Sources of Food Delivered to Ring-Billed, Herring and Great Black-Backed Gull Chicks in Marine Environments

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Abstract.—Beginning in the 1960s, Ring-billed Gulls' (*Larus delawarensis*) historic breeding range expanded from inland habitats and freshwater wetlands to marine sites in Atlantic North America. Adults winter on salt water but salt tolerance may entail costs (e.g. maintenance of salt glands) and favor reduced parental use of marine resources for feeding chicks. Diets of Ring-billed Gull chicks nesting on a marine island off Prince Edward Island, Canada, were investigated using soft regurgitant collection and stable isotope ($\delta^{13}C$ and $\delta^{15}N$) analysis of both regurgitants and blood samples. Isotopic signatures in blood of chicks of Ring-billed and sympatrically-nesting Herring (*L. argentatus*) and Great Black-backed Gulls (*L. marinus*) were also compared. Regurgitants of Ring-billed Gull chicks contained freshwater/terrestrial and marine invertebrates and fish. A stable isotope mixing model incorporating both $\delta^{13}C$ and $\delta^{15}N$ in chick regurgitants and blood estimated that 42.2% of Ring-billed Gull chick diet came from the marine environment, whereas estimates from blood for Herring and Great Black-backed Gulls were 43.6%, and 73.5%, respectively. Further, differences existed among gull species in estimates for dietary contribution from various food sources from marine and terrestrial/freshwater environments. Although Ring-billed Gulls can use marine food sources to feed their young, whether salt in marine food imposes a physiological cost on these young in comparison to young reared exclusively on non-marine foods is unclear. *Received 11 December 2008, accepted 24 June 2009.*

Key words.—diet, Great Black-backed Gull, Herring Gull, *Larus argentatus, Larus delawarensis, Larus marinus,* regurgitant, Ring-billed Gull, salt tolerance, stable isotopes.

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Ring-billed Gulls (*Larus delawarensis*) historically nested near freshwater and had a breeding range from British Columbia, Washington, California and Nevada, north to the Northwest Territories and east to Atlantic Canada (Ryder 1993). A population boom and expansion in the Great Lakes during the 1960's and 1970's resulted in an extension of the breeding range into areas adjacent to marine habitats in Atlantic Canada (Lock 1988; Boyne *et al.* 2001; Boyne and Hudson 2002). Although Ring-billed Gulls winter along both coasts of North America (Ryder 1993), possess salt glands (Nechay *et al.* 1960) and presumably feed in the marine environment as adults, it is unknown whether the chicks can tolerate marine concentrations of salt in their diet (Hildebrandt 2001). There are costs to dealing with salt in diets; for example, ducklings of American Black Duck (*Anas rubripes*), Mallard (*A. platyrhynchos*) and their hybrids had reduced survival when given diets with supplementary salt at levels that adults could tolerate (Barnes and Nudds 1991). Similarly, Laughing Gull (*L. atricilla*) chicks grew more slowly on salt-rich diets (Dosch 1997) and this species regularly breeds in marine habitats (Burger 1996). In the only data we are aware of, three "full-grown, hand-reared immature" Ring-billed Gulls survived on *ad libitum* diets of fresh frozen herring (*Clupea harengus*) (Bédard *et al.* 1980), but younger chicks were not tested. Moreover, because Bédard *et al.* (1980) were interested in nutrient-cycling, they did not report on consequences of marine diets to the gulls. In comparison, both Herring (*L. argentatus*) and Great Black-backed Gull (*L. marinus*) chicks and adults are capable of ingesting marine foods and removing excess salt via salt glands (Pierotti and Good 1994; Good 1998). In this paper, we test whether wild Ring-billed Gull chicks on a marine island were being fed marine foods by their parents.

