteurs comme les conditions météorologiques, le régime alimentaire, l'ordre d'éclosion et le sexe des oisillons au nid dans l'interprétation des effets potentiels de l'exploitation des sables bitumineux sur le succès de nidification et la croissance des oisillons au nid. [Traduit par la Rédaction]

Mots-clés : sables bitumineux, hirondelle bicolore, *Tachycineta bicolor*, croissance des oisillons au nid, succès de nidification, régime alimentaire à base d'insectes, réseau trophique, stress environnemental.

Introduction

The effects on birds of contaminants from industrial waste and emissions have been investigated widely and include reproductive (Fry 1995; Dods et al. 2005) and physiological effects potentially indicating tissue or organ damage (Sanderfoot and Holloway 2017). Disturbance from development and exposure to contaminants may increase stress, divert energetic resources, affect the quality of nesting habitat, and reduce food resources. Sublethal and chronic effects from pollutant exposure occur more frequently than acute responses such as higher mortality (Scheuhammer 1987).

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Indeed, reproductive endpoints such as clutch size, hatching success, survival to fledging, and nestling growth are influenced by environmental contamination from industrial development (Eeva and Lehikoinen 1996; McCarty and Secord 1999; Custer et al. 2003; Dods et al. 2005; Brasso and Cristol 2008).

Surface mining of the Alberta oil sands has been ongoing north of Fort McMurray, Alberta, Canada, since 1967 (Gosselin et al. 2010). Oil sands production has grown substantially over the last decade and development is expanding. Bitumen extracted from the oil sands is upgraded to synthetic crude oil in mine upgrading facilities for shipment by pipeline to refineries. Waste materials are released in tailings process water and in air emissions from the mine upgraders, potentially contaminating surface waters and the surrounding environment (Barton and Wallace 1979; Kelly et al. 2010; Puttaswamy and Liber 2012). Passive air monitoring sampling devices placed at wetlands near surface mining activity accumulated greater amounts of polycyclic aromatic compounds compared with wetlands located south of Fort McMurray (Cruz-Martinez et al. 2015; Mundy et al. 2019). Organic and inorganic compounds measured in snow were attributed to oil sands emissions (Kelly et al. 2009, 2010). The levels of hydrocarbon emissions from oil sands upgraders are modest compared with major petrochemical facilities, although levels are significantly elevated above natural conditions (Simpson et al. 2010).

Tree Swallows (*Tachycineta bicolor* (Vieillot, 1808)) have been used as an indicator of environmental exposure to contaminants in many locations across North America (Bishop et al. 1995; Wayland et al. 1998; Jones 2003; Custer 2011), including in the oil sands region (Gentes et al. 2006; Smits and Fernie 2013; Cruz-Martinez et al. 2015). Tree Swallows are a useful model organism because they are semi-colonial and readily breed in nest boxes, allowing for larger sample sizes and standardization of methods (McCarty 2002; Jones 2003). Tree Swallows will forage within view of their nest site when feeding nestlings (McCarty and Winkler 1999*a*), allowing contaminant exposure studies to attribute effects to diet and inhalation of compounds. Physiological effects measured in nestling Tree Swallows near oil sands mining included induction of the liver detoxification enzyme ethoxyresorufin-*o*-deethylase (EROD) (Gentes et al. 2006; Cruz-Martinez et al. 2015), increased thyroid hormone levels (Gentes et al. 2007*a*), and immune function response (Harms et al. 2010; Cruz-Martinez et al. 2015). Although physiological effects have been measured, indicating exposure to environmental contaminants and potentially negative health effects, an association between particular oil sands process affected materials in wetlands and reproductive performance has not been found (Smits et al. 2000; Harms et al. 2010). A 2-year study of Tree Swallows in the oil sands found that nestlings on reclaimed sites weighed less than those on a reference site, although effects were found in only 1 year (Gentes et al. 2006). Changes in foraging behaviour to include more distant habitats have been suggested to explain some of the variation in nestling growth that was observed in Tree Swallows nesting near oil sands process affected wetlands (Farwell et al. 2014).

An alternative explanation for the observed variation in growth and mass of nestlings may be variation in local habitat leading to differences in diet (Quinney et al. 1986; Hussell and Quinney 1987; Dunn and Hannon 1992; Wayland et al. 1998) and variation in weather conditions affecting the abundance of insects available as food (McCarty and Winkler 1999*b*). Studies have also found that the density of breeding birds, parental care, ambient daily temperature, and parasite load are also important factors influencing nestling growth (McCarty 2001; Ardia 2006; Gentes et al. 2007*b*).

The objective of our study was to measure variation in reproductive and growth endpoints in Tree Swallows inhabiting areas near oil sands mine operations and regional reference sites unaffected by mining to determine whether oil sands disturbance has an effect on Tree Swallows. We hypothesized that Tree Swallows near oil sands operations experience higher levels of environmental stress, and thus predicted reduced reproductive success and nestling growth near oil sands operations compared with less disturbed habitats. We also predicted that reproductive success and nestling growth would be positively influenced by warmer and drier conditions. We identified the invertebrate prey in the stomach contents of nestlings to understand the variability in the diet and its potential to affect nestling growth and survival. Finally, we predicted a lower return rate of TreeSwallows near operations due to reduced habitat quality, a potential indicator of annual survival.

Materials and methods

Study sites

We monitored Tree Swallows from 2011 to 2015 using nest boxes at eight sites near Fort McMurray (56.7278°N, 111.3804°W) (Fig. 1). However, an extensive regional forest fire permeated the area with ash and smoke in 2011. Environmental conditions likely had a large impact on Tree Swallow occupancy and nest success in the 2011 season and all but one clutch failed, so the data from 2011 were excluded from statistical analyses.

