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IMPACT OF OIL-SANDS BASED WETLANDS ON THE GROWTH OF MALLARD (*ANAS PLATYRHYNCHOS*) DUCKLINGS

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Abstract—Identifying the potential effects of industrially formed wetlands on waterfowl populations is important for assessing the suitability of such wetlands in industrial reclamation strategies. Mallard ducklings were held in situ on two industrially formed wetlands and one reference wetland in northern Alberta, Canada. Duckling mass and skeletal size were measured at regular intervals over 33 d, and blood was collected to investigate the analysis of plasma metabolites (triglyceride and glycerol) as an indicator of physiological condition. In repeated-measures analysis of variance (ANOVA), multivariate ANOVA, and subsequent multiple-comparisons tests, body mass and skeletal size were significantly lower in ducklings maintained on the industrial wetland after 2, 5, 9, and 13 d of exposure. In this situation, plasma metabolite analysis did not provide additional information on mass-independent condition. We conclude that if the observed differences in growth and size translate into a decreased survival of juvenile waterfowl inhabiting these wetlands, then populations of these birds in the area could be negatively affected. We emphasize the importance of field-based ecological research in toxicological studies of wildlife.

Keywords—*Anas platyrhynchos* Duckling Wetlands Ecotoxicology

INTRODUCTION

Oil-sands mining and extraction is the primary economy in the Fort McMurray area of northeastern Alberta, Canada, accounting for approximately 15% of Canada's total oil production. The current process for the recovery of oil from the sands involves the Clark hot-water extraction method, which simply separates the bitumen from the sand through flotation. The recovered bitumen is subsequently upgraded to sweet crude oil. The remaining by-products form a tailings slurry comprised of a fine-particulate or fine-tailed hydrocarbon solid, sand, water, and unrecovered bitumen of no economic value. Large volumes of this slurry are produced each year [1–3], with more expected as the mining industry continues to expand.

Currently, the tailings slurry is stored in retaining ponds constructed from massive dykes made of leftover sand from the extraction process. This sand has been affected by the extraction procedures such that the interstitial spaces are charged with both wastewater and industrial contaminants. As the dykes compress because of their great mass, dewatering occurs. Consequently, wetlands form peripheral to the dykes with a water composition of approximately 80% of the original tailings slurry [1]. These wetlands contain traces of unrecovered bitumen and other by-products of the oil-sands mining processes (e.g., high sulfates, naphthenic acids, and salinity) [1–3].

In addition to wetlands formed as a consequence of the uncontrolled seepage from the earthen dykes, some wetlands are intentionally created by the oil-sands industry as part of the mine closeout procedures. These wetlands are to receive consolidated tailings effluent (CTE), another by-product of the oil-sands extraction process. In this case, the tailings slurry receives calcium sulfate to accelerate flocculation of the fine tails and other chemical constituents. As the fine tails consolidate, they dewater, generating CTE that contains high concentrations of sulfate and naphthenic acids.

In a previous paper [2], we reported on the ecological viability of such wetlands created from oil-sands effluent. The conclusion from that study was that the wetland ecosystems that had developed in response to oil-sands effluent were capable of supporting low-diversity benthic communities dominated by the Chironomidae and semiaquatic plants, such as cattail. However, fish [2] and amphibians [3] would be unable to survive. Importantly, the type of wetland community that would become established in response to the oil-sands effluent would be a habitat highly suitable to migratory waterfowl and insectivorous birds. Hence, an important recommendation generated from the study of Bendell-Young et al. [2], which serves as the objective of the present study, was to evaluate the potential impacts of such wetlands on the avian fauna that would use them for breeding.

To meet this objective, we reared juvenile ducklings on wetlands created from oil-sands effluent, and we compared their rates of growth to those of ducklings held on a reference wetland. Blood samples were taken from the ducklings, and plasma metabolites (triglyceride and glycerol) were assayed to determine if such measurement would provide useful additional information regarding mass-independent physiological condition [4,5]. This paper presents the findings regarding the differences in growth and plasma metabolite profiles be-

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Table 1. Relevant water chemistry for the three wetlands (AB, Canada)[a]

Parameter	NW	HU	SI
pH	8.2 ± 0.057	7.75 ± 01	8.5/8.4
Conductivity μS/cm	1,318.3 ± 37	2136.0 ± 76	745/647
Sodium (Na)	344.3 ± 10	39.18 ± 28	66/63
Sulfate (SO_4)	182.6 ± 28.9	643.6 ± 39	36/33
Ammonia (NH_3)	2.61 ± 0.52	2.75 ± 0.24	0.025/0.025
Naphthenic acids	60.8 ± 5.7	62.1 ± 2.89	0.5/0.5