Ring-billed Gulls feed opportunistically on fish, insects, earthworms, human refuse, rodents, grains, etc. (Vermeer 1970; Jarvis

and Southern 1976; Blokpoel and Haymes 1979; Ryder 1993). Dietary analyses for gulls have used feces, indigestible hard pellets, soft regurgitants (partially digested and regurgitated prey items), stomach contents and observations of prey delivery to young (Threlfall 1968; Vermeer 1970; Jarvis and Southern 1976; Kirkham and Morris 1979; Welham 1987; Chudzik *et al.* 1994; Brown and Ewins 1996; Bearhop *et al.* 2001; Kubetzki and Garthe 2003). There are biases associated with each technique and limited time frames represented in the data collected. As an alternative, stable isotope analysis provides feeding information without diet collection or feeding observations, removing biases associated with differences in digestibility of soft- versus hard-bodied prey items, providing dietary information for foods assimilated into body tissues (not just those ingested) and revealing long term diet information without long-term monitoring (Evans Ogden *et al.* 2004). Stable isotope signatures persist in body tissues for different periods of time depending on elemental turnover rates of the tissue, thus providing feeding trends over a larger time scale (Hobson and Clark 1992a). Established turnover rates generally range between five and 15 days for whole blood (half-life) (reviewed in Hobson and Bairlein 2003), range between 0.4-2.9 days for plasma (Hobson and Clark 1993; Pearson *et al.* 2003), and average 29.8 days for cellular components (Hobson and Clark 1993). Stable-carbon and stable-nitrogen analyses reveal nutrient contributions to the diet from isotopically distinct sources (e.g. freshwater and terrestrial habitats versus marine habitats; Hobson 1987, 1990; Mizutani *et al.* 1990), and trophic relations within ecosystems (DeNiro and Epstein 1981; review in Kelly 2000).

We investigated diets of Ring-billed Gull chicks on a marine island adjacent to Prince Edward Island (PEI), Canada. We identified prey items in chick soft regurgitants and, combined with stable isotope analysis of blood and regurgitants, estimated the contribution to the diet from the marine environment. We also compared blood isotopic signatures with chicks of sympatrically-nesting Herring and Great Black-backed Gulls to assess differences in diet among these closely-related species. Finally, we compared blood isotopic signatures of Herring and Great Black-backed Gulls from two geographically separated locations.

STUDY AREAS AND METHODS

Breeding gulls were located at Indian Point Sandhills West (46°37'34"N, 64°17'13"W) and Poverty Beach Islands in Murray Harbour (46°02'13"N, 62°28'55"W), PEI, between 1-15 July 2003. Both sites are near-shore, vegetated sandbar islands in marine environments. Indian Point Sandhills West has ~500 pairs of Ring-billed, ~650 pairs of Herring and ~200 pairs of Great Black-backed Gulls, whereas Poverty Beach has approximately 100 pairs of Ring-billed, ~350 pairs of Herring and ~450 pairs of Great Black-backed Gulls (Boyne and McKnight 2005).

To assess diet of Ring-billed Gull chicks, 28 soft regurgitants were collected opportunistically during handling of chicks (McLellan 2005). Regurgitants were separated into prey items, identified and put in a drying-oven at 60ºC for 48 h before weighing. Dried regurgitants were ground with a mortar and pestle in preparation for stable isotope analysis. Blood samples of 1-2 ml were taken from the meta-tarsal vein of 25 Ring-billed Gull chicks. To compare isotope signatures of plasma and blood cells, a subset of 15 blood samples was centrifuged to separate these components. Chicks were randomly captured from within the colony, where nest histories of chicks were unknown. Wing-lengths of chicks were measured to the nearest 0.1 cm with a wing-ruler to provide a correlate of age.

For comparison, blood samples were collected from sympatrically-nesting Great Black-backed ($N = 8$) and Herring Gull ($N = 8$) chicks from Indian Point Sandhills. As a geographic comparison, blood samples were taken from chicks of both Great Black-backed ($N = 5$) and Herring Gulls ($N = 5$) at Poverty Beach. No regurgitants were collected from these species.