Each of the eight sites supported 15 to 30 nest boxes and was near a wetland or pond. Four sites (sites 1, 2, 3, and 4) were within 5 km of active mine operations and mine upgraders and were exposed to deposition from aerial emissions (Bari et al. 2014; Mundy et al. 2019), as well as potentially to contaminants in water originating from bitumen processing. Tree Swallow populations had been established at some of these sites prior to this study (Smits et al. 2000; Gentes et al. 2006, 2007*a*, 2007*b*; Harms et al. 2010). Site 1 was at a pond built in 1993 to support tailings research and contained fine tailings at the bottom. Site 2 was a reclaimed area on the edge of a wetland that naturally formed following reclamation in 2003. Site 3 was also reclaimed and planted with coniferous trees in 1983. This site was an overburden dump from mine development and now supports an upland forest and wetland habitat. Amphibian tadpoles from the wetland at this site had high levels of polycyclic aromatic compounds in tissues (Mundy et al. 2019). Site 4 was adjacent to a reservoir used to store water for mine operations. Reference sites were added south of Fort McMurray in 2012. Four reference sites (sites 5, 6, 7, and 8) were located 55 to 65 km south of active mining. Nest boxes had also been installed previously at two of these reference sites, although data were unpublished at the time of our study. The reference sites 5 and 8 were on the edge of old borrow pits that provided gravel fill for highway construction, which have naturally revegetated and filled with water. Site 6 was adjacent to a beaver pond and natural drainage system. Site 7 was in a grass–sedge wetland on the edge of Maqua Lake. Additional nest boxes were added at sites near oil sands operations and at reference sites each year to increase occupancy and hence sample sizes at both locations (Table 1).

Nest box monitoring

From mid-May to mid-July, we visited nest boxes daily or every second day during nest building and egg laying, and daily close to hatching, to determine date of clutch initiation, clutch size, and day of hatching. The first day that half or more eggs had hatched was designated day 0. Nestlings hatched asynchronously and hatching was generally completed over a 24 h period. To measure the effects of disturbance on reproductive success and the differential mortality during incubation and the nestling stage, we determined hatching success and nestling fledging success separately, similar to other toxicological studies (Bishop et al. 1999; Dods et al. 2005; Brasso and Cristol 2008). Hatching success was therefore determined by the number of eggs hatched divided by clutch size, not including nests that were destroyed or preyed upon prior to hatching. Fledging success was determined by the number of nestlings reaching 14 days of age divided by the num-

Fig. 1. Study sites near oil sands mining operations north of Fort McMurray, Alberta, Canada, and at reference sites south of the city for the study of Tree Swallow (*Tachycineta bicolor*) reproductive success and nestling growth. The number of occupied nest boxes at sites 1, 2, 3, and 4 near oil sands operations from 2011 to 2015 were 10, 17, 24, 36, and 50 in each year, respectively. The number of occupied nest boxes at the reference sites 5, 6, 7, and 8 from 2012 to 2015 were 10, 25, 31, and 36 in each year, respectively. Colour version online.

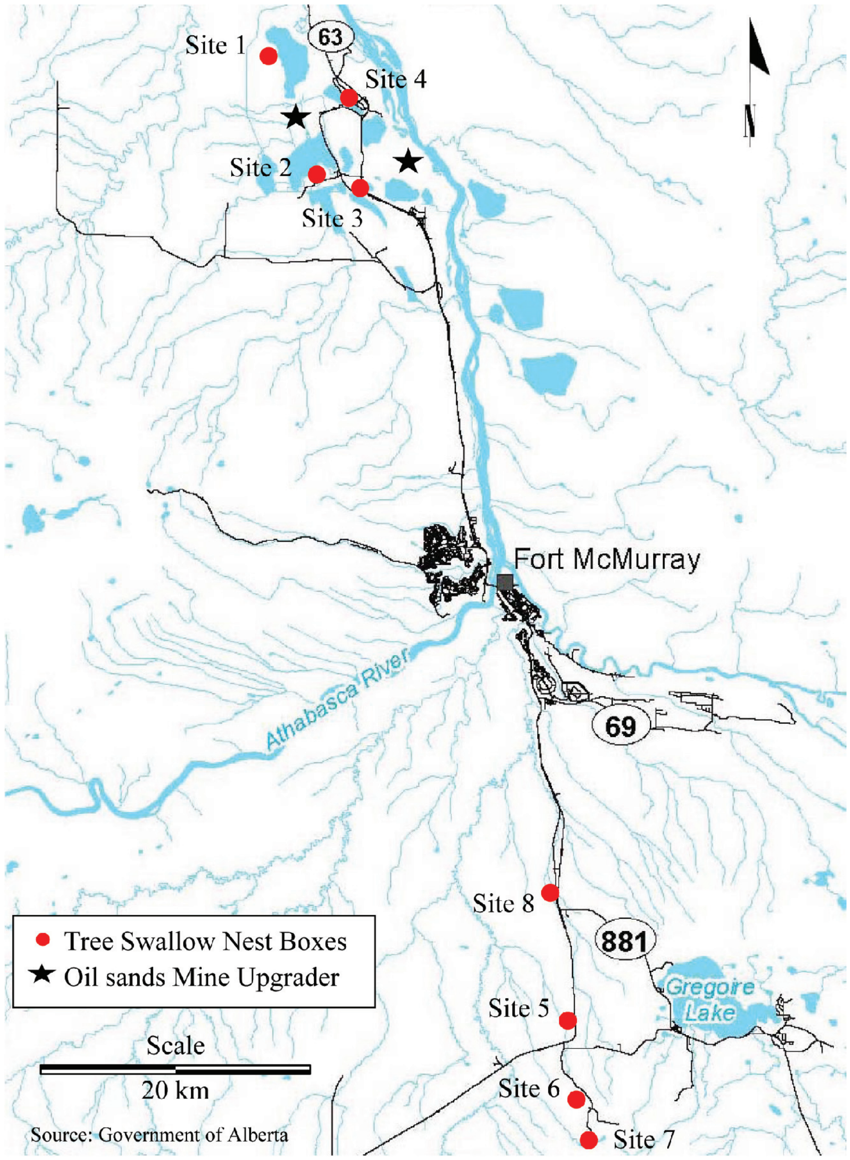


Table 1. The number of nest boxes occupied by Tree Swallows (*Tachycineta bicolor*) at study sites near Fort McMurray, Alberta, Canada, and percent occupancy near mining operations and at reference sites in each year.

