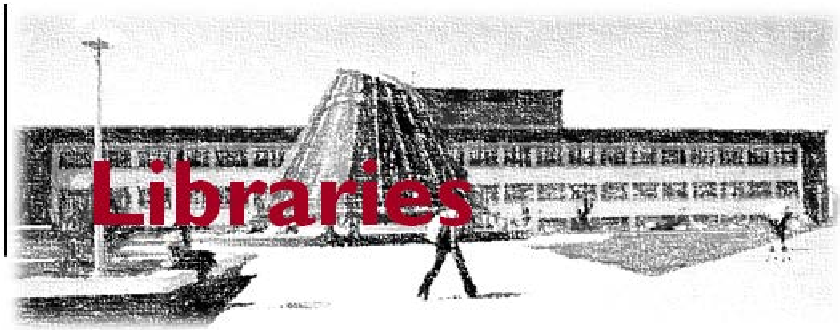
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TREE SWALLOWS (*TACHYCINETA BICOLOR*) NESTING ON WETLANDS IMPACTED BY OIL SANDS MINING ARE HIGHLY PARASITIZED BY THE BIRD BLOW FLY *PROTOCALLIPHORA* SPP.

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ABSTRACT: Oil sands mining is steadily expanding in Alberta, Canada. Major companies are planning reclamation strategies for mine tailings, in which wetlands will be used for the bioremediation of water and sediments contaminated with polycyclic aromatic hydrocarbons and naphthenic acids during the extraction process. A series of experimental wetlands were built on companies' leases to assess the feasibility of this approach, and tree swallows (*Tachycineta bicolor*) were designated as upper trophic biological sentinels. From May to July 2004, prevalence and intensity of infestation with bird blow flies *Protocalliphora* spp. (Diptera: Calliphoridae) were measured in nests on oil sands reclaimed wetlands and compared with those on a reference site. Nestling growth and survival also were monitored. Prevalence of infestation was surprisingly high for a small cavity nester; 100% of the 38 nests examined were infested. Nests on wetlands containing oil sands waste materials harbored on average from 60% to 72% more blow fly larvae than those on the reference site. Nestlings on reclaimed sites suffered mean parasitic burdens about twice that of those on the reference site; and for comparable parasitic load, they exhibited greater pathologic effects (e.g., decreased body mass) than control nestlings. The heavy blow fly infestation on oil sands-impacted wetlands suggests that oil sands mining disturbs several components of the local ecosystem, including habitat characteristics, blow fly predators, and host resistance to parasites.

Key words: Birds, contaminants, oil sands, parasites, polycyclic aromatic hydrocarbon, *Protocalliphora*, *Tachycineta bicolor*, tree swallows.

INTRODUCTION

Birds are widely used as biological indicators of environmental pollution (Grasman and Fox, 2001; Janssens et al., 2003). Most studies traditionally assess reproductive performance of adults, growth and survival of nestlings, and the activity of hepatic enzymes such as ethoxyresorufin-*o*-deethylase, which is commonly measured to evaluate the degree of exposure to xenobiotics. Whereas endoparasite and ectoparasite counts are regularly included in aquatic toxicologic studies (reviewed by Williams and MacKenzie, 2003), this endpoint is rarely used in research focusing on terrestrial wildlife. To our knowledge, only one study has investigated the link between exposure to environmental pollution and ectoparasite infestation (Eeva et al., 1994). This oversight is surprising, because assessing ectoparasite load can be done relatively easily in the field, is nondestructive, and could perhaps provide some indication of animal health status.

This research was conducted on the oil sands of northeastern Alberta, Canada. The Athabasca deposit reaches approximately 42,000 km^2 and represents one of the world's largest reserves of crude oil (Alberta Department of Energy, 2005). With the worldwide decline of conventional fossil fuels, development of the Alberta oil sands has become an economic priority in Canada. Separation of the heavy crude oil from sand is accomplished by the addition of vast volumes of hot water mixed with sodium hydroxide (caustic soda). During the extraction process, contaminants such as polycyclic aromatic hydrocarbons (PAHs) and a group of carboxylic acids, named naphthenic acids (NAs), leach from the ore and become concentrated in the process water. Process-affected water has been shown to be toxic to plankton communities (Leung et al., 2003), fish (van den Heuvel et al., 2000), and amphibians (Pollet and Young, 2000). Once the oil has been extracted, process water, residual sand, clay, and unrecovered bitumen along with organic and inorganic contaminants are diverted to vast settling ponds on the mining sites (Mikula et al., 1996). These tailings are accumulating at the rate of $\sim 10^5$ m^3/day (Madill et al., 2001), and because there is currently no discharge of the mining effluents from the mine leases, as much as 1 billion m^3 of oil sands tailings will require detoxification and reclamation upon mine closure (Fine Tailings Fundamental Consortium, 1995).