Stable isotope analysis was conducted at the Stable Isotopes in Nature Laboratory, Canadian Rivers Institute, University of New Brunswick. Following Jardine *et al.* (2003), dried samples were combusted in a NC2500 elemental analyzer connected via continuous-flow to a Thermo Finnigan Mat Delta XP mass spectrometer. Isotope ratios are reported in δ notation relative to international standards for carbon (PeeDee Belemnite carbonate) and nitrogen (atmospheric N_2). A commercially available organic analytical standard (Acetanilide, Elemental Microanalysis Ltd.) had mean ± SD $\delta^{13}C$ and $\delta^{15}N$ values of -33.57 ± 0.07‰ and -3.05 ± 0.22‰, respectively. Regurgitants were lipid-extracted using a chloroform:methanol solution. Because avian blood rarely has significant lipid content, blood samples were not lipid-extracted (Hobson and Clark 1992b, 1993; Bearhop *et al.* 2000).

Statistical analyses were performed using SPSS (version 11.01.318 2001). $\delta^{13}C$ isotopic signatures for Great Black-backed Gulls from Indian Point Sandhills were not normally distributed (Shapiro-Wilk's test, $P < 0.05$) so these data were rank-transformed. Blood isotopic signatures for gull species at Indian Point Sandhills were

compared with ANOVA and MANOVA, with $\delta^{13}C$ and $\delta^{15}N$ values of blood as response variables and species as a fixed factor. We compared species' $\delta^{13}C$ and $\delta^{15}N$ values at Poverty Beach and geographic differences in isotope signatures with *t*-tests. We tested for differences in isotope signatures of blood cells versus plasma with a paired *t*-test. All means are reported ± SD unless otherwise noted, and correlations are parametric.

To evaluate proportions of diet from identified food sources, a stable isotope mixing model (Phillips and Gregg 2003) was used (using IsoSource Version 1.3.1) with $\delta^{13}C$ and $\delta^{15}N$ isotope signatures. Mean isotopic values for marine fish, marine invertebrate, terrestrial arthropod and earthworm prey items collected from Ring-billed Gull chick regurgitants were used to represent the four sources in all models. A single freshwater fish was not included because we did not obtain a $\delta^{15}N$ value. Mean isotopic signatures from the three gull species represented the mixtures in the models. Diet-tissue fractionation factors established for Ring-billed Gull blood (Hobson and Clark 1992b) were applied to the isotopic signatures of blood from the three gull species prior to running models. Diet-tissue fractionation factors for plasma and cellular components of blood (Evans Ogden *et al.* 2004) were applied prior to statistical testing.

RESULTS

Freshwater/terrestrial prey items were found in 22/28 (79%) Ring-billed Gull regurgitants and marine prey items in 10/28 (36%). When regurgitants contained terrestrial prey items, they made up on average 90% of dry mass (range 10-100%) and when regurgitants contained marine prey items, they made up on average 82% of dry mass (range 25-100%). Many regurgitants, particularly those containing fish, were partially digested, making identification difficult. Although they did not make up the majority of dry mass, the most numerous identifiable prey items in regurgitants were insects (Fig. 1), of which Diptera, Lepidoptera, Hymenoptera, and Coleoptera were most common among 11 orders. Other identifiable prey items included Rainbow Smelt (*Osmerus mordax*; marine), an unidentified stickleback species (marine), an unidentified marine shrimp, and a marine polychaete (*Nereis virens*). A mummichog (*Fundulus heteroclitus*; brackish to marine) was also found within the Ring-billed Gull colony, suggesting it may have been provided as food.

At Indian Point Sandhills, both $\delta^{13}C$ (MANOVA: Wilks' Lambda, $F_{4,44} = 7.5$, $P < 0.001$; Fig. 2 and Table 1; Tukey's Tests, Ps < 0.001) and $\delta^{15}N$ (Fig. 2 and Table 1; Tukey's Tests, Ps ≤ 0.001) were greater in Great Black-backed Gulls compared to the other two species. There were no significant differences in isotopic signatures between Ring-billed and Herring Gulls (Tukey's Tests, Ps > 0.05). At Poverty Beach, there were significant differences in $\delta^{13}C$ and $\delta^{15}N$ values between Herring and Great Black-backed Gull chicks (Table 1). $\delta^{15}N$ in Great Black-backed Gull chicks from Poverty Beach was greater

