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CALCIUM SUPPLEMENTS IN THE DIET OF NESTLING TREE SWALLOWS NEAR ACID SENSITIVE LAKES[1]

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Abstract. We quantified supplemental sources of calcium in the diet of nestling Tree Swallows (*Tachycineta bicolor*) near acid sensitive lakes in northwestern Ontario. Among the calcium-rich items brought to nest boxes by adult swallows and ingested by nestlings, fish bones (particularly flat pieces) were most numerous, followed by crayfish exoskeleton, clam shell, and bird eggshell in that order. Only 5% of the items eaten were longer than 10 mm, whereas over 29% of the items found in nest boxes were in this size class. We found significantly fewer calcium-rich items in the stomachs of nestlings from acidic lakes than in those from reference lakes, suggesting that items suitable for ingestion may be scarcer there. However, Tree Swallows flew at least 50 to 650 m from their nest-site lake to obtain calcium-rich items. Because lake acidification has reduced numbers of animals providing calcium for Tree Swallows in regions in which many lakes are atmospherically acidified, the availability of calcium sources for nestlings may be seriously affected.

Key words: Acidification; Tree Swallows; Tachycineta bicolor; *dietary calcium; reproductive success.*

INTRODUCTION

Dietary calcium is essential for birds, especially for females producing eggs and for mineralization of bone in developing chicks (see Simkiss 1961 for review). Birds in the wild often augment normal dietary calcium in times of increased physiological need by selectively consuming items rich in this element. Consumption of bits of bones has been recorded in a variety of birds (e.g., Red Crossbills, *Loxia curvirostra,* Payne 1972; sandpipers, *Calidris* spp., MacLean 1974, Byrkjedal 1975; Griffon Vultures, *Gyps* spp., Houston 1978), as have shells of molluscs (several swallow species, Beal 1918, Mayoh and Zach 1986, Blancher et al. 1987), calcareous grit (Ring-necked Pheasants, *Phasianus colchicus,* Kopischke 1966; Red-billed Queleas, *Quelea quelea,* Jones 1976; Barn Swallows, *Hirundo rustica,* Barrentine 1980), and ash rich in calcium (e.g., Boreal Chickadees, *Parus hudsonicus,* Ficken 1989).

Recently, a number of studies have suggested that calcium may be a limiting factor in the diet of birds breeding in or near anthropogenically-acidified habitats (Blancher et al. 1987, Ormerod et al. 1988, Drent and Woldendorp 1989; also see Scheuhammer 1990). For example, Blancher et al. (1987) found that shells of snails and clams, and crayfish exoskeleton, all components of the diet of Tree Swallows (*Tachycineta bicolor*) nesting near nonacidic wetlands in Ontario, were frequently absent from the diet of swallows breeding near acidic wetlands. These authors postulated that the loss of these calcium-rich species due to acidification may have contributed to small clutch size and slow growth of nestlings (Blancher and McNicol 1988). Ormerod et al. (1988) suggested that the small but significant variation they found in Dipper (*Cinclus cinclus*) eggshell thickness in relation to stream acidity in Wales and Scotland might be related to the significant positive relationship they observed between stream pH and calcium in two insect orders preyed upon by Dippers. Adult female Dippers at acidic streams had significantly lower serum calcium in the prebreeding period than birds at nonacidic sites (Ormerod et al. 1990). Drent and Woldendorp (1989), studying Great Tits (*Parus major*) breeding in the Buunderkamp forest in the Netherlands, noted a drastic increase between 1983–1988 in the proportion of shell-less eggs and eggs with shells so thin that embryos became desiccated during incubation. They proposed that as a consequence of acid rain, uptake of calcium by certain tree species was impaired, resulting in low levels of calcium in the leaves of these trees and in the caterpillars feeding on them. Eggshell thinning may have resulted from tits preying on caterpillars low in calcium.