	2012		2013		2014		2015	
	Available	Occupied	Available	Occupied	Available	Occupied	Available	Occupied
Near operations	54	17 (31%)	83	24 (29%)	103	36 (35%)	98	50 (51%)
Reference	55	10 (18%)	70	25 (36%)	85	31 (36%)	83	36 (43%)
Total	109	27 (25%)	153	49 (32%)	188	67 (36%)	181	86 (48%)

ber of eggs hatched. Mortality of nestlings after 14 days was less than 2% of the nestlings that were banded based on the number of birds found dead in nest boxes during cleaning. Therefore, the number of nestlings at day 14 adequately reflects fledging success. Nest boxes were not visited beyond day 14 until they were cleaned after about 25 days to minimize the risk of premature fledging (Dunn and Hannon 1992). Nest predation did not occur prior to 2014. In 2014 and 2015, 9 nest boxes were lost to predation and 11 nest boxes were destroyed by black bears (*Ursus americanus* Pallas, 1780) just prior to nestlings reaching 14 days of age. Nests that were preyed upon were excluded from the analysis of fledging success.

To examine the effects of annual weather conditions on hatching and fledging success, we used Environment and Climate Change Canada data collected at the Fort McMurray airport weather station located about 40 km south of mining operations

Table 2. Annual returns of banded adult female Tree Swallows (*Tachycineta bicolor*) near mining operations and at reference sites near Fort McMurray, Alberta, Canada, and the percentage of females from occupied boxes that were captured in each year.

	Near operations				Reference			
Year	New	Recaptures	Occupied boxes	Females captured (%)	New	Recaptures	Occupied boxes	Females captured (%)
2011	10		10	100				
2012	10	1 (10%)	17	65	10		10	100
2013	18	3 (15%)	24	88	16	4 (40%)	25	80
2014	29	4 (11%)	36	92	21	6 (23%)	31	87
2015	32	17 (25%)	50	98	26	12 (26%)	36	>100[a]
Total	99	25	137	91	73	22	102	93

[a]The number of new females captured includes floaters that were not breeding in nest boxes, exceeding the number of occupied nest boxes.

and about 15 km north of the nearest reference site. We used daily precipitation (mm) and maximum temperatures (°C) observed during the incubation and feeding of nestlings.

Nestling growth

From 2012 to 2014, we collected morphological measurements from 582 nestlings. Sample sizes in each year were 54, 66, and 200 near mine operations and 34, 66, and 162 at reference sites, respectively. On days 9 and 14, we weighed nestlings using a digital balance (iBALANCETM) (±0.1 g) and measured the wing cord with a wing ruler. Nestlings were marked individually on day 9 by colouring the feathers of the femoral tract behind the legs using a non-toxic marker. Nestlings were banded with individually numbered Canadian Wildlife Service bands on day 14. We banded a total of 887 nestlings from 2011 to 2015, but we could not assess nestling return rates due to the low recapture rate.

Nestling diet

In 2012 and 2013, we collected 104 nestling Tree Swallows for contaminant studies (Godwin et al. 2016) and examined their stomach contents for dietary composition. At 14 days of age, we sacrificed one to three randomly selected nestlings from each nest box. Although nestling sex could not be pre-determined, an equal number of males (52) and females (52) were sampled: 28 females and 29 males near operations; 24 females and 23 males at reference sites. Three nestlings were collected only from nests of larger clutch sizes (six or more nestlings). During the necropsy, the stomach of each nestling was removed and placed on ice in a cooler for transportation. Samples were transferred to a freezer as soon as possible once the necropsies were completed. The sex of each bird was determined by visual examination of the gonads. Prior to nestling euthanization, morphological measurements were taken and these data were included in the growth analysis.

We determined the relative proportion of invertebrates and other items such as grit and mollusc shells in the nestling diet by examining the stomach contents of 98 nestlings at 14 days of age in 2012 and 2013. We scanned the stomach samples under a compound microscope and identified the contents to the lowest possible taxonomic level (usually family or genus). We visually estimated the percent volume of each taxon by determining their proportional contribution to the total volume of the stomach contents. We also determined the percent occurrence of each taxon from the total number of stomach contents within which each taxon occurred. Even though stomach contents were partly digested, it was possible to identify each type and quantity of food items from the heads, whole bodies, matching pairs of wings and elytra, and mandibles. Trace amounts were given a value of 1% as an indication of presence. Similar methods are used to estimate the proportion of food items in the diet of birds (Wheelwright 1986; Todd et al. 1998) and bats (Kunz and Whitaker 1983; Reimer et al. 2010).

