MERCURY IN GULLS OF THE BAY OF FUNDY

by

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B.Sc. (biology), University of New Brunswick, 2002

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of

M.Sc.F. (Forestry and Environmental Management)

In the Graduate Academic Unit of Fall 2005

This thesis is accepted by the Dean of Graduate Studies

THE UNIVERSITY OF NEW BRUNSWICK

August, 2004

Abstract

Many studies have used birds as bioindicators of mercury contamination of the environment, but none have assessed the role of birds in cycling mercury through an ecosystem. This study explores mercury exposure and possible role of two gull species in mercury cycling on select breeding grounds along the coast of the Bay of Fundy. Mercury and methyl mercury concentrations in gulls were measured in blood, feathers and eggs of herring gulls (*Larus argentatus*) and great black-backed gulls (*L. marinus*) nesting on the Hospital Islands, and also in soil, terrestrial plants, water seepage, and rockweed beds on and adjacent to the islands. Methylmercury concentrations in feathers ranged from 6-48% of total mercury in herring gulls and 20-91% of total mercury in great black-backed gulls. Gulls breeding in the Bay of Fundy do not seem to be at risk from mercury contamination, nor do they contaminate the marine ecosystem surrounding their nesting colonies with mercury. Mercury concentrations in herring gulls were similar to those found elsewhere in North America, but lower than those found in one European study.

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1. Introduction and Objectives

This thesis is about studying mercury and methyl mercury levels in herring gulls (*Larus argentatus*) and great black-backed gulls (*Larus marinus*) and on and around their nesting sites in the Bay of Fundy. These gulls, as is the case for other seabirds also, are thought to be exposed to increased Hg intake due to their fairly high trophic position, if their habitat is subject to increased atmospheric mercury deposition on coastal ecosystems downwind from major industrial and urban mercury emission sources. Gulls are convenient regional and world-wide indicators of increasing or decreasing ecosystemic pollutant exposure, because of their ubiquity, their easy accessibility when nesting, their per-annual attachment to the same breeding colony, and their regionally restricted migration patterns (Monteiro and Furness 1995).

Herring gulls and great black-backed gulls are sympatric and nest from April to August on un-treed uninhabited islands along the Bay of Fundy coast. Great black-backed gulls differ from herring gulls because they are larger, tend to nest on less rocky areas and more vegetated areas, and have earlier molt and breeding season (Table 1). Great black-backed gulls may have a higher percentage of fish as diet, but generally have the same prey items as herring gulls (Figure 1).

The overall objectives of this thesis are:

Objective 1. To trace mercury concentrations in feathers and blood of both species of gulls from egg to chick, fledgling, and adult.

Objective 2. To determine both gull species' trophic level, dietary mercury levels, and marine or terrestrial dietary contribution as an indicator of the source of the gulls' mercury body burden.

Objective 3. To establish if gulls contribute mercury to their breeding colony, through gradual Hg accumulations in the soil next to the nests.

Objective 4. To check whether seepage water from the breeding colonies is enriched with mercury and methyl mercury.

Progress made towards meeting these objectives is summarized below as follows:

- **Chapter 2** contains a literature review about mercury in general, and in gulls and the marine environment in particular.
- **Chapter 3.** Methods.
- **Chapter 4.** To compare mercury concentrations between herring gulls and great black-backed gulls. As well as to compare mercury concentrations between genders and to assess total mercury to methyl mercury ratio in feathers of adult gulls.
- **Chapter 5.** To assess mercury contribution to chicks.
- **Chapter 6.** Assess mercury contribution to eggs.
- **Chapter 7.** To determine mercury transfers from adult gulls to their chicks, eggs, and breeding colony's soil.
- **Chapter 8.** To establish the two species of gulls trophic levels, dietary sources, and relationship of trophic level and diet to their mercury levels. As well to compare the two species mercury levels in the chicks' diet.
- **Chapter 9** describes whether there are differences in the gull's mercury concentrations at different times of the year and location, by analyzing total mercury

levels in feathers grown during different times of the year and from different breeding colonies alone the Bay of Fundy coast.

- **Chapter 10.** To establish if gulls contribute mercury to their local ecosystem surrounding their breeding colony.
- **Chapter 11.** Risk assessment, conclusions, and recommendations.

General background about mercury

Mercury, once exposed to the atmosphere through natural or anthropogenic activities moves through the environment through a continuous series of volatilization and re-deposition (Wiener *et al.* 2002). As such, mercury travels from warm to cold global regions by way of "global distillation" (Beauchamp *et al.* 1997). Mercury stays in the biosphere for a long time, and cycles between the atmosphere, the land, and the oceans (Mason *et al.* 1994). In this, oceans play a major role in global mercury cycling, and widespread contamination of marine ecosystems in coastal environments is a concern (Monteiro and Furness 1995). Coastal fogs are expected to be part of the process of scavenging atmospherically transported mercury, only to deposit this mercury into coastal catchments as fog banks or fog-enriched aerosols drift through coastal forest canopies. Fog formations are particularly pronounced in the Bay of Fundy, especially during summers, when moist and pollutant-rich air masses enter the Bay and meet the cold fast-flowing, tidal waters. Thus, the Bay of Fundy is an important area to assess local ecosystemic mercury impacts (Ritchie 2003).