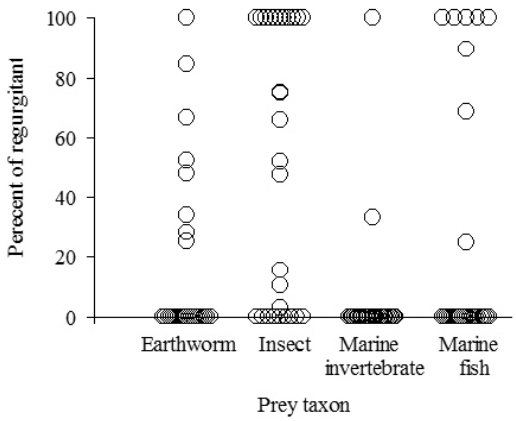

Figure 1. Percents of different food items in 27 regurgitants collected from Ring-billed Gull chicks. Overlapping values are offset. A single regurgitant containing 100% freshwater fish is not shown because of incomplete isotope data (missing $\delta^{15}N$).

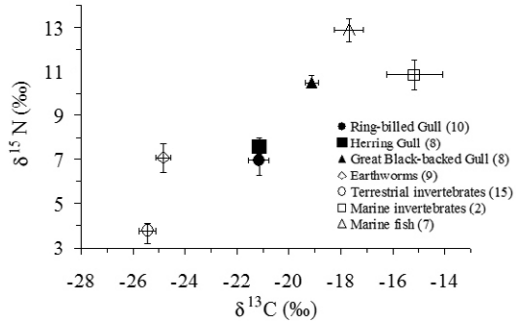

Figure 2. Mean whole blood carbon-nitrogen isotopic signatures (+/- 95% C.I.) for Ring-billed, Herring and Great Black-backed Gull chicks, and for prey items collected from regurgitants of Ring-billed Gull chicks. Fractionation factors established for Ring-billed Gull chicks (Hobson and Clark 1992b) have been applied to the $\delta^{13}C$ and $\delta^{15}N$ values of the three gull species. Sample sizes are in parentheses. A single regurgitant containing 100% freshwater fish with incomplete isotope data (missing $\delta^{15}N$) had a $\delta^{13}C$ value of -25.93‰.

Table 1. Comparisons of mean (±SD) blood stable isotope values for gull species from Indian Point Sandhills and Poverty Beach, PEI.

Gull species	$\delta^{13}C$	$\delta^{15}N$
	Indian Point Sandhills	
Ring-billed (n = 10)	-21.5 ± 0.8	10.1 ± 1.2
Herring (n = 8)	-21.5 ± 1.1	10.7 ± 1.9
Great Black-backed (n = 8)	-19.4 ± 0.7	13.6 ± 0.8
Model F	15.8	16.0
P	<0.001	<0.001
	Poverty Beach	
Great Black-backed (n = 5)	-19.0 ± 0.5	14.9 ± 0.3
Herring (n = 5)	-20.3 ± 0.5	13.0 ± 0.4
Model t	-4.0	-8.1
P	0.004	<0.001

compared to Indian Point Sandhills (t = -3.1, P = 0.01), but no significant difference was found in $\delta^{13}C$ between study sites (t = -1.2, P = 0.26). For Herring Gulls, there were both greater $\delta^{13}C$ and $\delta^{15}N$ (t = -2.3, P = 0.04 and t = -2.7, P = 0.02, respectively) from Poverty Beach compared to Indian Point Sandhills. Mean wing-length of Ring-billed Gull chicks was 245.1 ± 40.3 mm and ranged between 171- 295 mm, but there were no significant relationships between wing-length and $\delta^{15}N$ (r = 0.19, P = 0.50) or $\delta^{13}C$ (r = 0.38, P = 0.16) in blood plasma, suggesting no significant change in the proportion of marine food with chick age.

$\delta^{15}N$ values were significantly higher for plasma versus cellular components of the blood in Ring-billed Gulls (paired t-test, t = -4.6, P < 0.001). No significant differences were found in $\delta^{13}C$ values (t = 0.7, P = 0.50).