Female return rate

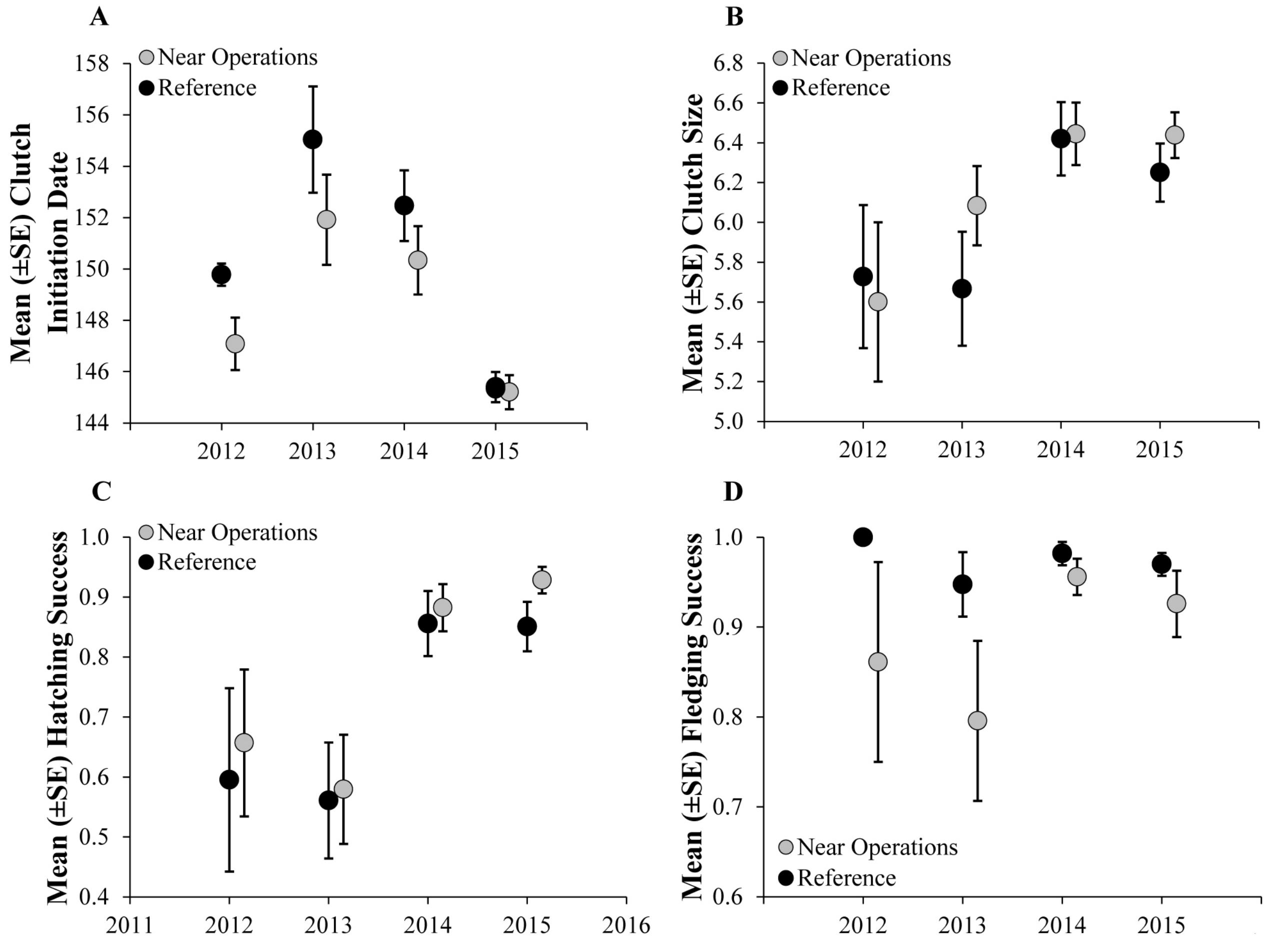
During egg laying, incubation, and feeding of nestlings, adult females were captured in their nest box and banded using similar methods described in Shutler and Clark (2003). Therefore, efforts were made during each site visit from late May until the end of June to capture the females from occupied boxes. Nest boxes were quietly approached and the female trapped inside by covering the box entrance. Over all years, more than 90% of females were captured from occupied boxes and between 10% and 40% of females returned the next year (Table 2). We banded 172 adult females from 2011 to 2015. A total of 99 females were banded near operations, 21 were aged second year (SY) and 60 after second year (ASY), and 73 females were banded from reference sites, 12 were aged SY and 54 ASY. Females were aged as SY or after ASY based on plumage characteristics (Hussell 1983; Pyle 1997). Twenty-five females could not be aged and were called after hatching year (AHY). Occasionally males were also captured and banded. As the capture–recapture effort focused on adult females, we make no inferences about males.

The protocols used in this study were approved by the Animal Care Committee at the University of Calgary (LESACC protocol No. BI11R-27), in compliance with standards set by the Canadian Council on Animal Care, and tissues from the nestlings were shared among three research teams to maximize information gained from each bird. We were issued a Canadian Wildlife Service Permit (11-AB-SC015) and Alberta Wildlife Research Permit (No. 51072) and Collection Licence (No. 49386) for this study.

Data analyses

We conducted statistical analyses using SAS software version 9.3 (SAS Institute, Inc. 2008). We tested for location and year differences in clutch initiation date (day 152 = 1 June), clutch size, hatching success, and fledging success, using generalized linear mixed models (PROC GLIMMIX procedure in SAS), with site as a random effect. We also included year × location as an interaction term in each model. Clutch initiation date was included as a fixed effect in models for clutch size, hatching success, and fledging success. Precipitation and maximum temperature were correlated, and when tested without precipitation, temperature did not have an effect on hatching success and fledging success. Therefore, only total precipitation during egg incubation and the nestling stage was included in the models for hatching success and fledging success, with the interaction term year × precipitation. The GLIMMIX model combines the features of a generalized linear model for analyzing non-normal data, with the random variable site nested within location (near oil sands mine operations or reference) to account for non-independence of nest boxes within a site that may be affected by local weather conditions and timing of adult bird arrival. A Poisson distribution fit the clutch initiation date better than a normal distribution because of high

Fig. 2. Mean (±SE) (A) clutch initiation date (1 June = day 152), (B) clutch size, (C) hatching success, and (D) fledging success for Tree Swallows (*Tachycineta bicolor*) nesting near mining operations (n = 12, 22, 35, and 39 in each year, respectively) and at reference sites (n = 9, 23, 26, and 35 in each year, respectively) in the Fort McMurray, Alberta, Canada, area from 2012 to 2015.



overdispersion since most Tree Swallows initiated their clutches during the last week of May, but late nesting occurred up to mid-June increasing the variability and skewing the data. A Poisson distribution also fit clutch size and fledging success. A negative binomial distribution was used for hatching success to address overdispersion in the model.

Nestling growth parameters were normally distributed, and nestling mass and wing cord on days 9 and 14 were modelled separately, comparing locations and years using a mixed model analysis of variance (ANOVA) (PROC MIXED procedure in SAS) with nest box as a random effect. This statistical procedure is a more reliable test for normally distributed data than generalized modelling approaches, and the random variable nest box (nested in year) accounts for the lack of independence among nestlings within the same nest box. The MIXED model also minimizes the effects of unequal sample sizes. Each model contained year, location (near operations, reference), interaction between year and location, and the number of nestlings present in the nest box at the time the measurements were taken as fixed effects. We also tested for size differences between male and female nestlings.