Table 1. Summary of sample size, mean, and standard error of adult herring gull and great black-backed gull measurements and general information from the Hospital Islands 2003.

Species	Mean weight (g)	Head bill (mm)	Bill depth (mm)	Gonus depth (mm)	Clutch size	Feeding grounds	Feeding habitat	Migration
Great black-backed gull	1758 ± 48 (19)	148 ± 1 (20)	26 ± 0.3 (20)	NA	3	In-shore	Scavenging	Regional
Herring gull	1008 ± 28 (20)	128 ± 1 (21)	19 ± 0.3 (21)	21 ± 0.3 (21)	3	"	"	"

Figure 1. Summary of moult and breeding seasons for great black-backed gulls and herring gulls.

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As a heavy metal, mercury has many chemical forms: it occurs in volatile form (Hg^0), in aqueous solutions (mainly Hg^{2+}), in solids (HgS), and in biological tissues. Mercury (Hg) concentrations and mercury levels refer to "total" mercury unless otherwise indicated. The most common nomenclatures are:

elemental mercury = Hg (0) = Hg^0;

mercurous ion = Hg (I) = Hg_2^{2+}; and

mercuric ion = Hg (II) = Hg^{2+}.

The most commonly used units are parts per billion = ppb = ug/g = mg/Kg and parts per million = ppm = ng/g = g/Kg. Unless otherwise stated, mercury concentrations are represented in ppb.

Mercury also has a methylated form CH_4Hg (methylmercury or MeHg). Hg in this form is thought to be more toxic than in its other forms (Jeffries 1982, Wiener *et al.* 2002). Methylmercury is a neuro-toxin, which can pass the blood brain barrier and cells' nucleus barrier (Sloss 1995). Most vertebrates are vulnerable to methylmercury because they lack substantial detoxification systems, and their central nervous system is very sensitive to methylmercury exposure.

Methylmercury remains in body tissues longer than mercuric mercury. The latter is fairly quickly removed from the blood through kidney and liver functions. The former cycles from the intestines into the blood, and may than be transferred across the blood barriers into muscle, brain, hair and feather tissues, and also into eggs and foetusses.

Anaerobic sulfur-reducing bacteria are responsible for mercury methylation by adding CH_3 to Hg^{2+}, giving CH_3Hg^+ (Robinson and Tuovinen 1984). Thus, most methylation occurs where sulfate-reducing bacteria are abundant, i.e. in shallow warm

sediments and in sediments with fresh organic matter (Ramlal *et al.* 1986). Methylmercury binds readily to organic material containing proteins with sulfhydryl groups (Burger 1993). When Hg (II) is transformed into methylmercury, it becomes much more bio-available and toxic (Weiner *et al.* 2002).

Methylmercury biomagnifies up the trophic chain (Weiner *et al.* 2002). In aquatic food webs, uptake by organisms starts by acquiring methylmercury through water directly, or indirectly through their diet (CCME 2000). Direct uptake from water occurs because methylmercury is water-soluble, and adsorbs or absorbs through skin and respiratory surfaces (USEPA 1997). Uptake of methylmercury by way of contaminated food is common in fish, and piscivorous birds and mammals (USEPA 1997).

Methylmercury intestinal absorption rate is nearly 100%, where inorganic mercury absorption is only a few percent (Schuhammer 1987). Methylmercury is first absorbed through the gastrointestinal tract and enters the blood stream where it is carried to all parts of the body. Methylmercury accumulates in growing tissues such as hair, fur, and feathers (Zillioux *et al.* 1993).

Sub-lethal effects of methylmercury in birds are limited to behavioural and reproductive effects. Dietary methylmercury exposure of levels below the concentrations causing signs of toxicity can reduce reproductive success (Wolfe *et al.* 1998). The Canadian residue tissue guideline recommends a reference concentration (RCs value) of less than 33 ppb (diet WW) methylmercury for protecting mammals and birds, which consume marine biota (CCME 2000).

Methylation co-occurs with demethylation. Inorganic mercury found in higher trophic level tissues are often attributed to the demethylation mechanism (Weiner *et al.* 2002). Demethylation is thought to occur by microbial activity and photodegeneration in

shallow, clear freshwater bodies (Robinson and Tuovinen 1984, Sellers *et al.* 1996). Demethylation is the cleavage of the carbon-mercury link, followed by Hg^{2+} going back to elemental mercury, and re-emitting back into the atmosphere (Robinson and Tuovinen 1984). Other biologically-derived methylmercury detoxification mechanisms may exist within gulls. Unfortunately, demethylation mechanism(s) are poorly understood.

Hg binding to sulfur (S) and selenium (Se) may give some natural protection against methylmercury poisoning. There appears to be a decrease in methylmercury levels when in co-occurrence with selenium. Selenium in large concentration is also toxic, but at normal levels restores the activity of certain liver enzymes and glutathione-possessing anti-toxin defenses (Heinz and Hoffman 1998). Heinz and Hoffman (1998) conducted a study on mallard ducks fed selenomethionine, and found adult ducks had fewer signs of methylmercury exposure and the adverse effects of Hg were greater in their offspring leading to decreased survival and growth.