[a] For the wetland formed from dyke seepage effluent (NW) and the western hummock zone formed from consolidated tailings effluent (HU), values are the mean ± standard error of six measurements during July ($n = 3$) and August. For the reference wetland (SI), values are replicate measures taken once each in July and August.

tween exposed and reference birds. Growth was measured as the change in overall body mass, length and depth of bill, and length of tarsus and wing cord. Growth was chosen as an endpoint for assessing the suitability of oil-sands based wetlands as habitat, both because it provides for a low measurement error [6] and because a strong link has been demonstrated between body morphology and survival and reproductive success [7–10]. From such a comparison, we hope to assess whether oil-sands based wetlands can provide suitable habitat for breeding of avian fauna.

MATERIALS AND METHODS

Study Area

The study area was located in the Athabascan oil-sands region (the largest of four oil-sands areas in northeastern Alberta, Canada), Suncor Oil-Sands Group, Lease 86. This lease land is approximately 25 km north of Fort McMurray, on the western bank of the Athabasca River. The region is part of Alberta's taiga forest zone and is comprised of both undulating plains and some upland areas. The undulating plains are characterized by muskeg soil and wetlands containing black spruce (*Picea mariana*), willow (*Salix* spp.), birch (*Betula* spp.), and sphagnum moss (*Sphagnum magellanicum*). The higher, well-drained areas are primarily vegetated with white spruce (*Picea glauca*), aspen (*Populus* spp.), and jack pine (*Pinus contorta*). The taiga zone typically has long, severe winters (−54 to −1°C) and short summers (−7–21°C) [11].

Three different experimental wetlands were used for the present study, including a wetland formed from dyke seepage effluent (natural wetland [NW]), the western hummock zone formed from CTE (HU), and a reference wetland located off of the lease and east of Highway 63 (SI). Relevant water chemistry for the three sites is presented in Table 1.

The dyke seepage wetland, or NW, formed in the mid-1980s on the eastern side of one of the tailings ponds as a result of seepage from a large dyke that surrounded the tailings pond. Because it was formed through dyke seepage rather than constructed, this wetland is referred to as being natural (i.e., NW). Admittedly, this designation is confusing, in that *natural* would normally refer to a nonimpacted site. However, to maintain consistency among the various studies conducted within this region of the oil sands (see, e.g., [2,3]), we have retained this terminology to describe this site. In addition to dyke seepage water, the wetland also receives surface runoff water and groundwater [12]. In 1998, the surface area of NW was approximately 1.3 ha, of which approximately 70% was open water. The NW is a direct result of industrial activity in the Athabasca region and most likely will persist, remaining an integral part of the final reclaimed landscape. Evaluating the quality of this habitat is critical in considering reclamation strategies. The western hummocks zone study site (i.e., HU), which is located west of NW, was created specifically by Suncor Oil-Sands Group to study the efficacy of a tailings slurry detoxification technique. This grassy area has been intentionally flooded with CTW periodically since 1996. After being discharged, the CTE became distributed along natural gradients in the area and, consequently, mixed with dyke drainage water, surface runoff, and groundwater in the area. This has led to the formation of several shallow pools throughout the grassland. Ideally, this landscape represents a simulation of the final reclaimed ecosystem and will provide insight regarding the acceptability of a wet-landscape reclamation strategy. The Highway 63 reference wetland (i.e., SI) is located approximately 2 km south of the active oil-sands Lease 86. In 1963, the excavation of gravel left an empty borrow pit at this site. The area slowly became vegetated, and a shore marsh–type wetland formed at the edge of the lake that filled in the pit. The lake is similar to NW in that it is primarily open water and is surrounded by aquatic vegetation and shrubs. However, the water in SI is deeper than that in NW. The SI wetland, as indicated by its water chemistry (Table 1), represents a relatively undisturbed ecosystem that is remote from industrial activity.