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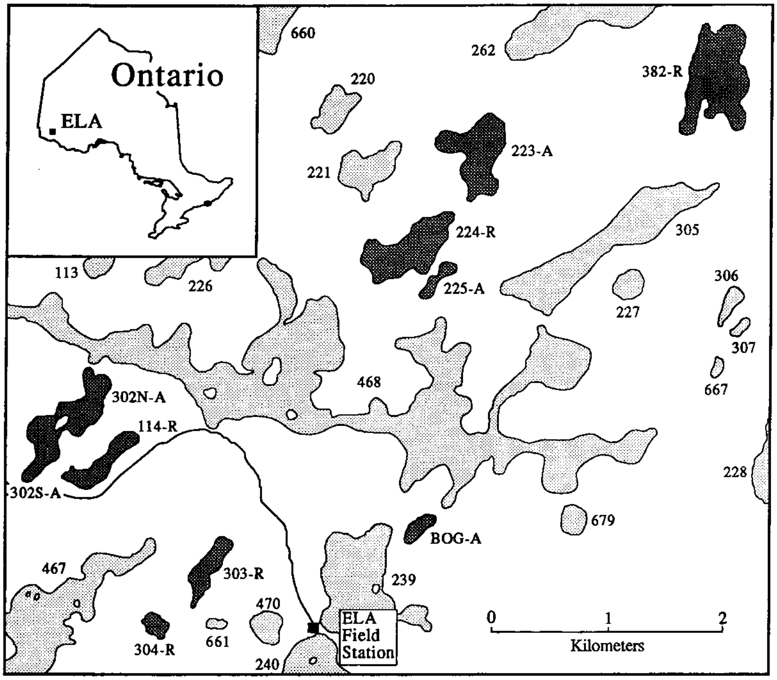

FIGURE 1. Location of the Experimental Lakes Area, and the lakes and bog used in this study (shaded dark grey). Letters following study lake numbers refer to: R—reference lakes; A—acidic lakes. Map adapted from Cleugh and Hauser (1971).

We are examining the effects of lake acidification on Tree Swallows at the Experimental Lakes Area in northwestern Ontario. Tree Swallows commonly nest near water and forage primarily on emergent aquatic insects (Holroyd 1972, 1983; Quinney and Ankney 1985; St. Louis et al. 1990). Stimulated by the above investigations, we documented the sources of supplemental calcium in the diet of nestling Tree Swallows at our study site to determine if the animals providing calcium sources are among those known to be susceptible to the effects of acid rain.

METHODS

STUDY SITE

We conducted our study at the Experimental Lakes Area (ELA), Kenora-Dryden District, Ontario, Canada (93°30′–94°00′W and 49°30′–49°45′N; Fig. 1). The ELA is a Federal Fisheries and Oceans field station that specializes in whole lake ecosystem experiments (Johnson and Vallentyne 1971). Recently the focus of ELA research has been on acid precipitation (Schindler 1980, Mills and Schindler 1987); certain lakes are experimentally acidified, while nearby lakes are left untreated and serve as references.

Between 1986 and 1989, 9 to 20 (depending on lake size) Tree Swallow nest boxes were placed ca. 30 m apart along the shores of each of five reference lakes (114, 224, 303, 304, 382; average May–August 1986–1989 epilimnia pH ranging between 6.3 and 7.0 among lakes), one lake naturally acidified by organic acids (225; mean pH 5.1), and three experimentally acidified lakes (223, 302N, 302S) (Fig. 1). Lake 223 was gradually acidified beginning in 1976 with sulfuric acid to an average pH of 5.1 in 1982–1983 (Schindler et al. 1985), and was allowed to recover to pH 5.53 to 5.86 in years 1986–1989. Lake 302 is a two basin lake divided by a seacurtain. The south basin (302S) was acidified by approximately pH 0.25/yr with sulfuric acid to mean pH 4.6 in 1988–1989. The north basin (302N) received additions of nitric acid until 1986 (mean pH 6.2), and was further acidified with hydrochloric acid to mean pH 5.84 to 5.05 in years 1987–1989 (also see Turner et al. 1987). We also placed up to 15 nest boxes in one poor fen peatland (Bog;

Fig. 1), a portion of which was experimentally acidified with sulfuric and nitric acids to simulate rainfall of approximate pH 4.0 (Bayley et al. 1987). Mean pH of the center pool in the bog was 4.0.