Reclamation of such large volumes of contaminated water is a major challenge for the industry and involves the creation of artificial water bodies (wet landscape reclamation). Mine tailings are transferred from settling basins into excavated areas such as mined-out pits and constructed wetlands, where they are subsequently capped with a layer of clean water (Gulley and MacKinnon, 1993). It is anticipated that most of the acute toxicity to aquatic organisms will be mitigated by natural processes such as microbial biodegradation (Lai et al., 1996). However, the long-term ecological impacts of this reclamation strategy are still unknown.

To investigate the feasibility, efficiency, and sustainability of the wet landscape reclamation strategy, the two largest oil sands mining companies in Canada, Syncrude Canada Ltd. and Suncor Energy Inc., have constructed in the past 15 yr a small number of experimental wetlands and test ponds. These sites were partly filled with mine tailings to mimic reclamation plans. Tree swallows (*Tachycineta bicolor*) nesting on these sites are a good species in which to study the transfer of oil sands compounds through food webs, because aquatic insects, whose larvae develop in intimate contact with contaminants present in water and sediments, account for more than 80% of their diet (Smits et al., 2000).

We investigated whether exposure of tree swallows to chemicals present in oil sands process materials (OSPM) would be associated with increased infestation of tree swallows with one species of ectoparasite, the bird blow fly *Protocalliphora* spp. (Diptera: Calliphoridae). Larvae of these blow flies are obligate hematophagous parasites of altricial birds. They live in nest material and feed intermittently on the blood of nestlings until pupation (Sabrosky et al., 1989). The prevalence and intensity of infestation with *Protocalliphora* spp. were measured on experimental reclaimed wetlands containing oil sands waste water and sediments and were compared with that of a reference site. Nestling growth also was monitored.

MATERIALS AND METHODS

Study sites

The study was conducted near Fort McMurray, Alberta, Canada, from May to July 2004. Study sites were located on the leases of Syncrude Canada Ltd. and Suncor Energy Inc. (57°00′N, 111°30′W) and included three experimental reclaimed wetlands constructed by oil sands companies and one reference site. The reclaimed wetlands have been partly filled with mine tailings (OSPM) to mimic reclamation scenarios and contain sand, unrecovered bitumen as well as measurable levels of two contaminants of concern for the industry, PAHs and NAs. Based on the last input of mine tailings (Table 1), the three OSPM wetlands were identified as newly reclaimed, maturing, and complete. This categorization represented the different expected stages of reclamation and allowed the evaluation of the progress of bioremediation (i.e., degradation of PAHs and NAs) over time. The concentrations of NAs in water (collected in 2003) were obtained from Golder Associates (2004) and from Syncrude's Edmonton Research facility (MacKinnon, pers. comm.) and are presented in Table 1. Concentrations of PAHs in three of these reclaimed wetlands have been described previously (Smits et al., 2000), and because more recent data were unavailable, they are

TABLE 1. Characteristics of the study sites, including concentrations of naphthenic acids in water (milligrams per liter) and concentrations of polycyclic aromatic hydrocarbons[a] (nanograms per gram) in sediments.

	Poplar Creek (PC)[b]	Demo Pond (DP)	Natural Wetlands (NW)	Consolidated Tailings wetlands (CT)
Last input of mine tailings	None	1993	2001	2004[c]
Degree of bioremediation	Reference site	Complete	Maturing	Newly reclaimed
NAs[d]	0.3	10.3	51.9	68.0
Parent PAHs[e]	81.5	140.1	207.7	
Alkylated PAHs[f]	175.9	1,010.0	2,273.1	

[a] Unavailable for CT.

[b] Reference site.

[c] Received tailings through a discharge pipe throughout the study period.

[d] Measured in water collected in 2003 (milligrams per liter) by Golder Associates, 2004, and by M. MacKinnon, Syncrude Research Facility.

[e] Measured in sediments collected in 1998 (nanograms per gram). Source: Smits et al. (2000).

[f] Total of C1–C4 naphthalenes, C1–C4 fluorenes, C1–C4 phenanthrenes/anthracenes, C1–C4 fluoranthenes/pyrenes, and C1–C3 dibenzothiophenes; summarized from Smits et al. (2000).

reproduced here for descriptive purposes (Table 1).