2. Literature Review

2.2 Sources of Mercury

2.2.1 Natural sources

Mercury occurs naturally in the environment and is responsible for 2000-3000 tonnes/yr. of total global emissions (USEPA 1997). Natural mercury comes from 6 major sources: 1) volatilization in aquatic environments; 2) volatilization from vegetation; 3) degassing of geological materials; 4) volcanic and geothermal activity; 5) dust and; 6) wildfires (USEPA 1997).

2.2.2 Anthropogenic sources

Some of the anthropogenic sources of mercury emissions and re-emissions are due to chlor-alkali plant operations, fossil fuel burning, coal burning, landfills, metal smelting, cement manufacturing, and waste incineration (Douglas 1994). Currently, two thirds of mercury in the environment come from anthropogenic sources in the form of Hg^0. It has been estimated that it would take twenty years after the termination of all anthropogenic mercury sources for this mercury to be eliminated from atmsopsheric re-cycling (Mason et. al 1994).

Globally, Canada is not a major contributor of mercury emissions into the environment and Atlantic Canada is so to an even lesser extent. Doiron *et al.* (1998) found Atlantic Canada was responsible for 6.4% (960 Kg/yr.) of the national 15 tonnes/yr emissions. In Atlantic Canada, electric power generation is the primary mercury source at 30%, and municipal waste incineration is second at 25%. The third and fourth highest mercury polluters refer to non-utility fuel oil combustion and to municipal wastewater production. These first four contributors amount to 80% of

Atlantic Canada's anthropogenic mercury emissions into the environment (Doiron *et al*. 1998).

Much of Atlantic Canada's mercury comes from anthropogenic sources from other districts. Long-range atmospheric transport from the Midwestern U.S., Eastern U.S., and central Canada is starting to have an influence on the air qualityin New Brunswick (Rutherford and Matthews 1998). The U.S. contributes to mercury deposition in Canada, but Canada also deposits air-borne pollutants in the northeastern U.S. (NESCAUM 1998). Since mercury is a global pollutant, mercury emissions need to be dealt with by governments and industry at all levels (Beauchamp *et al.* 1997).

2.2.3 Abiotic sources

Mercury occurs naturally in rock and ores (Jonasson and Boyle 1972). Concentrations of mercury in mineral soil layers generally vary based on bedrock type and the rate of bedrock and soil weathering. Canadian soils tend have relatively low mercury concentrations in mineral soil layers (around 20-150 ppb), except in cinnabar deposits with high weathering rates (Jonasson and Boyle 1972). Atmospherically deposited mercury tends to be absorbed by the organic matter in to top soil layers. Generally, most of the mercury found in soils occurs within the top 10 cm of soil (Hogg *et al.* 1978).

2.2.4 Biotic sources

Wildlife is mainly exposed to mercury through feeding on bio-accumulated mercury in prey and in vegetation. Within the wildlife organisms, mercury accumulates in organs such as kidneys, liver, and brain. Mercury is returned to the environment

through shedding feather, fur, feces and urine, and through carcasses. Mercury is also transferred into eggs and off-spring. Wildlife contributes mercury recycling through bio-concentrating mercury along the foodchain. If wildlife is concentrated in small areas, such as gulls on their breeing colonies, then mercury may accumulate locally in these areas and affect the local ecology. In wildlife, there is a separation of bio-accumulated mercury and methyl mercury. Generally, methyl-mercury accumulates in muscle tissues, blood, brain, fur, hair, and feathers. Inorganic mercury accumulates in kidneys and liver.

2.3 Previous Mercury Research in Atlantic Canada

2.3.1 Piscivorous wildlife

Piscivorous wildlife may be at the greatest level of risk of ingesting elevated mercury levels (Weiner 2002, Scheuhammer and Blancher 1994). For example, the common loon (*Gravia immer*) has become a fish-eating wildlife indicator species of Hg levels in Atlantic Canadian fresh water ecosystems. There is no such indicator species yet for the Bay of Fundy region. Gulls may be ideal indicator species for this area because they are abundant, easy to locate, and relatively easy to capture during their breeding season. Already, herring gulls are used elsewhere as sentinels of human exposure levels, environmental pollution, and assessment of potential effects on the animals themselves (Burger 1997). Eggs from great black-backed gulls are used as indicators of contaminant levels in the eggs of bald eagles (*Haliaeetus leucocephalus*) from Lake Ontario. Great black-backed gulls and bald eagles are suspected to show similar food sources and trophic positions (Weseloh *et al.* 2001).