We tested for location and year differences on the estimated proportion of prey consumed by nestlings using a MANOVA within the SAS procedure PROC GLM. Correlations among taxa were provided using the PRINTE option in the MANOVA statement. We excluded taxa not present in at least 50% of the samples for at least one location in 1 year, or at least 25% of all samples. Therefore, the taxa that we included were Coleoptera, Ephemeroptera, Odonata, Diptera, and Hymenoptera. The proportional data were arcsine transformed for analysis, appropriate for these data to stretch out the tails of the distribution (Sokal and Rohlf 1995). A significance level of $p < 0.05$ was used for all statistical tests.

Location differences in the age of adult females and the number of annual returns of banded females were tested by analyzing contingency tables using the Fisher's exact test in SAS PROC FREQ.

Results

Nest success

Except in 2015 when the mean clutch initiation date was the same at reference and near mining operations sites, the mean date for the first egg laid was 2 to 3 days earlier near operations compared with reference sites, although this difference was not statistically significant (Fig. 2A, Table 3). Year had a significant effect on clutch initiation (Table 3); egg laying began earlier in 2012 and 2015 compared with 2013 and 2014. Clutch size was not different between locations (Fig. 2B, Table 3), but year had an effect and clutch sizes in 2014 and 2015 were larger than those in 2012. Clutch size was significantly related to the date of clutch initiation and declined as the season progressed.

Hatching success in our study varied across years, ranging from 56% to 93%, whereas fledging success ranged from 80% to 97%. There was no location difference in hatching success (Fig. 2C, Table 3). Hatching success was not influenced by clutch initiation date. Precipitation during egg incubation significantly influenced

Table 3. Type III tests of fixed effects for Tree Swallow (*Tachycineta bicolor*) nest success and nestling growth models for locations defined by near oil sands operations and reference sites near Fort McMurray, Alberta, Canada.

Item	Explanatory variables	df Numerator	df Denominator	*F*	*p*
Clutch initiation date	Year	3	190.2	24.39	0.00
	Location	1	5.5	1.93	0.22
	Year × location	3	190.2	0.19	0.90
Clutch size	Year	3	190.7	4.79	0.00
	Location	1	8.6	0.09	0.78
	Year × location	3	190.8	1.51	0.21
	Clutch initiation date	1	191.3	51.53	0.00
Hatching success	Year	3	118.6	3.56	0.02
	Location	1	19.4	1.81	0.19
	Year × location	3	16.8	0.53	0.67
	Clutch initiation date	1	186.7	0.90	0.34
	Precipitation incubation	1	184.3	4.97	0.03
	Precipitation incubation × year	3	181.0	4.15	0.01
Fledging success	Year	3	88.4	1.47	0.23
	Location	1	17.2	1.25	0.28
	Year × location	3	16.5	0.24	0.87
	Clutch initiation date	1	163.4	1.06	0.30
	Precipitation nestlings	1	156.7	5.83	0.02
	Precipitation nestlings × year	3	156.7	1.45	0.23
Nestling mass day 9	Year	2	90.4	2.13	0.12
	Location	1	91.1	2.18	0.14
	Year × location	2	90.8	1.09	0.34
	Number of nestlings at day 9	1	92.6	0.83	0.36
Nestling mass day 14	Year	2	95.4	3.49	0.03
	Location	1	96.2	1.78	0.18
	Year × location	2	96.7	0.29	0.74
	Number of nestlings at day 14	1	103.0	0.06	0.81
Wing cord day 9	Year	2	90.1	0.70	0.50
	Location	1	90.8	1.13	0.29
	Year × location	2	90.5	1.24	0.30
	Number of nestlings at day 9	1	92.2	1.12	0.29
Wing cord day 14	Year	2	92.2	0.09	0.91
	Location	1	93.0	0.09	0.76
	Year × location	2	93.5	0.04	0.96
	Number of nestlings at day 14	1	99.1	6.57	0.01

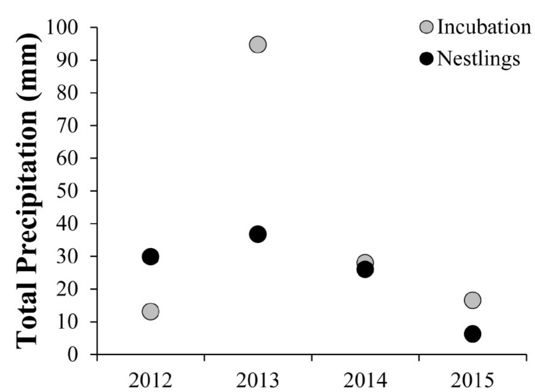
hatching success. Year also had a significant effect, with nests in 2014 and 2015 being most successful. There was no significant location difference in fledging success (Fig. 2D, Table 3), although variation was especially high at sites near operations in 2012 and 2013. Fledging success was not influenced by clutch initiation date. Precipitation during the nestling stage did have a significant effect on nestling fledging success. Rainfall was highest in the 2013 breeding season (Fig. 3). Over the 4 years, 24 of the 201 clutches failed to hatch, with 14 of these occurring in 2013.

Nestling growth

Nestlings near operations tended to weigh less on day 9 in 2013, compared with reference nestlings and nestlings in other years (Figs. 4A–4D). However, when the effect of the number of nestlings in the nest box was taken into account, this difference was not statistically significant (Table 3). By 14 days of age, nestlings at both near mine operations and reference sites in 2013 remained below the mean mass of nestlings of the same age in other years (Table 3). No location or year differences in day 9 and day 14 wing measurements were found.

Male nestlings weighed more than females at day 9 ($F_{[1,87]} = 7.38$, $p < 0.01$) and at day 14 ($F_{[1,87.3]} = 9.15$, $p < 0.01$). The wing cord of males was longer at day 9 ($F_{[1,76.2]} = 4.19$, $p = 0.04$), but this difference was not significant by 14 days of age ($F_{[1,83.2]} = 2.86$, $p = 0.09$).

Fig. 3. Total precipitation (mm) from 2012 to 2015 during egg incubation and nestling feeding by Tree Swallows (*Tachycineta bicolor*) near Fort McMurray, Alberta, Canada.