$\delta^{13}C$ and $\delta^{15}N$ were significantly and positively correlated for Ring-billed (r = 0.87, P = 0.001), Herring (r = 0.98, P < 0.001), and Great Black-backed Gulls (r = 0.79, P = 0.018) from Indian Point Sandhills. In contrast, no significant relationships were found for Herring (r = 0.49, P = 0.40) or Great Black-backed Gulls (r = 0.36, P = 0.55) from Poverty Beach, although sample sizes were only five for each species from this study area.

The stable isotope mixing model (Phillips and Gregg 2003) estimated differences in contributions to diet of different prey sources (Table 2). The biggest difference were that terrestrial arthropods contributed significantly to Ring-billed and Herring Gull diets, whereas marine fish were of much greater significance to Great Black-backed Gulls.

DISCUSSION

Ours is the first study of which we are aware to investigate diets of Ring-billed Gull chicks in a marine environment. Prey items in regurgitants were comparable to those from freshwater environments (earthworms, arthropods and fish) (Ryder 1993), with insects the most common item in diets. Although marine prey items were not as common as freshwater/terrestrial prey, they were found in more than one third of all regurgitants. There was a tendency for regurgitants to be composed of either entirely marine or entirely terrestrial/freshwater food, suggesting that adults were feeding in one environment or the other before delivering food to young. Regardless, our results indicate that Ring-billed Gull chicks can handle elevated salt concentrations in their diets.

Studies of diet in Ring-billed Gull reveal substantial regional variation (Ryder 1993). Fish appear the major food item fed to chicks in Ontario, followed by insects and earthworms (Jarvis and Southern 1976; Haymes and Blokpoel 1978; Kirkham and Morris 1979; Chudzik *et al.* 1994). In comparison, chicks in Alberta were fed insects,

Table 2. Estimated contributions of different food items to diets of the three gull species.

Species (N)	Percent (SD) of diet estimated from isotope signatures			
	Earthworms	Terrestrial Arthropods	Marine Invertebrates	Marine fish
Ring-billed Gull (10)	4.4 (3.2)	53.4 (2.5)	38.9 (1.9)	3.3 (2.4)
Herring Gull (8)	16.1 (9.7)	40.3 (7.3)	31.3 (5.0)	12.3 (7.4)
Great Black-backed Gull (8)	15.2 (9.2)	11.3 (7.0)	22.6 (5.0)	50.9 (7.0)

birds, rodents, plants and human refuse (Vermeer 1970) and in Manitoba, insects and grain (Welham 1987). These differences reflect not only differences in available resources but also in diet assessment methods. For example, Vermeer's (1970) data were based mainly on pellet collection and a few regurgitants whereas Welham (1987) sampled mainly adults at foraging sites and adults flying toward the colony, with a few samples ($N = 13$) of chick regurgitants. We found a diversity of prey items in Ring-billed Gull regurgitants reflecting opportunistic feeding. Long-term diet sources are more reliably reflected in our stable isotope analyses.

Stable isotope analyses of Ring-billed Gull chick blood further suggest that chicks were fed from both a marine and terrestrial/freshwater environment. Isotopic signatures for the three sympatrically-nesting gull species from Indian Point Sandhills revealed similar isotopic signatures of Herring and Ring-billed Gulls, plus more marine signatures of Great Black-backed Gulls, even though Great Black-backed and Herring Gulls commonly nest together and can use similar food items (Pierotti and Good 1994; Good 1998).

More marine signatures in gulls from Poverty Beach may occur because this colony is adjacent to a fishing harbor, thus providing opportunity for fishery discards as prey items. Both species were observed following boats returning to harbor. Alternatively, comparisons of stable isotope signatures from geographically distinct sites may differ because of differences in base isotopic signatures or isotopic signatures from organisms at the bottom of the food web from each site (Hebert *et al.* 1999; Vander Zanden and Rasmussen 1999; Post 2002; Jennings and Warr 2003). Future studies controlling for base isotopic signatures could confirm whether these differences reflect feeding differences between gull colonies.