SOURCES OF CALCIUM

We assessed sources of dietary calcium of nestling Tree Swallows by sorting through the contents collected from 111 nest boxes between 1987 and 1989 (often items are dropped in the nest or rejected by nestlings when adults feed their young; Blancher et al. 1987), and also examining the stomach (gizzard) contents of 114 ca. 18 day-old nestlings sacrificed from the same area between 1986 and 1989. Contents of each nest box were sorted at least twice while being examined under a magnifying glass or a binocular dissecting microscope. Stomach contents were also sorted at least twice under a binocular dissecting microscope. To identify high calcium aquatic species fed by adult Tree Swallows to their nestlings, items rich in calcium were classified at least to taxonomic class using reference collections and keys in Lagler (1956).

AVAILABILITY OF CALCIUM SOURCES

Information about organisms indigenous to lakes and the bog was obtained from ongoing and historical species surveys of ELA lakes (ELA personnel, pers. comm.) and Beamish et al. (1976). For each study lake, we compared organisms used for calcium found in our stomach and nest-box samples among all years with presence of those organisms in the lake using the Russell and Rao (1940) measure of similarity to determine if Tree Swallow nestlings were primarily fed items available near the nest site. The Russell and Rao (1940) similarity coefficient is a measure of co-occurrence (Jackson et al. 1989), dividing the number of taxa present in both our samples and the nest-site lake (positive matches) by the total number of taxa surveyed. If a lake was not surveyed for a particular organism, that organism was not included in the measure of similarity. Similarity measures range between 0 and 1, with low values indicating little correspondence between items found in our samples and those indigenous to the nest-site lake. Furthermore, we estimated distances Tree Swallows may have flown to obtain items not available at the nest-site lake using topographical maps of the ELA and knowledge of the species composition of lakes near our study lakes.

To further determine if lake acidification affected the abundance of calcium sources available to Tree Swallows, we used *G*-tests of independence (Sokal and Rohlf 1981) to compare the percentage of nest-box and stomach samples that contained calcium-rich items between acidic and reference lakes. We also tested for differences between acidic and reference lakes in the mean number of calcium-rich items per nest box and stomach sample with a one-way analysis of variance (ANOVA) using the SAS package of programs for personal computers (SAS Institute Inc. 1988). Values were ranked prior to ANOVA because they were not normally distributed (Conover and Iman 1981).

SIZE OF ITEMS CONSUMED

To determine if nestling Tree Swallows showed preference for calcium sources of certain sizes, we used a binocular dissecting microscope with a calibrated eyepiece micrometer to measure maximum length, width, and depth of each item. Items collected from the stomach were clearly small enough for nestlings to swallow. However, those found in the nest-box contents could include items rejected by nestlings or too large to consume. For both stomach and nest-box samples, items potentially rich in calcium were pooled among all years at each lake to increase sample sizes for further comparisons. When the number of items found both in the stomach and in the nest box was greater than five, we tested for differences in mean sizes of the different calcium source items with ANOVA. However, certain sample sizes were still small, so all values were ranked prior to ANOVA. If Tree Swallow nestlings consistently rejected specific types of items brought to them by adults (possibly because of their size or shape), one would expect a higher frequency of that item in the nest box than in the stomach samples. We tested this prediction using *G*-tests of independence on data pooled among all lakes for the years 1987 to 1989. Items found in stomachs of nestlings collected in 1986 were omitted from analyses because nest-box contents were not collected for that year.

RESULTS

SOURCES OF CALCIUM

Among all lakes and the bog, 33.1% of stomach and 52.1% of nest-box contents contained items that had high calcium content (Table 1). The majority of these items were aquatic in origin.

TABLE 1. Percentage of each type of high calcium content item found in nest boxes and the stomachs of nestlings collected from around each study lake. Figure 2 illustrates the different types of items listed below.