Growth

One-day-old mallard ducklings (mixed gender) from Whistling Wings (Hanover, IL, USA) arrived in Fort McMurray on May 19, 1998. After 48 h of acclimation, each bird was fitted with a metal-web identification tag and measured ($t = 0$ d; May 21). Body measurements obtained for each bird included body mass (± SE throughout) (pesola ± 0.3%), length of the left wing cord (±0.5 mm), length of the right tarsus (±0.025 mm), length of the bill (±0.025 mm), and depth of the bill (at thickest point, ±0.025 mm). Subsequent measures of growth were taken on May 23 ($t = 2$ d), May 26 ($t = 5$ d), May 30 ($t = 9$ d), June 3 ($t = 13$ d), June 9 ($t = 19$ d), June 15 ($t = 25$ d), and June 23 ($t = 33$ d). Birds were held in situ on NW, HU, and SI. Fifteen 3-d-old ducklings were placed into one of three stable, stainless-steel pens (182.9 × 182.9 × 121.9 cm) on each experimental site. Pens were placed such that at least one-third of the enclosed area included shoreline and open water of the wetland. Pens were open at the bottom, allowing ducklings free access to natural forage material (aquatic plants and invertebrates). Pens were modified such that elevated platforms (30 × 46 cm) and shelter boxes lined with straw were available inside each pen. For the first week of exposure, all ducklings were confined to their shelter boxes at night. Por-

tions of each pen also were provided with a roof so that ducklings had access to cover.

An important experimental aspect of the present study was that ducklings were provided Masterfeeds™ (London, ON, Canada) duck and goose starter (20% protein) ad libitum. This was to ensure that any detected differences in bird growth could be attributed to overall habitat effects rather than simply to differences in food accessibility (e.g., among-pen variation in invertebrate density) within the experimental cages. A hanging feeder was suspended from the roof of each pen so that the food was protected from water spoilage and was accessible to all ducklings. Additionally, the pens were moved every 5 d (within the experimental sites). This limited the environmental damage that could be done within one area, and it also allowed the ducklings to have continually renewed access to natural forage material.

Plasma metabolite measurements

Blood samples (1–3 ml) were taken from all ducklings at 13 and 33 d of age via the jugular vein using a heparinized syringe and 25-gauge, 0.5-in. needle. All blood was collected between 0600 and 1100 h, and handling times were 1 to 4 min. Whole blood was centrifuged and the plasma stored at −20°C until assayed. Plasma samples were assayed in duplicate for triglyceride and glycerol using a standard diagnostic assay (Kit 337-B; Sigma-Aldrich, Oakville, ON, Canada) following the manufacturer's protocol, except that assays were modified for use with small plasma volumes (5 μl). The interassay coefficient of variation was 11.5% ($n = 7$) and 18.1% ($n = 7$) for plasma triglyceride and plasma glycerol, respectively.

Assessment of toxicant exposure

At the termination of the study ($t = 33$ d), the ducklings were killed and necropsied. A subsample of 10 birds ($n = 5$ each from NW and SI) were randomly selected for immediate necropsy (i.e., within 2 min of death). Samples of bile were removed from the gallbladders of these birds using a 1-ml tuberculin syringe (27-gauge, 0.5-in. needle). Small (1- to 2-g) cross-sections of the left lobe of the livers of these birds also were removed and placed in Cryovac™ tubes (East Saddle Brook, NJ, USA). These samples were immediately frozen in liquid nitrogen (−173°C). Both bile and liver samples were sent to the National Wildlife Research Laboratory, Canadian Wildlife Service, in Hull, Quebec, for further analyses. The bile samples were analyzed for polyaromatic hydrocarbon (PAH) metabolites according to the methods described by Krahn et al. [13]. Metabolites of interest included pyrene, benzo[*a*]pyrene, naphthalene, and phenanthrene. Liver samples were analyzed for ethoxyresorufin *O*-deethylase (EROD) activity according to the techniques described in the Canadian Wildlife Service Laboratory Services Section Report [14]: BMK-EROD-98-01. Here, we use levels of EROD as a measure of induced cytochrome P450. The use and care of project animals conformed to guidelines specified by the Natural Sciences and Engineering Research Council of Canada and the Canadian Council on Animal Care.

Data analyses

All statistical analyses were performed using SAS software (SAS Institute, Cary, NC, USA) [15]. All graphs were produced in SigmaPlot (SPSS, Chicago, IL, USA) [16]. In all analyses, only data from birds that survived the duration of the experiment were used (Table 2). Exact causes of duckling mortality are unknown, but these deaths most likely resulted from aggression by other ducklings within the enclosures.

Table 2. Total number of male and female ducklings that survived the 33-d exposure[a]

Site (AB, Canada)	Surviving birds (*n*)		
	Females	Males	Total birds
Highway 63[b]			
Pen 1	4	4	8
Pen 2	2	4	6
Pen 3	5	6	11
Hummocks			
Pen 1	9	2	11
Pen 2	4	5	9
Pen 3	3	2	5
Natural wetland			
Pen 1	6	5	11
Pen 2	6	6	12
Pen 3	4	0	4

[a] Ducklings are separated by pen and by gender.
[b] Reference wetland.