2.3.2 Loons

Mercury levels in blood of Common loons from Kejimkujik National Park were found to be twice as high as loons from elsewhere in North America (Evers *et al.* 1998), even greater than the Great Lakes loons. Male loons have higher mercury concentrations compared to females, and the chicks have up to 10 times lower levels than the adults (Evers *et al.* 1998). Barr (1986) found loons with a diet of 0.2-0.4 ppb (WW) had no overt signs of toxicity but produced fewer eggs and had decreased site fidelity. Mercury concentrations in the significant prey of the loons varied from 0.3-0.4 ppb (WW), and this decreased their reproductive success. No chicks were produced at levels above 400 ppb (Evers *et al.* 1998). The lowest observed adverse effect concentration (LOAEC) based on a laboratory study of mallard ducks is 100 ppb (WW). This is considered the LOAEC for sensitive species (Eisler 1987).

Nocera and Taylor (1998) speculated that changes in the reproductive behaviour and nesting may be due to eating high mercury prey. Some of the behaviour changes observed by Nocera and Taylor's (1998) were: increased time preening the chicks, decreased brooding time, increased chick mortality due to greater risk of predation, and changes in energy expenditure.

2.3.3 Juvenile osprey

Juvenile ospreys (*Pandion haliaetus*) from Atlantic Canada have similar mercury concentrations as loons. Blood concentrations from twelve juvenile osprey had a median of 0.13ug/ml (wet weight) or 2.4ug/g (dry weight) (Burgess and Garrity 1998). Burgess and Garrity (1998) surmised that juvenile fish-eating birds like common loons, osprey, and bald eagles from the maritime provinces (eastern Canada) and Maine (United States

have similar mercury concentration because of dietary exposure. Although levels may be similar toxic effects may not be similar because different species have different sensitivities to mercury and will show different degrees of adverse effects (Burgess and Garrity 1998).

2.3.4 Double crested cormorants and herring gulls

Elliott *et al.* (1992) found double-crested cormorants (*Phalacrocorax auritus*) from the Saint John Harbour area Bay of Fundy had higher mercury concentrations than other seabirds in the same area. Mercury and selenium concentrations were significantly lower in herring gulls than in Leach's storm petrels (*Oceanodrama leucorhoa*), Atlantic puffins (*Fratercula arctica*), and double-crested cormorants (Elliott *et al.* 1992). Herring gulls from Magawagonish Island had significantly lower mercury concentrations in their livers and kidneys compared to herring gulls from Kent Island and Gull Island (Elliott *et al.* 1992) (Fig. 1). High variability in mercury concentrations exists between species and between individuals of the same species.

2.7 Elimination Pathways

2.7.1 Eggs

Since 1972, the Canadian Wildlife Service (CWS) has used herring gull to monitor mercury and other toxic chemicals in the Great Lakes (Koster *et al.* 1996). The egg mercury concentrations have decreased from 1972-1992 and are now at a steady state, although the levels are not expected to decline further unless efforts are made to further reduce anthropogenic mercury sources (Koster *et al.* 1996). Mean total mercury

levels from the Great Lakes herring gull eggs collected in 1992 range from 0.14 – 0.2 ug/g (WW) (Koster *et al.* 1996).

Few people have studied mercury concentration in eggshells but mercury has been linked to egg shell thinning (Scheuhammer 1990), although the shell is not a major mercury elimination pathway (Vermeer *et al.* 1973). The shell was found to account for 8.3% of the total egg weight but only 1% of the egg mercury burden (Vermeer *et al.* 1973). Egg yolk, albumen, and shell have different mercury concentrations. Burger (1994) found that eggshells had significantly lower mercury concentrations compared to homogenized egg contents in herring gulls.

2.7.2 Blood

Although blood is not widely used to measure mercury concentrations it has the advantage that it gives the actual mercury concentration at the time of sampling. In mew gull (*Larus canus*) chicks, mercury in blood is significantly correlated with mercury concentrations in flank feathers but not with down feathers (R^2= -0.09, P= 0.760) (Kahle and Becker 1999). Flank feather mercury concentrations are 5 times higher than blood mercury concentrations on a dry weight basis, and 23 times higher on a fresh weight basis. No relationship between blood and down mercury concentrations is found because down develops in the egg and reflects the body burden of the embryo, while blood reflects the body burden of the chick (Kahle and Becker 1999).

2.7.3 Feathers

Methylmercury is the biologically significant form of mercury for birds because methyl mercury accumulates in the tissues of fish and other prey items (Hahn *et al.* 1993, Elliott *et al.* 1996). With birds, feathers are a major excretion pathway for methyl-mercury (Honda *et al.* 1986, Braune 1987, Furness *et al.* 1986). Feathers are easy to collect, have minimal risk of secondary contamination, and can be stored since organic mercury is firmly bonded to the feather keratin (Hahn *et al.* 1993).

Thompson and Furness (1990) found 100% of mercury in the feathers to be organic mercury in marine birds. Burger (1993) found 70-93 % of a birds total body burden of mercury is eliminated via the feathers. Lewis and Furness (1991) found 49% of a single dose of methylmercury was eliminated via the feathers.

Intraspecific variations are common in seabird mercury studies with a few birds usually having quite high mercury concentrations (Monteiro and Furness 1995). The high variability among individual birds within a population may be attributed to individual specialization in diet and mercury excretion (Monteiro and Furness 1995).