Lake	Origin	Number nests/ stomachs examined	Percent containing items	Number items	Fish bone type 1	2	3	4	5	Fish bone Total	Crayfish	Clam	Bird eggshell	Plastic
Acidic lakes														
223	Nest	12	50.0	26	—	—	23.1	26.9	26.9	76.9	23.1	—	—	—
	Stomach	7	28.6	3	33.3	33.3	33.3	—	—	100.0	—	—	—	—
302S	Nest	13	53.8	58	20.7	3.4	19.0	20.7	5.2	69.0	1.7	—	5.2	24.1
	Stomach	12	16.7	2	—	—	100.0	—	—	100.0	—	—	—	—
302N	Nest	8	37.5	6	—	—	50.0	33.3	—	83.3	16.7	—	—	—
	Stomach	7	28.6	3	66.7	—	33.3	—	—	100.0	—	—	—	—
225	Nest	11	18.2	6	—	—	16.7	16.7	33.3	66.7	33.3	—	—	—
	Stomach	9	22.2	3	—	—	66.7	—	—	66.7	—	—	—	33.3
Bog	Nest	4	75.0	55	5.5	—	58.2	16.4	16.4	96.4	1.8	—	1.8	—
	Stomach	6	33.3	2	—	—	100.0	—	—	100.0	—	—	—	—
Reference lakes														
114	Nest	14	64.3	63	15.9	3.2	30.2	9.5	6.3	65.1	7.9	1.6	11.1	14.3
	Stomach	17	41.2	13	53.8	—	23.1	15.4	—	92.3	—	—	7.7	—
224	Nest	10	60.0	45	22.2	—	37.8	8.9	2.2	71.1	20.0	—	8.9	—
	Stomach	9	33.3	17	5.9	—	82.4	5.9	5.9	100.0	—	—	—	—
303	Nest	8	50.0	35	8.6	2.9	28.6	20.0	37.1	97.1	2.9	—	—	—
	Stomach	10	70.0	8	37.5	—	62.5	—	—	100.0	—	—	—	—
304	Nest	7	57.1	21	23.8	9.5	19.0	14.3	14.3	80.9	4.8	14.3	—	—
	Stomach	11	45.5	18	11.1	—	50.0	11.1	—	72.2	27.8	—	—	—
382	Nest	24	54.2	102	5.9	—	22.5	4.9	12.7	46.0	32.4	15.7	—	5.9
	Stomach	26	11.5	12	—	—	50.0	—	—	50.0	41.7	8.3	—	—

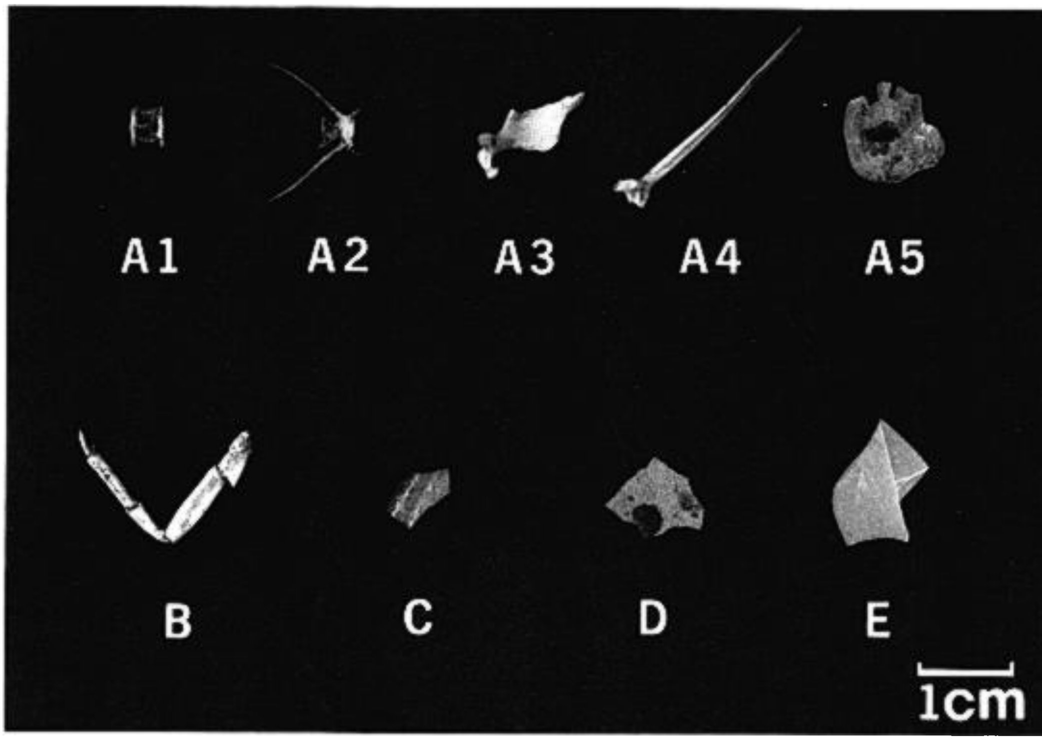

FIGURE 2. Range of high calcium items found in nest boxes and the stomachs of nestlings at the Experimental Lakes Area. Items are: A1: fish vertebrae; A2: fish vertebrae with spines; A3: flat fish bones; A4: long fish bones; A5: fish scales; B: crayfish exoskeleton; C: freshwater clam shell; D: bird eggshell; E: plastic.