Growth. Data were checked for normality and heteroscedasticity (procedure UNIVARIATE), and a multivariate analysis of variance (ANOVA) using the general linear model (GLM) was used to examine the effect of gender on duckling size. The model found that the effect was significant ($F_5 = 4.98$, $p < 0.0002$) and that this difference became more pronounced as the ducklings aged. Hence, data for male and female ducklings were analyzed separately. The GLM procedure was used on each dataset to examine intrasite variability. In general, pens within the sites were not found to have significantly different measurements for any of the growth parameters ($p > 0.05$); therefore, all pens within a site were pooled for both the female and the male ducklings. Sample sizes for the analysis are presented in Table 2.

The mass of the birds was compared by a repeated-measures analysis (mixed), and a Ryan-Einot-Gabriel-Welsch multiple-comparisons procedure (corrected for the number of comparisons) was used to group the data by site. Wing cord, tarsus, bill length, and bill depth measurements were analyzed as indicators of general body size. A multivariate ANOVA (GLM) was used to examine between-site differences of these dependent variables at each sampling time, and a Ryan-Einot-Gabriel-Welsch multiple-comparisons procedure (corrected for the number of comparisons) was used to group the data by site.

Plasma metabolites. As with growth, all plasma samples within a site were pooled for analysis. Glycerol was normally distributed (Shapiro-Wilks test, $p > 0.05$); however, triglyceride levels were nonnormal ($p < 0.001$) and were $\log_{10}$ transformed for analysis. A multivariate ANOVA (GLM) was used to determine if differences in plasma triglyceride and glycerol levels were dependent on body mass at 13 and 33 d of age or on gender. We observed no effect of duckling mass ($p > 0.05$) or sex on plasma triglyceride or glycerol levels at either age ($p > 0.15$ in all cases). Plasma metabolite levels also were independent of sex; hence, sexes were pooled for subsequent analysis. A multivariate ANOVA (GLM) on pooled data was applied to determine differences in plasma triglyceride levels between sites in ducklings at 13 or 33 d of age.

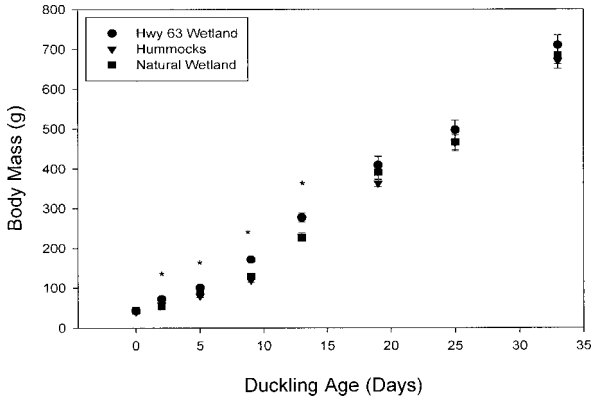

Fig. 1. Body mass as a function of time in female juvenile mallards. A repeated-measures analysis found that change in body mass was dependent on site ($F_2 = 2.92$, $p < 0.05$) and time ($F_7 = 235.1$, $p < 0.0001$). Values are presented as the mean ± standard error. Significant differences are denoted with an asterisk (*). Wetland sites are in Alberta, Canada.

Assessment of toxicant exposure. Both EROD and PAH metabolite data were examined for gender differences using a GLM procedure. The GLM also was used to determine site differences in activity of EROD in the liver and in concentrations of PAH metabolites in the bile. The PAH metabolites were analyzed as both independent (ANOVA) and dependent (multivariate ANOVA) variables.

RESULTS

Growth

We obtained data regarding total body morphology for 43 female and 34 male ducklings. The mass of female ducklings changed significantly over time ($F_7 = 235.1$, $p < 0.0001$) (Fig. 1). Site was significant in the model ($F_2 = 2.92$, $p < 0.05$,), with no significant interaction between site and time ($F_{14} = 0.91$, $p > 0.05$). The site effect was driven by the significantly higher masses of the SI females ($\alpha = 0.05$) between days 2 and 13. After 13 d, the masses of HU and NW birds were no longer significantly lower than the mass of SI birds. However, the general trend of bird mass for wetland SI > bird mass for wetland HU > bird mass for NW was observed until the termination of the present study.