Poplar Creek (PC, Reference Site): PC is a 125-ha reservoir located approximately 10 km south of mining operations (Fig. 1). It was created in 1975 when a river flowing through the area to be developed for mining had to be diverted before beginning operations. It does not contain any mine tailings. Concentrations of NAs and PAHs at this site (Table 1) are typical of those of natural lakes in the Athabasca region (Smits et al., 2000).

Demonstration Pond (DP, Syncrude): DP is a round 4- to 5-ha test pond that was constructed in 1993 (Fig. 1). It was filled with a 9-m-deep layer of mine tailings, on top of which diverted stream flow was added. This site is the oldest experimental site studied in this project, and concentrations of NAs as well as PAHs have substantially decreased over time (Table 1).

Natural Wetlands (NW, Suncor): The NW, on Suncor's lease, is adjacent to a large tailings pond (Fig. 1). Precipitation and dikes seepage gradually filled the 1.3-ha depression in 1984. Tailings were pumped from the tailings pond into NW between 1999 and 2001. This site is representative of maturing reclaimed wetlands, where microbial activities have led to some degree of bioremediation.

Consolidated Tailings Wetlands (CT, Suncor): CT, on Suncor's lease, are adjacent to the same tailings pond as NW (Fig. 1). This site was created in 1999 by flooding a 52-ha area with consolidated mine tailings. Since then, the wetlands have received tailings from the

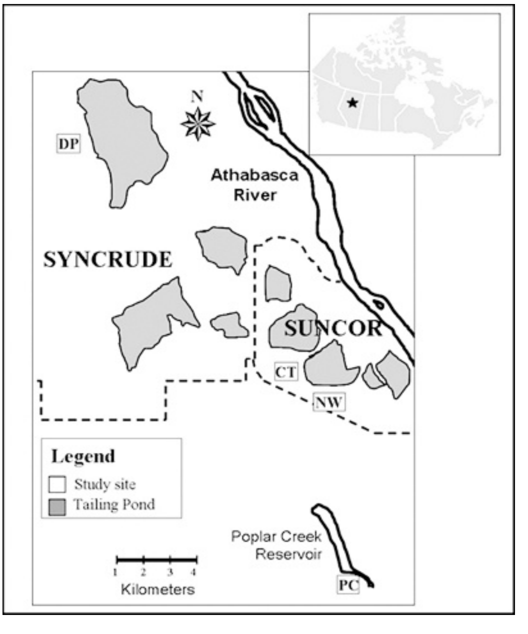

FIGURE 1. Map of the study area, showing the mining leases, tailings ponds, and study sites. The inset on the upper right corner shows the location of the oils sands in Canada. PC=Poplar Creek (reference site), DP=Demo Pond (Syncrude); NW=Natural Wetlands (Suncor); CT=Consolidated Tailings wetlands (Suncor).

settling basin through a discharge pipe. Because of this fresh input, this site is representative of early stages of reclamation. Concentrations of NAs are the highest among our study sites (Table 1). Concentrations of PAHs have not yet been measured in CT, but considering that it is the newest reclaimed site, they would likely be higher than that on the other study sites.

Monitoring of tree swallow activity

Tree swallows bred in wooden nest boxes located within 15 m of the shorelines of the wetlands; nest boxes were spaced 15–20 m apart. These nest boxes support well-established colonies that have been routinely monitored by researchers since 1995 on NW (n=21 boxes), since 1997 on PC (n=26 boxes) and DP (n=20 boxes), and since 2003 on CT (n=25 boxes). Old nest material has been cleared from all boxes in the spring every year since boxes were erected, except from 2000 to 2002. For this study, breeding activity was monitored from 19 May to 15 July 2004. Nest boxes were inspected daily during the laying period to determine the date of clutch initiation. Completed clutches were left undisturbed until hatching of the nestlings, and then clutches were monitored daily until the maximum number of eggs had hatched to determine brood size. Each nestling was uniquely identified with different color combinations on the claws. Nestling weight and wing length (carpus to end of longest primary feather) were measured on day 6 (D6) and D12 (hatch day=day 1). Although nestling tree swallows normally leave the nest between D18 and D21, those that survived to D14 were considered "fledged" for the purpose of this study, because disturbing them after that age can cause premature fledging.

Nest and nestling examination

Nestlings were systematically examined on D12 to record numbers of skin lesions induced by feeding larvae (pinpoint reddish brown scabs on the skin or at the base of emergent feather shafts). Within 7 days of the birds' fledging, nest material was collected and placed individually into sealed plastic bags until examination. Blow fly identification was conducted using keys described in Whitworth (2002). Voucher specimens were submitted to the Washington State Museum, Pullman, Washington, USA (Voucher #2007-1). Bag content was emptied on a large sheet of white paper and nest material was dissected to count pupae and empty puparia (outer shell left after the adult fly emerged). In this article, we report total puparia, because the nests contained mostly empty puparia at the time of examination. Mean nestling load reported here is based upon total puparia in a given nest divided by the number of nestlings occupying this nest (total puparia/brood size). All protocols used in this study were approved by the Animal Care Committee at the University of Saskatchewan (ACACS 2004 0042), in compliance with standards set by the Canadian Council on Animal Care.