Included were a range of fish bones (subdivided into five 'shape/type' categories for purposes of comparison) from five of the eight families of fish indigenous to our study lakes, crayfish (*Orconectes virilis*) exoskeleton, freshwater clam (*Anodonta grandis*) shells, and bird (Herring Gull, *Larus argentatus*, and Common Loon, *Gavia immer*) eggshells (Fig. 2, Tables 1 and 2). Because we were not always able to identify all items to family, more kinds of animals may have been in our samples than indicated in Table 2. In general, fish bones were the commonest items found among all our lakes and the bog, in both nest-box (70.3%) and stomach (84.0%) samples, with flat pieces the most common shape (Table 1). Crayfish exoskeleton was the second most common item (14.4% in nest-box and 12.3% in stomach samples). No other class of item was encountered with any regularity (Table 1). Pieces of hard white plastic (Fig. 2) were also found in nest-box and stomach samples. However, we suspect that the pieces of plastic were initially mistaken for items that contained calcium because of their color.

AVAILABILITY OF CALCIUM

All aquatic organisms used by swallows as supplemental calcium sources were absent in naturally acidic Lake 225, the bog, and reference Lake 304 (Table 2). Although certain species had been extirpated while others declined in abundance in the experimentally acidified lakes, these lakes were not devoid of all calcium source organisms (Table 2). Correspondence between the items we collected in our samples from around a particular lake and the animals indigenous to that lake ranged between 0 for the lakes containing no organisms to 0.40 for Lakes 224 and 382 (Table 2). The kinds of items found in our samples lacking at the nest-site lake suggest strongly that adult swallows sought calcium-rich items at other lakes. Minimum distances from nest-site lakes to lakes containing calcium items ranged from 50 to 650 m (median = 300 m).

There was no significant difference ($P > 0.05$) between acidic and reference lakes in the percentage of nest-box ($G = 0.64$) and stomach ($G = 0.66$) samples that contained calcium-rich items, or in the mean number of calcium-rich items per nest box ($F = 0.88$) (see also Table 1). However, we found significantly fewer ($F = 26.32$, $P = 0.001$) calcium-rich items per stomach sample collected at acidic lakes than in samples from reference lakes (see also Table 1), suggesting that items suitable for ingestion (see below) may be scarcer there.

SIZE OF ITEMS CONSUMED

Of the items tested (see Fig. 3), the mean size of the ones in stomach contents was significantly smaller ($P < 0.05$) than the mean size of items found in the nest box, except for length of fish vertebrae, width and depth of long pieces of fish bone, and depth of flat fish bones. Items in the stomach did not appear to be partly digested.

Both fish scales ($G = 12.04$) and plastic ($G = 4.40$) occurred significantly more frequently ($P < 0.05$) in the nest box than in the stomach contents. In contrast, flat fish bones were found significantly less often ($G = 14.02$) in nest-box than in stomach samples, suggesting a preference by swallow nestlings for them.