Body size of the females (wing cord length, tarsus length, bill depth, and bill length) also showed a significant site effect at $t = 2$ d ($F_8 = 3.54$, $p < 0.002$), $t = 5$ d ($F_8 = 2.45$, $p < 0.02$), $t = 9$ d ($F_8 = 3.75$, $p < 0.001$), and $t = 13$ d ($F_8 = 2.59$, $p < 0.01$) (Fig. 2). Single-variable ANOVA values and Ryan-Einot-Gabriel-Welsch results show that this effect resulted primarily from differences in the tarsus and the bill length, with the wing cord and bill depth measurements being less sensitive (Fig. 2).

The male ducklings show the same general trend as the females (Figs. 3 and 4). Site and time were both significant factors in the repeated-measures model (site: $F_2 = 7.65$, $p < 0.0006$; time: $F_7 = 434.9$, $p < 0.0001$), whereas the interaction of site and time were not ($F_{14} = 0.95$, $p > 0.05$).

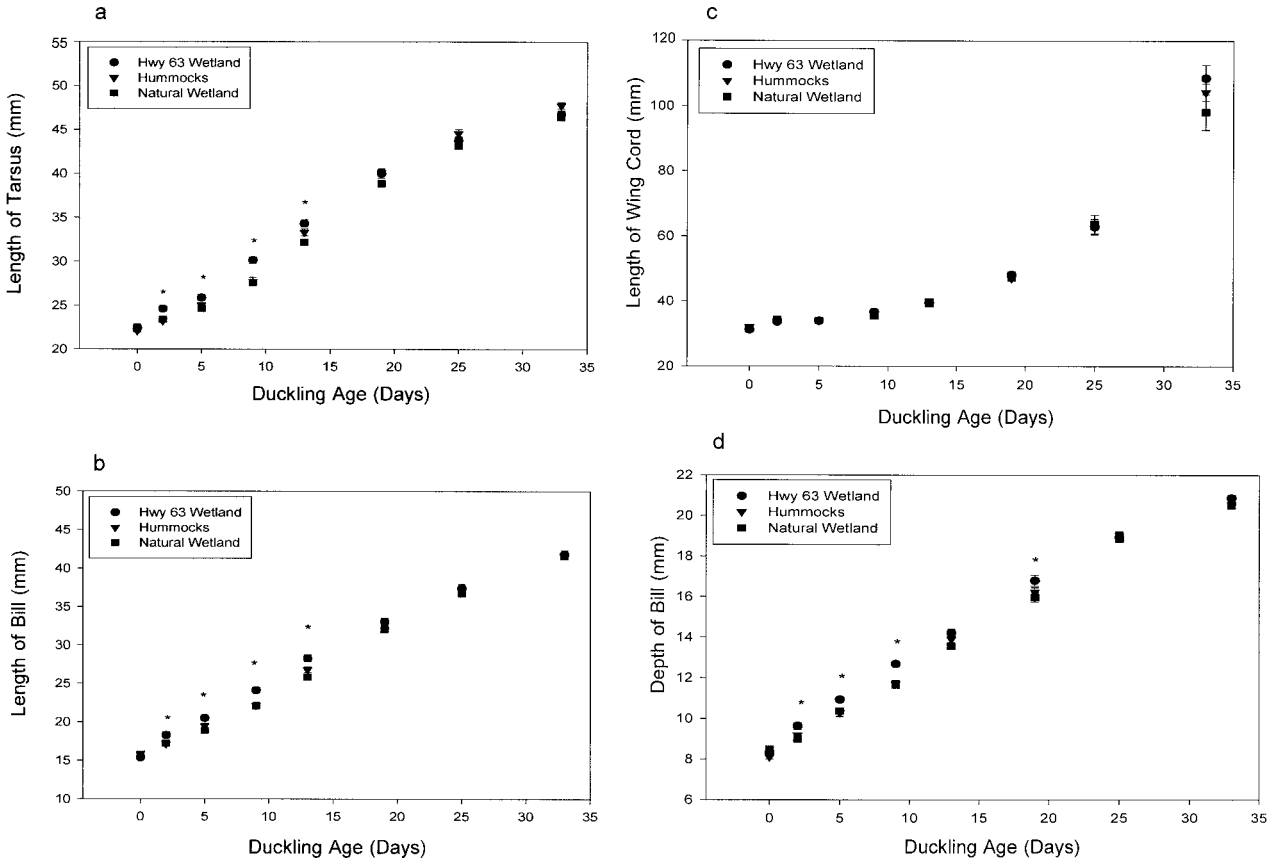

Fig. 2. Data regarding female tarsus (**a**), length of bill (**b**), wing chord (**c**), and depth of bill (**d**) are shown. Multivariate analysis showed a site effect for body size (as measured by wing chord, tarsus, bill length, and bill depth) at $t = 2$,5, 9, and 13 d. Significant differences are denoted with an asterisk (*). See text for full details. Wetland sites are in Alberta, Canada.