Statistical analysis

Multilevel models are designed to analyze clustered data (e.g., chicks clustered within broods), by using statistical equations that properly include all the appropriate dependencies (Hox, 2002). In this study, we used multilevel analysis (SAS for Windows, version 8.02, SAS Institute, Cary, North Carolina, USA) to detect associations between SITE and parasitologic endpoints, accounting for the lack of independence among chicks from the same brood in each model. Associations between SITE and continuous outcomes (nestling weight, wing length, and mean parasite load) were analyzed using linear mixed models (PROC MIXED, SAS), and associations between discrete outcomes (puparia counts and skin lesions) were analyzed using Poisson distribution models (PROC GENMOD, log link function, SAS). Because infestation can increase over the breeding season and larger broods may attract more blow flies (Hurtrez-Boussès et al., 1999; Wesolowski, 2001), hatch date and brood size were included in the models as covariates when $P \leq 0.05$ or when inclusion of the factor in the model changed the P value by more than 10%.

RESULTS

Patterns of *Protocalliphora* infestation

Fifty tree swallow breeding pairs nested on the study sites in 2004. We inspected 246 nestlings (12 days old) for larval feeding lesions (scabs), and 38 nests were collected for examination. Of the nests examined, 100% were infested with one or more *Protocalliphora* species. The most common species was *Protocalliphora sialia* Shannon & Dobroscky; *P. bennetti* Whitworth was present in lower numbers. One nest had two *P. braueri* Hendel pupae. Mixed infestations (with two species or

TABLE 2. Intensity (mean±SD)[a] of *Protocalliphora* infestation.

Nest burden		Poplar Creek (PC)[b]	Demo Pond (DP)	Natural Wetlands (NW)	Consolidated Tailings wetlands (CT)
Total puparia	Mean	44.1±24.2A	75.0±19.2B	76.0±38.0B	70.6±22.0B
	Range	9–75	35–95	30–125	40–100
Puparia/brood size	Mean	6.8±3.5A	14.7±3.4B	15.1±7.9B	11.5±2.9B
	Range	2–12	9–19	7–25	6–14
n[c]		17	7	5	9

[a] Different uppercase letters indicate a statistically significant difference ($P \leq 0.05$).

[b] Reference site.

[c] n is number of nests.

more) occurred in 59% of the nests. Nest burden varied from nine puparia (on PC) to 125 puparia (on NW), and mean nestling load (puparia/brood size) ranged from two to 25 (Table 2).

Hatch date was not associated with the number of puparia in a nest ($\chi^2=1.40$, $P=0.2$) or with mean nestling burden ($\chi^2=2.03$, $P=0.2$), but nestlings hatched later in the season exhibited more lesions ($\chi^2=9.75$, $P=0.002$). Brood size was not associated with nest burden ($\chi^2=0.52$, $P=0.5$), mean nestling burden ($\chi^2=2.92$, $P=0.09$), or scab count ($\chi^2=0.97$, $P=0.3$). The number of skin lesions on a nestling (Table 3) was not correlated with the total number of puparia in the nest where it was reared ($\chi^2=2.46$, $P=0.1$) or with its mean nestling load ($\chi^2=3.33$, $P=0.07$).

Protocalliphora infestation was greater in nests on OSPM-impacted wetlands compared with those from the reference site (Table 2). Compared with PC reference site, nests from DP ($Z=3.39$, $P=0.0007$), NW ($Z=2.29$, $P=0.02$), and CT ($Z=2.91$, $P=0.004$) harbored 1.6 to 1.7 times more puparia. Mean nestling burden of parasites was 2.2 times heavier on DP ($\chi^2=9.98$, $P<0.0001$) and NW ($\chi^2=17.37$, $P<0.0001$) than on PC, whereas it was 1.7 times higher on CT than on PC ($\chi^2=8.49$, $P=0.004$). Mean numbers of skin lesions on nestlings from reclaimed wetlands seemed to be higher than on those from the control site (Table 3), but site differences were no longer significant after inclusion of hatch date as a covariate in the model ($\chi^2=6.85$, $P=0.08$).