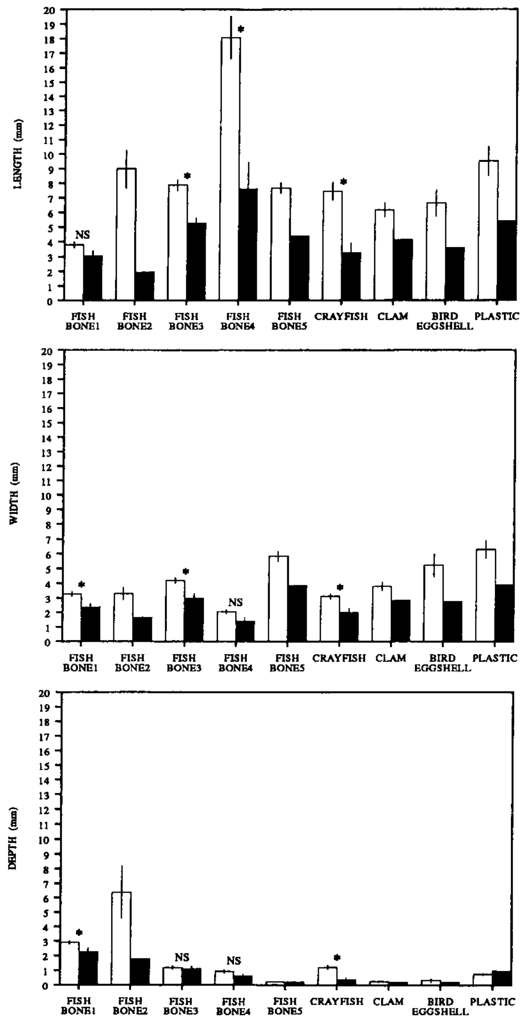

FIGURE 3. Mean length, width, and depth (with standard errors) of each calcium-rich item found in the nest box (clear bar) and stomachs of nestlings (solid bar) among all study lakes. An asterisk above a pair of bars indicates a significant difference ($P < 0.05$) in mean size between items found in the nest box and those found in the stomach. NS indicates no significant difference in size. Certain items were not common in stomach contents of nestlings (solid bars with no standard error bars), and as a result the size of these items was not statistically compared with the mean size of the item found in the nest box (also see text).

DISCUSSION

Items ingested by Tree Swallow nestlings in this study have been shown in other investigations to differ in concentrations of calcium. For example, Lockhart and Lutz (1977) and Fraser and Harvey (1982) reported mean calcium concentrations in white sucker (*Catostomus commersoni*) vertebrae, ribs, and scales as 22.4%, 23.1% and 11.7% respectively. Mean calcium concentrations in crayfish exoskeleton (France 1987), freshwater clam shells (Huebner et al. 1990), and bird eggshell (e.g., Domestic Chicken, *Gallus domesticus,* Romanoff and Romanoff 1963, Taylor 1970) were found to be 20.9%, 44.7% and 40.0%, respectively. Although certain items are richer in calcium than others, the high proportion of fish bones in our samples probably reflects their relative availability at our study site, thus contrasting with the high incidence of mollusc shells consumed by Tree (Mayoh and Zach 1986, Blancher et al. 1987, Blancher and McNicol 1988) and other swallows (Beal 1918) nesting in other areas. Local abundance of a particular calcium-rich animal could also influence use at specific nests, as shown by variation in occurrence of certain organisms in nest-box contents and stomach contents of nestlings among our own study lakes (e.g., high proportion of crayfish exoskeleton found in samples collected at Lake 382; also see Tables 1 and 2). Both fish scales and plastic were common in nest-box but not stomach samples and thus appeared to be rejected by nestlings, possibly because scales were difficult to swallow (see below) and plastic is inedible.

Prey items longer than 10 mm are fed to nest-

TABLE 2. Presence (+) or absence (−) of food items high in calcium found in nest-box and stomach samples collected from around a lake (Sample) and organisms in the lake (Lake). A ? indicates lakes were not surveyed for that particular organism. Loons and gulls are not listed on the table because they did not consistently nest near specific lakes among years.

Lake		Fish family[1] 1	2	3	4	5	6	7	8	Crayfish[2]	Clam[3]	Similarity coefficient[4]
Acidic lakes												
223	Sample	+	+	−	−	−	+	−	−	+	−	0.30
	Lake	+[5]	+[5]	−	−	−	+[5]	−	−[6]	−[6]	−[6]	
302S	Sample	+	+	−	−	−	+	−	−	+	−	0.20
	Lake	+	−	+[5]	−	−	+	−	+[5]	−[6]	+	
302N	Sample	+	−	−	−	−	−	−	−	+	−	0.20
	Lake	+	−	+	−	−	+	−	+	+[5]	+	
225	Sample	+	−	−	−	−	−	−	−	+	−	0.00
	Lake	−	−	−	−	−	−	−	−	−	?	
Bog	Sample	+	+	−	−	−	+	−	−	+	−	0.00
	Lake	−	−	−	−	−	−	−	−	−	?	
Reference lakes												
114	Sample	+	+	−	−	+	+	−	−	+	+	0.10
	Lake	−	−	−	−	−	+	−	−	−	−	
224	Sample	+	+	−	−	+	+	−	−	+	−	0.40
	Lake	+	+	−	−	−	+	+	+	+	+	
303	Sample	+	+	−	−	−	+	−	−	+	−	0.13
	Lake	−	−	−	−	+	+	−	−	?	?	
304	Sample	+	+	−	−	−	+	−	−	+	+	0.00
	Lake	−	−	−	−	−	−	−	−	−	?	
382	Sample	+	+	−	+	+	−	−	−	+	+	0.40
	Lake	+	+	−	−	−	+	+	+	+	+	