Ingested mercury enters the blood system through re-absorption in a methylated form. In general, methyl mercury binds to sulfhydryl groups (S-H bonds or disulfide bonds). Since feathers have a higher concentration of S-H groups, blood mercury is deposited in the feathers during feather growth (Lewis and Furness 1991, Lewis and Furness 1993). Unlike fish scales and mammal hairs, which grow continuously, feathers grow only during a few specific times of the year, so the mercury excretatory path via feathers is only available during the periods of feather growth. During periods of year when no feathers are growing the mercury accumulates in other tissues. Both adult and young birds use feathers as a methylmercury elimination pathway (Burger 1993).

Methylmercury concentration in the feather is determined by the diet and body burden at the time of feather growth and is indicative of methylmercury levels in other body tissues (Braune and Gaskin 1987).

2.8 Moult

Different feather tracts may have different mercury levels. Moult rhythms will help to interpret any mercury patterns in the feathers (Hahn *et al.* 1993). Feather type and stage of moult needed to be measured in order to make comparisons with other literature. Hahn *et al.* (1993) found a homogeneous distribution of mercury in primary feather vanes from herring gulls and goshawks; thus, analysis of only the tips of the 10^{th} primary feather was possible. The left and right primaries do not differ in mercury, which is expected because feather mercury is derived from the blood mercury at the time of growth and the left and right primaries are grown at the same time; therefore, right or left primaries can be used in mercury analysis (Braune and Gaskin 1987).

Braune (1987) found there was a decrease in mercury concentrations along the primary wing feathers from the inner primary #1 (first grown) to the outer primary #10 (last grown). The first grown primaries receive the highest mercury concentrations and, as the body burden of mercury decreases with the progress of the moult (Furness *et al.* 1986), mercury concentrations decreases from primary number 1 to primary number 10 (ex. Bonaparte's gulls (*Larus philadelphia*) (Braune and Gaskin 1987), sparrowhawk (*Accipiter nisus*) (Buhler and Norheim 1981), Peruvian booby (*Sula variegata*) (Gochfeld 1980), and other seabird species (Furness *et al.* 1986)).

The primary feather moult can be used as a gauge of the general progress in moult in herring gulls and great black-backed gulls. All feathers formed by juveniles are formed during a short period on the nesting grounds and are expected to have similar mercury concentrations. Great black-backed gulls and herring gulls typically end pre-basic moult in December (Pierotti and Good 1994, Good 1998). Thus, head feathers complete their growth sometime in December and represent late fall/early winter mercury levels (non-breeding season levels). The 5th greater covert feathers are moulted just prior to secondary moult, which starts when the 6th primary feather (P6) or the 7th primary feather (P7) moult (Pierotti and Good 1994, Good 1998); thus, the 5th greater covert feathers are grown in July or August and represent mercury concentrations around the time of fledging in great black-backed gulls and herring gulls. In great black-backed gulls the primary feather moult starts approximately May 1st and takes 4 months (Good 1998). Therefore, the 10th primary feather is grown in September and represents fall mercury levels. Herring gulls from the Bay of Fundy tend to start primary moult shortly after the great-black-backed gulls; thus, their 10th primary feathers represent fall mercury levels as well. Sampling feather tracts grown at different times of the year makes it possible to trace the mercury concentrations through the year.

2.9 Effect of Age and Gender on Mercury Levels in Birds

2.9.1 Gender

Braune and Gaskin (1987) conducted a study on Bonaparte's gulls migrating through New Brunswick in the fall, finding adult male gulls have significantly higher mercury concentrations than females in their 1st-5th primary feathers. Braune and Gaskin (1987) attributed the difference between genders to egg laying by females, emphasizing

the importance of mercury elimination via the primary feathers in males. Once the males had eliminated a large proportion of their mercury load into the first grown primary feathers their levels were similar to those of the female gulls. Further support for the importance of mercury deposition in the eggs by female gulls was reflected in the comparison of pre- and post-autumn moult head feather mercury concentrations. Braune and Gaskin (1987) found no significant difference between the genders in the mercury concentrations of pre- autumn moult head feathers.

Lewis *et al.* (1993) found body feather and internal tissue mercury levels were independent of gender in herring gull females from Germany, although females had lower concentrations of mercury in primary feathers. Female herring gulls had lower mercury concentrations in their primary feathers because they excrete approximately 20% of their body burden of mercury into their eggs (Lewis *et al.* 1993).

2.9.2 Age

Since gull chicks are fed on local food sources, their mercury concentrations reflect the mercury levels around the colony. No pattern of mercury related to age, has been found in herring gull, red-billed gull (*Larus delawarensis*), or great skuas (*Stercorarius skua*) (Hutton 1981, Furness *et al.* 1990, Thompson *et al.*1991). Thompson *et al.* (1991) did not find a relationship between adult feather mercury concentrations and age (in years) but did find adult feather mercury concentrations were significantly higher than chick feather mercury concentrations. The mercury concentration pattern is generally chick < fledgling < adult (Burger 1995). It is not possible for the present study to use adult birds of a known age, but it is possible to compare the mercury concentrations of chicks, eggs, and adults. Since adult feather mercury concentrations

are independent of age, ages are not necessary for intra-species comparisons of feather mercury concentrations (Thompson *et al.* 1991).