Nestling growth

Nestling body mass at 12 days of age (Table 4) was not associated with brood size ($F=0.13$, $P=0.7$) or hatch date ($F=3.53$, $P=0.06$). Nestlings on reclaimed wetlands were significantly lighter than those on the reference site. On CT, they weighed 1.1 g less than those on PC ($t=-2.16$, $P=0.03$); and on NW ($t=-2.15$, $P=0.03$) and DP ($t=-2.76$, $P=0.01$), they weighed 1.4 g less than those on PC. Nestling body mass decreased as numbers of puparia in nests increased ($F=13.62$,

TABLE 3. Skin lesions (mean±SD)[a] on tree swallow nestlings.

	Poplar Creek (PC)[b]	Demo Pond (DP)	Natural Wetlands (NW)	Consolidated Tailings wetlands (CT)
No. of lesions	4.2±3.4A	8.5±7.4A	8.7±7.9A	9.9±8.5A
Range	0–19	0–38	0–30	0–29
n[c]	112	53	26	55

[a] Different uppercase letters indicate a statistical difference ($P \leq 0.05$).

[b] Reference site.

[c] n is number of nestlings.

TABLE 4. Weight and wing length of 12-day-old tree swallow nestlings (mean±SD).[a]

	Poplar Creek (PC)[b]	Demo Pond (DP)	Natural Wetlands (NW)	Consolidated Tailings wetlands (CT)
Weight day 12 (g)	24.08±1.56A	22.68±1.61B	22.66±2.42B	22.95±1.73B
Wing length day 12 (cm)	5.0±0.4A	4.9±0.3A	4.8±0.5A	4.8±0.5A
n[c]	84	53	26	55

[a] Different uppercase letters indicate a statistically significant difference ($P \leq 0.05$).

[b] Reference site.

[c] n is number of nestlings.

$P=0.0003$) and as mean individual burden increased ($F=13.33$, $P=0.0004$), but the number of skin lesions was not correlated with nestling weight ($F=0.22$, $P=0.6$). Wing length of nestlings at 12 days of age (Table 4) was not associated with brood size ($F=1.09$, $P=0.3$) or hatch date ($F=0.40$, $P=0.5$), and it was not different among sites ($F=0.97$, $P=0.4$). Wing length was not associated with nest loading ($F=1.95$, $P=0.2$), mean nestling burden ($F=0.15$, $P=0.7$), or number of skin lesions ($F=0.51$, $P=0.5$).

Figure 2 illustrates the effect of nest parasitic burden on nestling weight. On the three reclaimed sites, nestling weight decreases as nest burden increases, whereas it seems relatively unaffected by parasitism on PC. When data were analyzed separately for the reference site and the reclaimed wetlands, body mass was not associated with nest burden on PC ($F=0.10$, $P=0.8$). However, there was a strong negative correlation between body mass and parasitism on OSPM wetlands ($F=13.29$, $P=0.0004$). This strongly suggested the presence of a statistical interaction between site and nest burden; therefore, the effects of site and nest burden on nestling weight were compared simultaneously. In spite of the biological evidence, the interaction was not statistically significant ($F=2.23$, $P=0.09$). This was likely driven by the small sample size on each of the reclaimed sites. When the combined effects of site status (reference versus OSPM) and nest burden on nestling weight were examined, the interaction between site status and nest burden became significant ($F=6.60$, $P=0.01$).

Nestling survival

Only four nestlings died during the course of the study, and mortality did not differ across sites ($\chi^2=0.43$, $P=0.5$). Whether a nestling survived to fledging or died was not related to its number of skin lesions ($\chi^2=2.01$, $P=0.2$), to the number of puparia in the nest from which it was reared ($\chi^2=0.54$, $P=0.5$), or to the mean nestling burden of its brood ($\chi^2= 0.94$, $P=0.3$).

DISCUSSION

Patterns of infestation

Total nest burden (puparia/nest) and nestling load (puparia/brood size) on our study sites were comparable with what has been reported for tree swallows (Rogers et al., 1991; Bennett and Whitworth, 1992; Roby et al., 1992; Thomas and Shutler, 2001; Dawson et al., 2005). However, the prevalence of infestation (100%) on our study sites was surprisingly high for tree swallows and for other species of small cavity nesters. The aforementioned studies reported prevalences ranging from 54% to 89%. In other species of small cavity nesters, the highest prevalence (96.5%) has been documented in one population of Corsican blue tits (Hurtrez-Boussès et al., 1999). It is difficult to determine the exact cause for such a high prevalence in our area, because the ecological factors that regulate *Protocalliphora* populations and that influence the prevalence and intensity