[1] Fish families are: 1. Catastomidae (suckers); 2. Salmonidae (trout); 3. Coregonidae (whitefish); 4. Esocidae (pike); 5. Percidae (perch); 6. Cyprinidae (minnows); 7. Gasterosteidae (stickleback); and 8. Cottidae (sculpins). See Beamish et al. (1976) for abundance estimates of fish in reference lakes.
[2] *Orconectes virilis* is the only species of crayfish at the ELA.
[3] Clams from the families Unionidae and Pisidiidae have been found in ELA lakes.
[4] Russell and Rao (1940).
[5] Population abundance decline because of experimental acidification.
[6] Extinction of population because of experimental acidification.

ling Tree Swallows only 0.7% to 16% of the time, according to other investigators (Holroyd 1983, Quinney and Ankney 1985, Blancher et al. 1987). Similarly, only 4.9% of calcium-rich items found in nestling stomachs in our study were longer than 10 mm, whereas over 29% of items found in the nest box were in this size class. This again indicates that items longer than 10 mm are likely to be difficult for nestlings to swallow. Holroyd (1983) suggested that bill size (especially maximum gape) was a limiting factor in the size of prey Tree Swallows could consume easily. Certainly the shape and hardness of an item would also affect swallowing; large soft bodied insects would be easier to swallow than a similar sized piece of bone. It is thus possible that nestling Tree Swallows at our study site preferred to consume pieces of small flat fish bone because they were easier to swallow than fish scales or long pieces of bone. Items suitable for ingestion, however, appeared to be less abundant at acidic lakes because we found significantly fewer items per stomach sample there than in samples from reference lakes, even though there was no difference between acidic and reference lakes in the mean number of calcium-rich items found dropped in the nest boxes.

Most calcium-rich species eaten by swallows at the ELA are sensitive to lake acidification. For example, the pH thresholds caused by experimental acidification of Lake 223 at which recruitment failure occurred in lake trout (*Salvelinus namaycush*), white sucker, and fathead minnow (*Pimephales promelas*) were 5.59, 5.02, and 5.93 respectively (Mills et al. 1987). Chronic exposure of the crayfish *Orconectes virilis* to pH's lower than 5.64 in Lake 223 led to recruitment failure and eventual extinction of this species there (France 1987, Davies 1989). There has been decreased reproduction and diversity in the mollusc community in many acidic lakes in southern Ontario (Mackie 1987; also see Rooke and Mackie 1984, Servos et al. 1985). Tree Swallows at the ELA also ingested eggshells of Common Loon and Herring Gull. Alvo et al. (1988), for example, reported a significant positive relationship between breeding success and lake alkalinity in Common Loons in Ontario, possibly resulting from a shortage of food for the young.

At the ELA, the experimental lakes have been acidified for a relatively short time, and still support some species known to be sensitive to long-term acidification. Furthermore, at the ELA the acidic lakes and nonacidic lakes lie near each other. The low correspondence we found between items in our samples and those indigenous to the nest-site lake (the highest similarity coefficient was only 0.40; see Table 2) suggests that Tree Swallows often flew to other lakes (as far away as 0.65 km) to search for items high in calcium. Similarly, P. J. Blancher and D. K. McNicol (pers. comm.) found that swallows sought clam and snail shells at least 0.5–2.2 km from their nest-site wetlands. It is also possible, of course, that swallows may use remains of animals locally discarded by predators (e.g., fish bones at gull nest sites). Therefore, calcium may only be limiting to breeding swallows if depletion of calcium-rich animals is widespread, as is potentially the case in parts of eastern Canada (e.g., Minns et al. 1990). Tree Swallows nesting in such calcium-poor areas may be unable to find substantial alternative sources of supplemental dietary calcium. As a consequence, their reproductive success in terms of egg production and nestling growth may be at risk.

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