Thompson *et al.* (1991) did not find a relationship between great skuas' chick feather mercury concentrations and chick age in days. The lack of age-mercury relationship is attributed to the increase in mercury intake because of increased food intake and the chick's increasing size (Thompson et al 1991). Chicks with diets consisting of lower trophic levels food items are expected to have lower mercury concentrations than chicks consuming higher trophic levels (Gariboldi *et al.* 1998). It is difficult to separate possible effects due to mercury and other ecological factors in the wild especially at low to moderate mercury levels (Gariboldi *et al.* 1998).

Becker *et al.* (1994) found mercury concentrations in down feathers were higher than those in back feathers in three species of seabirds (herring gull, black-headed gull *Larus ridibundus*, and common tern). In herring gulls, mercury concentrations decreased from 1420 ppb in down to 1270 ppb in back feathers (Becker *et al.* 1994). Becker *et al.* (1994) attributed the decrease in feather mercury concentration compared to down feathers to a depletion of the body burden of mercury. The mercury in the down comes from mercury deposited by the female gull into her egg, while the chick feather mercury concentrations are from mercury ingested in the chick's food (Becker *et al.* 1994). Becker *et al.* (1994) found significant differences between down and flank feathers and between flank and back feathers in highly contaminated herring gull chicks but no significant differences in feather types in less contaminated chicks. In highly contaminated chicks the back feathers had lower mercury concentrations than down by 26% and in less contaminated chicks mercury in back feathers was 12% higher than down; thus, more contaminated chicks eliminated mercury more quickly (Becker *et al.*

1994). Chicks with high mercury concentrations in their down also had higher body mercury concentrations (Becker *et al.* 1994).

2.10 Relationship of Feather Mercury Levels to Internal Body Tissue Mercury

Seabirds are not affected by mercury concentrations as strongly as terrestrial bird species; thus, they are likely adapted to naturally higher mercury diets (Thompson *et al.* 1991). Thompson *et al.* (1991) found feather total mercury concentrations in great skuas were correlated to internal body tissues (liver, kidney, and muscle) but the same correlation was not found with methylmercury. Biotransformation of methylmercury into inorganic mercury, stored in the internal tissues, acts as a detoxification mechanism (Honda *et al.* 1986, Braune and Gaskin 1987, Thompson and Furness 1989). Since a correlation between internal tissues and feather total mercury concentrations is present, sampling only feathers is adequate to assess the individual total mercury concentrations. Therefore, feathers represent an easy and robust way to assess mercury levels in birds.

If feathers are used to predict other tissue mercury concentrations, the time when the feathers are grown must be taken into account. Because herring gulls have a post-nuptial moult, it is possible to predict how much of the total body burden of mercury is deposited in the feathers and, in the case of females, the eggs (Lewis *et al.* 1993). Egg mercury levels are correlated with liver mercury levels, which are expected because the majority of yolk synthesis occurs in the liver (Lewis *et al.* 1993).

Feather mercury levels are directly related to the mercury concentrations in the internal tissues at the time of feather growth when an active blood supply is present (Burger 1997). Thus, feathers are stable archives of the internal tissue mercury. Herring

gulls are abundant, easily captured, and mercury concentrations are available from various worldwide locations; therefore, they are a good bioindicator species of non-point source mercury pollution (Gochfeld 1997). Mercury in the primary feather comes primarily in the form of methylmercury via a high proportion of fish in the herring gull's diet (Lewis *et al.* 1993).

Several authors use the ratio of 7:3:1 (fresh weight) in feather, liver, and muscle respectively and use one tissue type to predict the others (Jensen *et al.* 1972, Appelquist 1985). Lewis and Furness (1991) found black headed gull chicks deposit 49% of a mercury dose into their feathers. The highest level of mercury deposited in the feathers is estimated in Bonaparte's gulls at 93% of the body burden in adult gulls and 88% in juvenile gulls (Braune and Gaskin 1987). Lewis and Furness (1991) found only 71% of the administered dose (mean $\pm$ SE total excretion rate of 71.91 $\pm$ 13.74) was excreted during the fledging period and it is assumed the remaining mercury is stored in the internal tissues. Juvenile black-headed gull chicks have a mean $\pm$ SE excretion rate via feces of 22.58 +/- 13.74 and a mean $\pm$ SE excretion rate via feathers of 49.33 +/- 4.47 (65% of the total body burden) (Lewis and Furness 1991).

2.11 Biological Significance

2.11.1 Field versus laboratory studies

Gull mercury concentrations are good indicators of the mercury levels in the local marine environment and potential risks to human health. Herring gulls are used worldwide to show trends in mercury levels but there are few data about mercury loads in the Bay of Fundy region. Great black-backed gulls are less widespread and very little

information regarding their mercury levels is available. In the Bay of Fundy, great black-backed gulls and herring gulls are sympatric; thus, it will be interesting to assess any differences between mercury concentrations of the two species. Gull mercury levels give an indicator of local mercury levels in the ecosystem but it is more difficult to assess the biological significance of the mercury levels found in the gull species because the adverse effects of mercury on embryo development and chick survival, in wild herring gulls, are not well studied (Gochfeld 1997).