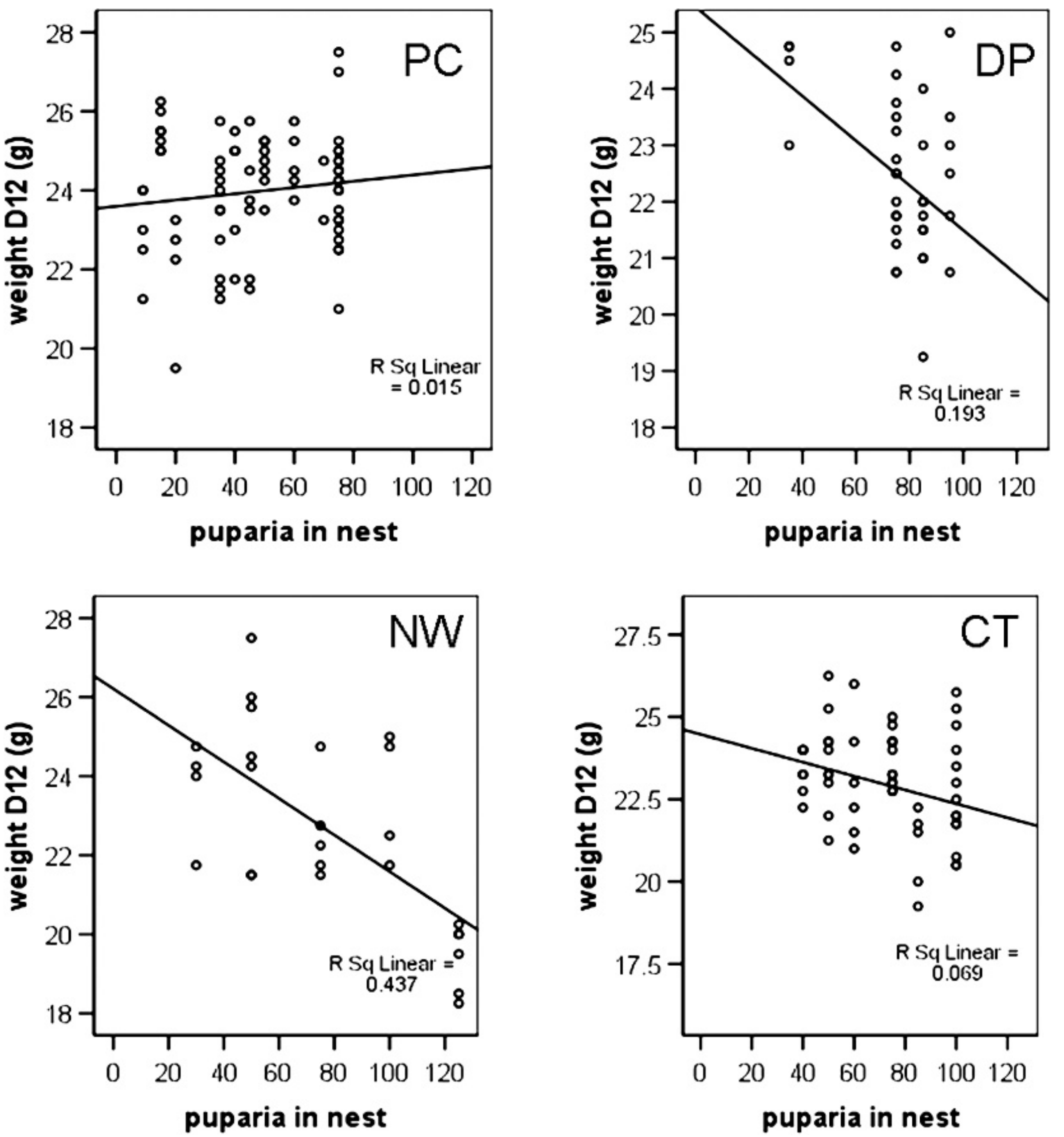

FIGURE 2. Nestling weight at day 12 in relation to nest parasitic burden. On the three oil sands sites (CT, DP, and NW), nestling weight decreases as nest burden increases, whereas nestling weight is unaffected by parasitism on the reference site (PC). PC=Poplar Creek; DP=Demo Pond; NW=Natural Wetlands; CT=Consolidated Tailings wetlands.

of infestations are still poorly understood. One possibility could be that there is a relative shortage of suitable cavities and consequently cavity-nesting birds in the area, which could explain why female blow flies were so attracted to our nest boxes. Indeed, the bitumen of the Athabasca oil sands is mostly harvested using open pit mining, which involves large-scale removal of boreal forest and topsoil to access the resource. Most of the leases that are currently being mined are devoid of trees. New trees have been planted in some reclaimed areas, but it will take decades before these trees are large enough to harbor natural cavities.