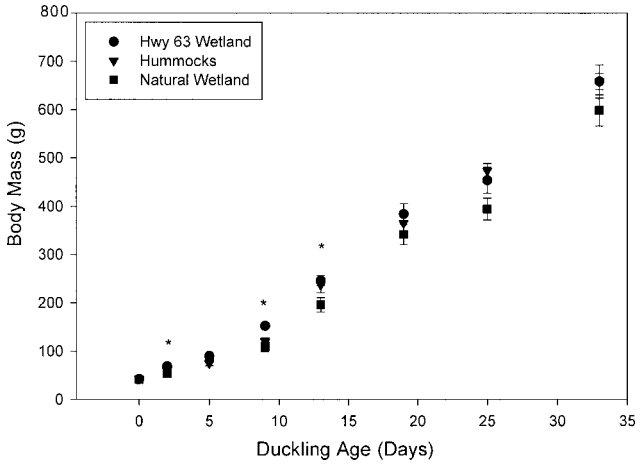

Fig. 3. Body mass as a function of time in male juvenile mallards. A repeated-measures analysis found that change in body mass is both site and time dependent (site: $F_2 = 7.65$, $p < 0.0006$; time: $F_7 = 434.9$, $p < 0.0001$). Values and asterisks (*) as described in Figure 2. Wetland sites are in Alberta, Canada.

Plasma metabolites

We found no difference in plasma triglyceride levels between sites in ducklings at 13 d ($F_2 = 0.39$, $p > 0.60$) or 33 d ($F_2 = 2.99$, $p > 0.05$) of age (Table 3). Plasma glycerol levels did differ significantly among sites in ducklings at 13 d of age ($F_2 = 4.74$, $p < 0.025$) but not at 33 d of age ($F_2 = 2.41$, $p > 0.05$). At 13 d of age, plasma glycerol levels were significantly higher at NW compared with both HU ($p < 0.01$) and SI ($p = 0.05$) (Table 4).

Evidence for toxicant exposure

Ducklings on NW did not appear to be exposed to significant levels of halogenated aromatic hydrocarbons (HAHs), as indicated by EROD activity (Table 4). However, ducklings were exposed to higher levels of PAHs, as indicated by metabolites of these compounds in their bile (Table 4).

DISCUSSION

Growth

Mallard ducklings held in situ on NW and HU weighed less than mallard ducklings that were held in situ on SI. Furthermore, length of tarsus, bill length, and bill depth were all smaller in ducklings held on NW and HU compared to those held on SI. This effect (SI > HU > NW) occurred for both females and males, although it was most obvious in the female ducklings. The values for body mass and size at all sites fall within the natural range of variability for game-farm mallards [17,18] but are slightly greater than those values reported for wild mallards [19].

Plasma metabolite analysis

Plasma triglycerides have been used successfully to estimate fattening rates in animals undergoing extreme lipogen-