Determining biological significance is difficult for the two gull species presented in this study, because tissue levels associated with adverse effects have not been assessed in the laboratory (Burger 1993). Furthermore, laboratory studies usually feed mercury to the gulls at a much higher level and in a different form than those found in wild gull populations. There is evidence gulls distribute mercury differently when exposed to artificially elevated mercury levels such as those used in laboratory studies (Lewis and Furness 1991). Braune and Gaskin (1987) found wild juvenile Bonaparte's gulls have 5.8% of their mercury body burden in the carcass, whereas Lewis and Furness (1991) found 39% of the body burden of mercury is in the carcass of laboratory reared juvenile black-headed gulls. Mercury in the diet is likely to be more damaging to chicks because they are in a developmental stage. It is also postulated that lower mercury concentrations than those causing obvious sub-lethal effects may cause more subtle behavioral changes such as decreased parental care and less efficient feeding by chicks (Nocera and Taylor 1998).

Risk assessment of herring gulls and great black-backed gulls is difficult because these species are generally used only as biomonitors of potential risk to human health. The "no observed adverse effect level" (NOAEL) for feather mercury concentrations is

not adequately studied for many bird species including herring gulls and great black-backed gulls (Burger and Gochfeld 1997). A better understanding of the effects of mercury in eggs and chicks exists in some species, although the effects of mercury on herring gulls and especially great black-backed gulls are not well studied in any stage of maturity. Many studies report on the levels of mercury in nature, but not whether these mercury levels have any effects on the study species (Burger and Gochfeld 1997).

In order to assess the biological significance of the mercury levels, the present study will compare feather and blood mercury concentrations to other species where the levels causing adverse effects are known. Understanding the relationships between total body burdens, levels in internal tissues, concentrations associated with adverse effects, and feather mercury concentration needs to be established in order to comprehend the biological significance. Unfortunately, no such study exists for either species of this study; thus, relative body burden and subsequent contributions to the local island ecosystem will be established using other gull species. Therefore, the present study will not provide a risk assessment of the gull populations but will establish potential mercury input levels to the local island ecosystem, provide a bench mark for future seabird mercury research, and a starting point for managers to interpret mercury levels in the Bay of Fundy.

2.11.2 Mercury levels causing effects

There is uncertainty about applying laboratory studies to wild birds because it is very difficult to establish whether any adverse effects are due to methylmercury dietary exposure or other factors (Gariboldi *et al.* 1998). Some species of seabirds can tolerate mercury concentrations of thousands of ppb. Herring gulls may be extremely tolerant to

mercury. No adverse reproductive effects were found in herring gull eggs with mercury concentrations as high as 15 800 ppb (WW), whereas other bird species have reduced hatching success at 500 ppb (WW) (Vermeer *et al.* 1973). Herring gulls and some other fish-eating birds may be tolerant to mercury because fish are high in selenium (Koster *et al.* 1996). Selenium reduces the toxic effects of methylmercury, thus enabling some piscivorous bird species to survive even with elevated mercury body burdens (Scheuhammer 1987). Monteiro and Furness (1995) believe some seabirds with elevated mercury concentrations have evolved tolerances to mercury associated with their high trophic level diet.

Many bird species have been tested for sub-lethal mercury levels but the concentrations are species-specific and no toxicity levels have been found for great black-backed gulls. Many inter- and intra-species differences exist in the mercury levels causing effects in eggs and feathers (Table 2, Table 3). For the current study, Burger and Gochfeld's (1997) general mercury level of 500-6000 ppb (WW) or 1500-18 000 ppb (DW) in eggs is considered the threshold mercury level causing effects in eggs and Eisler's (1987) general mercury level of 5000-40 000 ppb (DW) in feathers is considered the threshold mercury level causing effects in chicks as well as adults. Since these thresholds have such a wide range I am going to use the lower values of each threshold as the levels of possible risk to gulls.

Table 2. Levels of total mercury in eggs (ppb) (WW) associated with adverse effects in birds.

Species	Level (ppb) (WW)	Effect	Lab/Field (L/F)	Source from
Variety (not only sea-birds)	500-6000	Decreased egg weight Embryo malformations Lowered hatchability Decreased chick growth Lowered chick survival	F	Burger and Gochfeld 1997
Ring-necked pheasant (*Phasianus colchicus*)	1300-2000	Reduced hatchability	F	Borg *et al.* 1969
Ring-necked pheasant	50-1500	Reduced hatching success	L	Fimreite 1971
Black duck (*Anus rubripes*)	5530	Lower hatchability	L	Finley and Stendell 1978
Black duck	4700	Lower chick survival	L	Finley and Stendell 1978
Mallard duck (*Anus platyrhynchos*)	790-860	Significant reproductive and effects	L	Heinz and Hoffman 1998
Common loon (*Gravia immer*)	52 000	Zero young produced	F	Fimreite 1974
Common loon	2000-3000	Reduced reproduction	F	Barr 1986
Common tern	1080	Severely reduced hatching and nesting success	F	Gilbertson 1974
Common tern	1000 (MeHg 820)	No effect	F	Fimreite 1974
Common tern	3650 (MeHg 2400)	Reproductive failures	F	Fimreite 1974
Least tern (*Sterna antillarum*)	<900	No effect on hatching success	F	King *et al.* 1991
Caspian tern (*Sterna caspia*)	<900	No effect on hatching success	F	King *et al.* 1991

Table 2. Continued.