Mixed infestations on our sites were very common. Tree swallow nests in northern British Columbia also had high rates of mixed infestations; 66% of the nests harbored two or more species (Dawson et al., 2005). In contrast, Bennett and Whitworth (1992) found only 12.5% of the nests from the Great Lakes region of Ontario and 6.5% of the nests from Utah to have mixed infestations. Whitworth (1976) found that new nest boxes are rarely as infested as older nests. This trend was not verified on our study sites. Nests from the oldest colony (NW, 1995) were as heavily infested as those from the newest colony (CT, 2003). Nest boxes were erected on both DP and PC in 1997, but infestation was much heavier on DP than on PC.

Blow flies on OSPM sites: habitat characteristics

Nests and nestlings on all three OSPM-impacted sites exhibited much heavier infestation than those on the reference site. Perhaps habitat characteristics specific to each study site influenced blow fly abundance. Bennett (1957) first suggested that blow flies may be deterred by exposure to wind and rain, and Heeb et al. (2000) experimentally showed that humid nests were less likely to be infested with *Protocalliphora* than dry nests. Recently, Dawson et al. (2005) found that numbers of larvae in nests varied in a curvilinear manner with temperature (i.e., larval populations decreased when temperatures decreased below 25 C and increased above 25 C), possibly because of negative effects of cold and heat on survival of larvae. Nest boxes on the reference site are perched facing the water on the shore of a 125-ha lake. During episodes of inclement weather, strong winds over the lake pushed the rain into entrance holes, which often dampened the nests and the chicks. Exposure to wind and rain could have explained the smaller parasitic loads on this site, except that the same effect was not evident on DP, although boxes faced the 5-ha pond and there was no sheltering vegetation at that site. Yet, nestling burden on DP was more than twice that on PC.

It has been shown that the volume and quality of nest material are limiting factors in the survival of *Protocalliphora* larvae, possibly because of their need for absorbent material to isolate them from their excrements, which are toxic to them (Whitworth, 1976). Because recent research found no correlations between nest volume and *Protocalliphora* abundance (Rendell and Verbeek, 1996b, Hurtrez-Boussès et al., 1999), nest material was not quantified in this study. Nevertheless, an objective measure of nest volume should be included in future research. High nest density has been shown to increase the rate and intensity of infestation with *Protocalliphora* (Brown and Brown, 1986, Shields and Crook, 1987). Nest density was no greater on OSPM sites than on the control site. Moreover, PC had the highest number of boxes and the highest nest density, but it was the least infested.

Blow flies on OSPM sites: host characteristics

The immune responses of the host exert a critical role against ectoparasites. Proteins present in saliva of hematophagous arthropods are foreign antigens, which elicit potent localized immune responses, mediated by Langerhans cells in the skin, T and B lymphocytes, IgG and IgE antibodies, cytokines, and inflammatory cells (Wakelin, 1996; Wikel and Alarcon-Chaidez, 2001). Ectoparasites feeding on resistant hosts may detach from the host (Pruett, 1999), show stunted growth (Bowles et al., 1996), inhibited molting (Wikel and Bergman, 1997), and decreased fecundity (Walker et al., 2003). The immune responses are also systemic; thus; they are potentially costly to the nestlings. Interestingly, Simon et al. (2003) recently showed that *Protocalliphora* larvae aggregate on the smallest chicks of a brood, which tend to be less immunocompetent than their siblings (Christe et al., 1998). Several environmental contaminants are known to affect the immune system of wildlife (reviewed by Fairbrother et al., 2004). If chemicals present in OPSM were affecting the immune function of nestlings, perhaps parasitic larvae feeding on those nestlings would have greater survival rates than those developing on chicks with normal immune defenses, partly explaining the larger parasitic loads on reclaimed sites.

A small number of studies have demonstrated relationships between pollution and parasitism. Prevalence of infection with a parasitic nematode increased in frogs experimentally exposed to pesticides (Christin et al., 2003), and residual numbers of nematodes were positively correlated with residual mercury concentrations in common eiders collected in the Canadian Arctic (Wayland et al., 2001). Eeva et al. (1994) found no changes in ectoparasite burden of birds nesting along a gradient of air pollution, but Moles and Wade (2001) documented an increased prevalence of gill ectoparasites in fish exposed to high levels of PAHs. The number of nematodes in arctic breeding glaucous gulls increased with tissue-organochlorine levels (Sagerup et al., 2000), and it was later demonstrated that humoral immunity was impaired by organochlorines in this gull population (Bustnes et al., 2004).