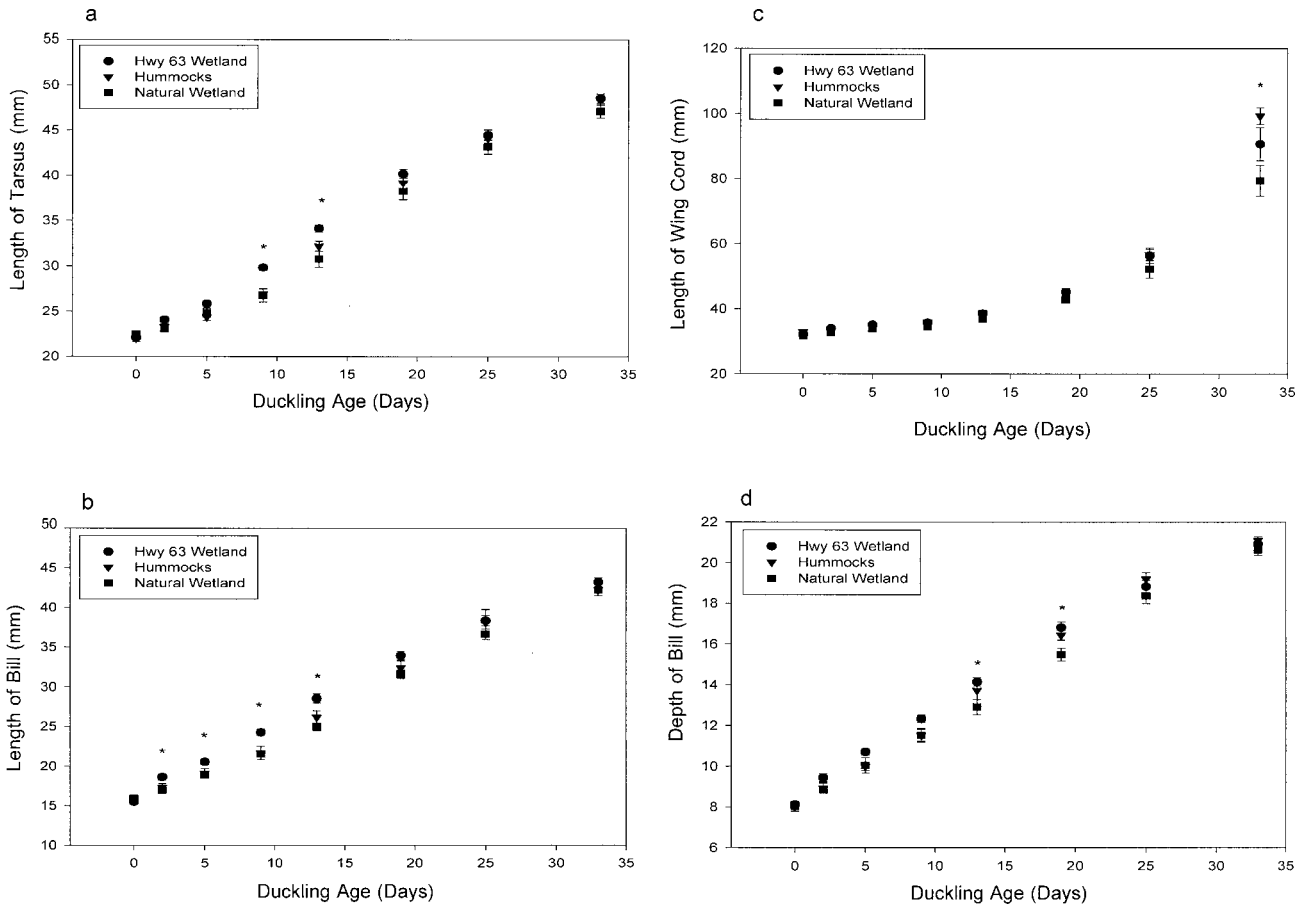

Fig. 4. Data regarding male tarsus (**a**), length of bill (**b**), wing chord (**c**), and depth of bill (**d**) are shown. Multivariate analysis showed a site effect for body size (as indexed by wing chord, tarsus, bill length, and bill depth) at $t = 2$, 5, 9, 13, and 19 d. Significant differences are denoted with an asterisk (*). See text for full details. Wetland sites are in Alberta, Canada.

Table 3. Variation in plasma triglyceride and glycerol levels in 13- and 33-d-old ducklings (where age is equivalent to days of exposure) reared at different sites[a]

Metabolite	Duckling age (d)	Site		
		HU	NW	SI
Triglyceride	13	1.01 ± 0.16	1.39 ± 0.24	1.29 ± 0.24
	33	1.31 ± 0.13	1.90 ± 0.26	1.35 ± 0.18
Glycerol	13	0.89 ± 0.03	1.05 ± 0.04	0.95 ± 0.04
	33	0.93 ± 0.09	1.23 ± 0.11	0.95 ± 0.11

[a] See text for details regarding sites. Values are the means ± standard error (n = 17–19). HU = hummocks; NW = dyke seepage wetland; SI = Highway 63 or the reference wetland (all sites in AB, Canada).

esis, such as during migratory fattening [5]. Here, we used plasma triglycerides as an indicator of mass-independent physiological condition. However, in contrast to duckling growth, plasma metabolite (triglyceride and glycerol) analysis either revealed no site differences (as in the case of triglycerides compared to growth measurements) or suggested site differences that were inconsistent with the growth data. Hence, differences in plasma triglyceride levels indicative of differences in rates of lipogenesis (fattening) or low plasma glycerol levels indicative of fasting or starvation were not detected. This suggests that metabolite analysis may be a poor indicator of condition or nutritional status in general among free-ranging animals, most of which will be in neutral or positive energy balance (see, e.g., [4]).

Extrinsic natural factors that influence the body morphology of waterfowl include density of food and dietary nutritional content [20–22]. However, all ducklings received supplemental feed ad libitum in addition to forage that they acquired from the wetlands, so any potential intersite differences in natural food availability could be accounted for in the present study. Alternatively, exposure to toxic substances, such as crude oil, a substance present within oil-sands wetlands, can affect morphological parameters [23] and could have been responsible, in part, for effects observed in the present study as discussed below.