Nestling diet

Insect taxa with a terrestrial larval life stage comprised up to one-third of the nestling Tree Swallow diet at 14 days old, and included Coleoptera, Hymenoptera, and several terrestrial Dipteran families (Table 4). Nestling diet was different between the two locations and between years (Wilks' λ, $p < 0.01$). Overall, the

Fig. 4. Median values and interquartile range of (A, B) nestling mass (g) and (C, D) wing cord (mm) at 9 and 14 days of age. Boxplot whiskers represent scores outside the middle 50% of values, whereas data that fall above and below the whiskers show outlying values indicating variability. Nestling mass at 14 days of age at both locations was lower in 2013 than in other years (*, $p < 0.05$).

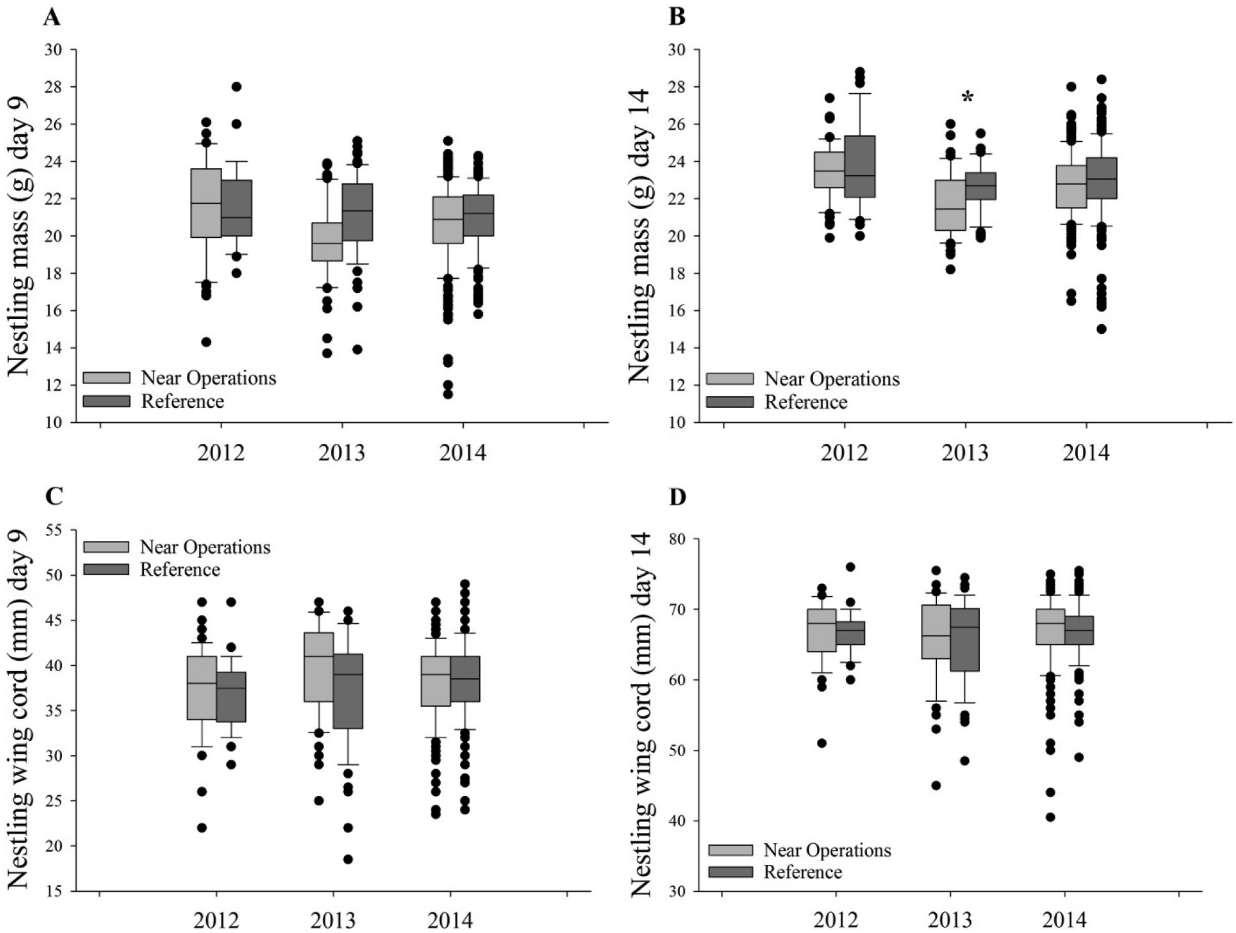


Table 4. Mean (±SD) proportion by volume of invertebrates and percent occurrence of common invertebrates consumed by 14-day-old Tree Swallow (*Tachycineta bicolor*) nestlings at sites near mining operations and at reference sites near Fort McMurray, Alberta, Canada, in 2012 and 2013 (see also Godwin et al. 2016).

	Near operations		Reference		
Stomach content[a]	2012 (*n* = 23)	2013 (*n* = 28)	2012 (*n* = 16)	2013 (*n* = 31)	Larval habitat[b]
Coleoptera	0.37 ± 0.21 (96%)	0.13 ± 0.15 (100%)	0.28 ± 0.20 (100%)	0.09 ± 0.08 (87%)	Terrestrial
Ephemeroptera	0.00 ± 0 (0%)	0.10 ± 0.24 (18%)	0.25 ± 0.31 (50%)	0.46 ± 0.36 (71%)	Aquatic
Diptera	0.09 ± 0.08 (87%)	0.29 ± 0.25 (96%)	0.27 ± 0.22 (94%)	0.21 ± 0.29 (84%)	Terrestrial and aquatic
Odonata	0.29 ± 0.30 (74%)	0.08 ± 0.22 (29%)	0.01 ± 0.03 (6%)	0.02 ± 0.09 (6%)	Aquatic
Hymenoptera	0.06 ± 0.10 (43%)	0.06 ± 0.10 (50%)	0.03 ± 0.07 (31%)	0.04 ± 0.08 (45%)	Terrestrial
Lepidoptera[c]	0.05 ± 0.20	0.01 ± 0.02	<0.01 ± 0	0.01 ± 0.02	Terrestrial
Trichoptera	0.00 ± 0	0.02 ± 0.06	0.01 ± 0.03	0.03 ± 0.12	Aquatic
Tipulidae	0.00 ± 0	0.04 ± 0.10	0.00 ± 0	0.01 ± 0.03	Aquatic
Hemiptera	<0.01 ± 0.01	0.01 ± 0.02	0.01 ± 0.01	<0.01 ± <0.01	Terrestrial and aquatic
Homoptera	<0.01 ± <0.01	<0.01 ± 0.01	<0.01 ± <0.01	0.01 ± 0.02	Terrestrial
Neuroptera	<0.01 ± 0	<0.01 ± 0.01	<0.01 ± 0	<0.01 ± 0	Terrestrial
Psocoptera	0.00 ± 0	0.00 ± 0	<0.01 ± 0	0.00 ± 0	Terrestrial
Other[d]	0.01 ± 0.04	<0.01 ± 0	0.02 ± 0.05	<0.01 ± 0.01	Incidental
Unidentified	0.13 ± 0.16	0.16 ± 0.18	0.13 ± 0.14	0.08 ± 0.15	Unidentified
Mollusca[e]	10	5	4	13	Aquatic
Grit[e]	11	5	3	9	Terrestrial
Plant[e]	5	8	2	6	Incidental