Isotopes also do not reach all tissues in the same proportions (diet-tissue fractionation factors). Fractionation factors vary among tissues, species, and diets (Hobson and Clark 1992a,b, 1993; Hobson *et al.* 1993; Haramis *et al.* 2001; Bearhop *et al.* 2002; Pearson *et al.* 2003). Diet-tissue fractionation factors for ^{13}C and ^{15}N from Ring-billed Gulls (Hobson and Clark 1992b) may have slightly biased estimates for nutrient contribution from the marine environment when applied to Herring and Great Black-backed Gulls. However, this was the best option available and is likely a close approximation given the close taxonomic relationships.

Mean isotopic values of Ring-billed Gull prey items were used to represent isotopic signatures of marine and terrestrial environments in models for the three gull species. These isotopic values should provide a good representation of isotopic signatures of potential marine prey items for Herring and Great Black-backed Gulls because they included a mixture of marine fish and invertebrates, both of which are food sources for these gull species (Pierotti and Good 1994; Good 1998). Isotopic signatures of terrestrial prey items had less variation than did marine items; thus isotopic signatures of Ring-billed Gull chick prey items should reflect isotopic signatures of potential prey items of Herring and Great Black-backed Gulls.

Estimations for nutrient contribution from the four prey items to the diet of the three gull species, based on Phillips and Gregg's (2003) model, suggest that marine fish are more significant to the diet of Great Black-backed Gulls than both Ring-billed and Herring Gulls. Although these results may reflect differences in proportion of bulk diet, it could also reflect how chicks physiologically use nutrients from each environment (called "isotopic routing"; Gannes *et al.* 1997). Thus, tissue isotopic composition may reflect the particular nutrient components (amino acids, fatty acids, sugars, etc.) from which they are synthesized rather than the bulk diet (Gannes *et al.* 1997), potentially leading to differences in assimilation rates of C and N (Bearhop *et al.* 2002). Protein is the major organic solute in blood, making up 90-95% of its dry mass (Bearhop *et al.* 2002); therefore $\delta^{13}C$ and $\delta^{15}N$ values of whole blood likely reflect isotopic signatures of blood protein. As well, lipid and carbohydrate contain no N, so $\delta^{15}N$ values of blood would mostly reflect dietary protein (Bear-

hop *et al.* 2002) and the extraction of lipids from blood, which are depleted in ^{13}C, does not significantly affect $\delta^{13}C$ or $\delta^{15}N$ values (Bearhop *et al.* 2000). Positive correlations between $\delta^{13}C$ and $\delta^{15}N$ for the three gull species suggest that nutritional pathways of carbon and nitrogen are coupled (Hobson *et al.* 2000) and gull blood isotopic signatures and diet contribution estimates may reflect protein from these sources, rather than bulk diet.

Higher values of $\delta^{15}N$ in the plasma component compared to the cellular component of Ring-billed Gull chick blood suggest increases in trophic level with chick age because of the shorter turnover time for the former (Hobson and Clark 1993). In contrast, there were no significant differences in $\delta^{13}C$ between plasma and cellular components. Furthermore, there were no significant associations between Ring-billed Gull chick wing-length and either $\delta^{15}N$ or $\delta^{13}C$ of blood plasma, suggesting no increase in trophic level with age, although both relationships were positive. Although the bulk of our evidence does not indicate change in the proportion of food delivered from marine sources to Ring-billed Gull chicks as they aged, samples were small.

We have shown that when nesting in the marine environment, Ring-billed Gulls can use marine prey items to feed their young. Thus, chicks are capable of dealing with elevated salt concentrations, although the extent of this capability still remains unclear. In particular, parents may already have purged a proportion of the salt from the food they regurgitate to their chicks; we are unaware of any studies on this. Captive studies similar to those of Dosch (1997) would be needed to more completely evaluate salt tolerance in Ring-billed Gull chicks. Future studies could also determine whether chicks receiving a higher proportion of marine food are disadvantaged relative to those receiving a higher proportion of non-marine food.

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