Evidence for toxicant exposure

King and Bendell-Young [24] recently demonstrated that grit ingestion by juvenile mallards could be a significant route of contaminant exposure, specifically for oil-sand related compounds such as oil and grease. Based on known concentrations of oil and grease contained in oil-sands wetlands [12], King and Bendell-Young [24] determined that for a 21-d, 16-h foraging period, ducklings ingesting sediments from oil-sands based wetlands consume approximately 54.1 mg of oil and grease. To determine if ingestion of sediment by ducklings could result in exposure to oil-sands derived contaminants, we determined levels of EROD and of PAH metabolites. A detoxification enzyme, EROD commonly is used in toxicity studies as a biological marker of exposure to HAHs, such as dioxins and polychlorinated biphenyls [25,26,]. In the present study, the activity of EROD in livers of NW birds was approximately equal to that in reference birds. Furthermore, the range of EROD values for all ducklings in the present study was extremely low (4.17–13.97 pmol/min/mg protein) relative to those in other studies of mallards [27,28,], which report EROD values ranging from 93.5 to 715.2 and from 70 to 1350 pmol/min/mg protein, respectively. Hence, given the low values of EROD in the present study, HAH exposure on the study sites likely was minimal.

Exposure to PAHs, however, did occur. Two PAH metabolites, pyrene and naphthalene, were found at significantly increased concentrations in the bile of NW ducklings relative to that in SI ducklings. This suggests that these birds were exposed to higher levels of the parent PAHs, possibly through ingesting wetland sediment as grit, a consequence of these wetlands being based on oil-sands effluent containing high concentrations of bitumen, oil, and grease compounds that contain PAHs. Hence, differences in growth observed between ducklings reared on oil-sands wetlands versus reference wetlands could be attributed, in part, to the differential exposure to oil-sands based contaminants. Moreover, the most obvious natural factors that could lead to differences in growth rates (e.g., climate, temperature, and moisture) and food availability were controlled for by conducting the experiment in situ and by providing food ad libitum. This further supports the conclusion that the reduced growth in ducklings reared on oil-sands based wetlands results, in part, from increased exposure to oil-sands derived contaminants.

Implications

Rhymer [29] has noted that smaller ducklings have increased thermoregulatory challenges and that heavy mallard ducklings have to expend less energy per gram of body weight to maintain homeothermy. Cox et al. [10] showed conclusive evidence that survival of mallard ducklings is positively re-

Table 4. Summary of hepatic ethoxyresorufin *O*-deethylase (EROD) activity and polyaromatic hydrocarbon (PAH) metabolite levels in the bile of juvenile mallards held on the natural wetland (NW) and a reference wetland (SI)[a]

	EROD	PAH metabolites			
		Pyrene*	B*a*P	Naphthalene*	Phenanthrene
NW	7.13 ± 1.13	434.4 ± 48.8	1.19 ± 0.1	330.0 ± 32.1	67.0 ± 8.2
WI	8.60 ± 1.22	261.3 ± 0.8	1.06 ± 0.07	251.0 ± 22.1	49.7 ± 7.7

[a] The EROD activity is measured in nmol/min/mg protein and metabolites are measured as PAH equivalents (see Krahn et al. [13]). For all measurements, values are the mean ± standard error. Values that are significantly different by site ($p < 0.05$) are marked with an asterisk. B*a*P = benzo[*a*]pyrene.

lated to growth. Therefore, prefledging ducklings reared on oil-sands based wetlands, given their smaller size, may be less likely to survive compared to ducklings reared on wetlands not receiving oil-sands effluent.

Currently, part of the mine closeout procedure incorporates the use of wetlands based on CTE. Furthermore, because current mine closeout plans do not include removal of the huge sand dykes used to enclose the fine-tails slurry, dyke seepage will continue for many years (estimated as 100 years or longer past mine closeout) [1–3]. The findings of the present study suggest that these oil-sands based wetlands are poor-quality habitats, as indicated by the reduced growth in ducklings inhabiting the wetland. Reduced duckling growth has been linked to poorer survival and, thereby, to reduced recruitment into the population as a whole [7–10]. Hence, larger-scale studies at the population level are needed to determine what impact current mining activities could have on bird populations within the region. Once the impact is assessed, appropriate reclamation strategies can be put in place to prevent further adverse effects on the avian communities within this region of northern Alberta, Canada.

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