[a]Invertebrate orders set in boldface type were included in the diet analysis.
[b]See McAlpine et al. (1981, 1987), McAlpine and Wood (1989), Bousquet (1991), and Goulet and Huber (1993).
[c]Order composed of unidentified moth species.
[d]Arachnids, larvae of the blow fly genus *Protocalliphora* Hough, 1899, and unidentified invertebrate eggs.
[e]Number of stomach samples containing Mollusca shells (class Gastropoda and class Bivalvia), grit composed of sandstone or quartz, or plant material.

proportion of Coleoptera consumed in 2012 was higher than in 2013 ($F_{[1,97]}$ = 41.04, p < 0.01), but not different between locations ($F_{[1,97]}$ = 3.84, p = 0.05). Nestlings at reference sites consumed a greater proportion of Ephemeroptera ($F_{[1,97]}$ = 37.48, p < 0.01), whereas nestlings near operations consumed more Odonata ($F_{[1,97]}$ = 18.93, p < 0.01). The presence of Ephemeroptera in the diet was significantly negatively correlated with the presence of Coleoptera (r = –0.21, p = 0.04) and Diptera (r = –0.58, p < 0.01). Almost no food was contained in the stomachs of six nestlings that were collected after the heavy rains in 2013. These nestlings were in two nest boxes near operations and appeared to have been abandoned, as the stomachs were either empty or contained grass from nest material.

Female return rate

The ratio of SY to ASY females was not significantly different between sites near operations (21 SY to 60 ASY) and reference sites (12 SY to 54 ASY) (Fisher's exact test, p = 0.09), although 15% of captured females could not be aged. The number of available nest boxes was increased in each year as the monitoring program developed, with a concomitant increase in occupancy. The number of banded females that returned near operations versus at reference sites was not significantly different (Fisher's exact test, p = 0.16). Thirty-six returning females occupied the same site, and occasionally, the same nest box that they had used the previous year. Eleven females returned to a different site; dispersal distances were up to 12 km from their original banding site. Multiyear recaptures of eight females banded 2 or more years previously were from both near operations (three females) and reference sites (five females).

Discussion

Contrary to our prediction, we found no evidence of a relationship between reproductive success or nestling growth of Tree Swallows and proximity to oil sands mining operations. Instead, the main factors associated with variation in these measures were year differences in clutch initiation date, precipitation, and nestling sex. Other studies near oil sands operations also found no association between exposure to oil sands contaminants and reproductive performance of Tree Swallows (Smits et al. 2000; Harms et al. 2010), and lower nestling mass at one site near operations could not be explained from available data (Smits et al. 2000).

Clutch size was negatively related to the date of clutch initiation, as has been found before (Winkler et al. 2002). Clutch size may also be influenced by latitude, with larger clutches in more northern latitudes related to longer day length and thus greater available foraging time (Rose and Lyon 2013). The latitudinal gradient in our study was small compared with other studies (Winkler et al. 2014; Imlay et al. 2018), and <1° separated our two study locations. When clutch initiation was earlier, this occurred near oil sands operations located farther north than the reference sites. Therefore, the latitudinal gradient in our study is not expected to have influenced clutch size or the date of clutch initiation.

Weather conditions influenced reproductive success and nestling growth in our study, as has been found in other studies as well (McCarty and Winkler 1999*b*; McCarty 2001; Winkler et al. 2013). In previous studies, nestling mortality was best predicted by cold snaps lasting 3 days with maximum daily temperatures below 18.5 °C, as well as brood age (Winkler et al. 2013). Nestlings aged from 6 to 12 days were the least likely to survive compared with younger or older nestlings (Griebel and Dawson 2019). Nest failures in our study occurred primarily from poor hatching success. Dry weather occurred in 2014 and 2015 when hatching success was highest than during the previous years. Precipitation was highest in 2013, the season that we found reduced hatching success, reduced fledging success, and slower nestling growth. Although the daily maximum ambient temperatures during the nestling stage in our study did fall below 18.5 °C for 3 to 5 days, this was observed in each year of our study. The high number of nest failures in 2013 can be attributed to the higher precipitation in that year. Reproductive success was unrelated to location, suggesting that Tree Swallows in our study were influenced more by the prevailing environmental conditions than by proximity to mining. Weather conditions can influence the reproductive success of Tree Swallows by reducing food availability (Quinney et al. 1986; Hussell and Quinney 1987; Dunn and Hannon 1992; McCarty and Winkler 1999*b*). In a previous study, wet, cold weather was implicated in dramatically higher nestling mortality in birds near oil sands mining operations compared with those on reference sites (Gentes et al. 2006).