It is premature to conclude that compromised immune responses resulting from exposure to OSPM chemicals was responsible for severe blow fly parasitism on reclaimed wetlands, because immune function of nestlings was not evaluated in this project. On the basis of our data, we suggest that other ecological factors also were involved, because there was not a clear relationship between the intensity of parasitism and the gradient of contamination of the different sites with oil sands materials. Parasitic loads were not heavier on the most newly reclaimed site (CT), which had the highest concentrations of NAs and presumably PAHs, than on the oldest experimental site (DP), in which bioremediation had been undergoing for 10 yr and in which concentrations of NAs and PAHs were low. We suspect that ongoing mining activities cause a substantial disturbance of several components of the local ecosystem, altering the balance of this host-parasite relationship.

Nestling fitness and blow fly infestation

Two measures of size (weight and wing length) were used as indicators of growth and fitness in this research. Whereas wing length was not different among sites, nestlings on OSPM wetlands weighed from 4% to 5% less than those from the control site. Nestling weight was negatively correlated with increasing parasitic load on reclaimed wetlands but not on the control site. These findings contrast with those from previous research with tree swallows in which nestling weight gain was generally not impaired, even for parasitic burdens comparable with what was observed on OSPM sites in this study (Rogers et al., 1991; Roby et al., 1992; Rendell and Verbeek, 1996a; Thomas and Shutler, 2001). On the basis of our results, we suggest that nestlings reared on OSPM wetlands did not tolerate blow fly infestation as well as nestlings unchallenged by contaminants. Simon et al. (2004) showed that infestation with *Protocalliphora* spp. alter metabolic capacities of nestlings. Perhaps heavily parasitized nestlings would be unable to allocate energy to both detoxification efforts and normal weight gain, or they may be redirecting energy from soft tissue accretion into immune responses against ectoparasites. Decreased weight gain may represent a strategy for surviving multiple stressors. Alternatively, there may be a threshold for parasitic burdens below which no compromise of growth is seen, and average nest burden on PC may have been below this threshold. Regardless of cause, nestlings from reclaimed wetlands may have to undergo compensatory gains before or just after fledging, and those that are unable to do so may suffer lower postfledging survival because of smaller body size, because postfledging survival is often correlated with body mass at fledging (Naef-Daenzer et al., 2001).

Blow fly infestation did not affect nestling survival in this study. Although an association between *Protocalliphora* parasitism and compromised fledging success has been reported in a few studies (Shields and Crook, 1987; Puchala, 2004), most of the recent research failed to correlate infestation with decreased survival (reviewed by Simon et al., 2004). However, most of these studies, including ours, were conducted under favorable meteorological conditions. It has been shown that the negative impacts of ectoparasites can be exacerbated during periods of harsh weather (Dufva and Allander, 1995). More research is needed to investigate the effects of synergistic stressors in wild birds, such as ectoparasitism, hypothermia, food shortage, and exposure to toxic chemicals. A widespread nestling die-off related to an episode of cold temperatures synchronized with persistent rain was documented on our study sites in 2003 (Gentes et al., 2006). It would have been very valuable to measure parasite load of nestlings during that die-off, because chances are that heavy blow fly infestation contributed to nestling mortality.

In conclusion, around Fort McMurray, northeastern Alberta, Canada, prevalence and intensity of infestation with the bird blow fly *Protocalliphora* spp. were measured in tree swallow nests on sites affected by oil sands mining. We documented one of the highest prevalence of nest infestation (100%) with blow flies for this bird species. Nests on experimental wetlands partly filled with waste materials from the oil sands extraction process (i.e., containing sand, water, unrecovered bitumen, polycyclic aromatic hydrocarbons, and naphthenic acids) were 60% to 72% more heavily infested than nests on a control site. Nestlings on oil sands reclaimed sites suffered mean parasitic burdens approximately twice as heavy that of those on the reference site. Nestling growth was negatively affected by parasite load on oil sands sites but not on the reference site. High infestation with blow flies on oil sands reclaimed sites may be linked with the disturbance of several components of the local ecosystem by mining activities, including habitat, availability of suitable host species, and modulation of host resistance, which may all be altering the balance of this host-parasite relationship. These findings raise questions regarding the sustainability of reclamation strategies currently planned by the oil sands industry. More research is needed to determine whether this occurring every year or whether it was a temporary phenomenon, and to characterize the factors affecting infestation as well as the impact of host fitness. This study highlights the value of incorporating parasite monitoring into wildlife toxicology research, in addition to the traditional endpoints.

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