Even though nest boxes were located near water, we found the consumption of insects with an aquatic larval stage averaged as low as 40% in 14-day-old nestlings, and some individual nestlings consumed less than 30% of insects with an aquatic origin. Other studies have also found Tree Swallows foraging on terrestrial insects (Custer et al. 2005; Beck et al. 2013). Therefore, exposure to contaminants from aquatic sources may be lower than anticipated. In-stream pollution from mining has been shown to reduce the emergence of aquatic insects (Paetzold et al. 2011; Kraus et al. 2014). If there was a reduction in aquatic prey in our study area from industrial activity contamination, then it might account for the increase in consumption of terrestrial prey. However, terrestrial prey items were consumed in similar amounts near mining and at reference sites. Although nestling Tree Swallows in our study consumed a relatively high proportion of terrestrial insects presumably in response to prey availability, the diet selection did not appear to affect nestling survival or growth. In response to reductions in food supply, aerial insectivores may switch their diet to a more available prey source (Turner 1982). Tree Swallow adults also appear to alter their nestling feeding rates in response to changes in environmental conditions and show strong variation in the frequency that they feed nestlings (Rose 2009). Imlay et al. (2017) found that low insect abundance was not related to a decrease in nestling survival and mass, as adults are able to increase their foraging efforts. Using isotopic analysis, Michelson et al. (2018) found high diversity and annual variation in the nestling Tree Swallow diet, but insects from aquatic orders were consumed in greater proportion than insects from terrestrial orders. Our study is unable to determine if aquatic insects were included in the diet in larger proportions during earlier stages of nestling development, which would require the collection of boluses. Aquatic invertebrates have specific habitat requirements (Bauernfeind and Moog 2000; Remsburg and Turner 2009). The site habitat conditions did not change during this study. The presence of appropriate aquatic habitat may be more important to availability of aquatic prey than the effects of environmental contamination. The variability in the consumption of aquatic and terrestrial insects by nestlings has implications for contaminant exposure.

In our study, nestlings exhibited asynchronous hatching, which likely contributed to the variability in mass and wing cord measurements (see also Zach 1982; Clotfelter et al. 2000; Johnson et al. 2003). Adult provisioning was not biased towards larger nestlings (Whittingham et al. 2003) and is not expected to have an influence on nestling size differences. Differences in growth were also related to sex, with male nestlings being significantly larger than females. Size differences due to hatch order (Clotfelter et al. 2000), nestling sex (Hogle and Burness 2014), and poor early growth due to diet (Wiggins 1990) are less pronounced as nestlings reach fledging age. The compensatory mechanisms in nestling growth are not well understood but may be explained by the heritability of body size. The mass of younger nestlings may be a better predictor of post-fledging survival (McCarty 2001). However, nestling growth rate may not be a sensitive metric for studies of subclinical effects from industrial influences on Tree Swallows unless the many factors affecting growth can be accounted for appropriately.

Even though physiological effects including higher liver detoxification activity and disrupted immune responses have been measured in Tree Swallows near oil sands mining (Gentes et al. 2006, 2007*a*; Harms et al. 2010; Cruz-Martinez et al. 2015), these effects do not appear to affect the reproductive success or growth of Tree Swallows. The dietary quality of nestlings in the oil sands region may play a role in the observed physiological effects. Nestlings fed insects of an aquatic origin are likely to be in better condition because aquatic insects are a higher quality food resource compared with terrestrial insects (Twining et al. 2016). Tree Swallow nestlings fed a diet high in fatty acid content similar to that found in aquatic insects had increased immunocompetence, likely improving their immune response (Twining et al. 2016). Alternatively, the nestlings in our study were not exposed to environmental contaminants at sufficient levels to affect reproduction and growth as predicted.

Nest box occupancy was similar across our study area, but it was lower than the long-term nest box studies in southern Ontario, Canada, where occupancy rates of 75% to 100% for Tree Swallows have been observed (Hussell 2012). Generally, the occupancy rates at study sites for Tree Swallows appear to be decreasing across their range (Shutler et al. 2012). We were not able to determine comparable trends in nest box occupancy due to the short period of our study and for reasons associated with the changes in the number of nest boxes. Regional differences in recapture rates can be expected, although annual recapture rates at a site tend to be more consistent (Clark et al. 2018). The mean return rate of banded adult females in our study was 21% across all years, which was within the range of 13% to 28% reported for Alberta and Saskatchewan, Canada (Houston and Houston 1987; Dunn and Hannon 1992). It is possible that nestling collection in 2012 and 2013 affected the dispersal of breeding adult females in our study. However, experimental manipulation of breeding success by egg removal did not have an effect on the dispersal of adult breeding females (Shutler and Clark 2003).

The long-term biological effects of exposure of Tree Swallows to oil sands contaminants are not known, but the proportion of returning females in our study did not appear to be lower than those observed in uncontaminated areas (Houston and Houston 1987; Dunn and Hannon 1992). Also, the proportion of females aged SY and older appeared to be similar near oil sands operations and at reference sites, and the lack of an observed effect suggests that older female Tree Swallows in our study were as successful as younger females. Older females tend to be more successful breeders (Stutchbury and Robertson 1988). The proportion of older females in our study may have been influenced by the changes over time in the number of available nest boxes and occupancy. Winkler et al. (2011) found that the age structure of a population may be related to the length of time since population establishment, with a higher proportion of older females in populations that are long established. Reproduction in Tree Swallows is strongly influence by environmental conditions, adult female body condition, and foraging ability (Nooker et al. 2005). We did not measure the fitness of adult Tree Swallows, but environmental conditions were important contributors to the reproductive success of Tree Swallows in our study.

The results from our study suggest that the breeding and nestling success of Tree Swallows was not influenced by proximity to oil sands mine operations. Environmental conditions did influence reproductive performance, with nestling sex and potentially the order of hatching being important contributors to the variability in nestling growth. The types of food consumed by nestling Tree Swallows may have confounded our ability to detect effects from oil sands mining. Tree Swallows are reported to selectively consume insects of aquatic origin (Mengelkoch et al. 2004). In our study, the prevalence of terrestrial insects in the diet may have limited the exposure to aquatic contaminants near operations. The abundance and quality of insects as food items is worth exploring in relation to contaminant burdens and food-chain transfer. Our study illustrates that a number of different factors must be considered when interpreting the effects from industrial development and that the physiological effects observed in Tree Swallows near oil sands mining may not be important contributing factors to reduced nestling survival.

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