Species	Level (ppb) (WW)	Effect	Lab/Field (L/F)	Source from
Black skimmer (*Rynchops niger*)	460	No effect on hatching success	F	King et al. 1991
Herring gull (*Larus argentatus*)	15 800	No effect	F	Vermeer et al. 1973
Herring gull	220	No effect	F	Gilman et al. 1977
Northern gannet (*Morus bassanus*)	490	No effect	F	Barrett et al. 1985
Merlin (*Falco columbarius*)	1240	Reduced productivity	F	Ellis and Okill 1990
Osprey (*Pandion haliaetus*)	100-400	No effect	F	Hakkinen and Hasanen 1980
White-tailed eagle (*Haliaeetus albicilla*)	3000-11 000	Reduced hatching success	F	Borg et al. 1969

Table 3. Levels of total mercury in feathers (ppb) associated with adverse effects in birds.

Species	Level (ppb)	Effect	Source location
Feathers (variety of birds)	5000-40 000	Reduced hatch of eggs laid by birds with such levels	Eisler 1987
Black duck (*Anus rubripes*)	65 600	No duckling survived	Finley and Stendall 1978
Black duck	40 800	Lower reproduction	Finley and Stendall 1978
Mallard duck (*Anus platyrhynchos*)	9000-11 000	Reproductive and behavioral effects	Eisler 1987
Sparrowhawk (*Accipiter nisus*)	40 000	Sterility	Solonen and Lodenius 1990

3. Methods

3.1 Study area

In 2001 and 2002, ten islands in the Bay of Fundy, New Brunswick, Canada were sampled. The ten islands were divided into three regions and further categorized as part of the inner or outer Bay of Fundy (Figure2, Figure3, Table 4). Herring gulls and great black-backed gulls live in mixed species colonies except on Hog Island where only herring gulls are present. Within each breeding colony, the gull species have distinctly different nesting territories. During the 2003 field season, only the Hospital Islands and Mink Island gull colonies were sampled. The Hospital Islands are two islands connected at low tide by a ridge; thus, forming one island at low tide and two islands at high tide.

Figure 2. Location of great black-backed gull and herring gull colony sites sampled for adult mercury levels in 2001-2002.

Figure 3. Location of the Hospital Islands where the great black-backed gull and herring gull colony was sampled for mercury levels in 2003. Mink Island is a control site with no gull colony, and was also sampled for mercury levels in 2003. The map is modified from http://www.outerislandtours.com/map_files/mapgif.gif.

Table 4. Details of Bay of Fundy collection site locations for herring gull and great black-backed gull adults, eggs, chicks, and prefledglings.

Location in Bay of Fundy	Region	Island	ID code	Year	Ages
Inner Bay	Saint John area	Manawagonish Island	STJ	2001, 2002	Adult
Inner Bay	Maces Bay	Salkeld Islands	MB	2001, 2002	Adult
Inner Bay	Maces Bay	New River Beach Island	MB	2001, 2002	Adult
Outer Bay	Passamaquoddy Bay	Hog Island	PB	2001, 2002	Adult
Outer Bay	Passamaquoddy Bay	Dick's Island	PB	2001, 2002	Adult
Outer Bay	Passamaquoddy Bay	Hospital Island	PB	2001, 2002	Adult
Outer Bay	Passamaquoddy Bay	Flatpot Island	PB	2001, 2002	Adult
Outer Bay	Deer Island area	Sandy Island	DI	2001, 2002	Adult
Outer Bay	Deer Island area	The Hospital Islands	DI	2001, 2002, 2003	Adult, chicks, prefledglings, eggs
Outer Bay	Deer Island area	Mink Island	DI	2003	NA

3.2 Study Design

Two designs were used in this study. In 2001 and 2002, ten island gull colonies from the inner to outer Bay of Fundy were sampled for mercury. The samples were collected in conjunction with Nichola Benjamin's research project (in progress) and used to asses the variation in great black-backed gulls and herring gulls along the Bay of Fundy coast. During 2003, a different study design was used where only one gull colony (one island) in the outer Bay of Fundy and a control island (no gulls) were sampled for mercury. The 2003 study design was based on the objectives, questions, and hypothesis presented in the introduction.

3.3 Sample Preparation

All samples, except blood and feathers, were freeze-dried for 48 hours prior to analysis. Feather samples were analyzed whole except the adult 5^{th} greater covert feathers, which were split down the center of the shaft using a scalpel (Lewis et al 1993). Feather splitting enabled the same feather to be tested for total mercury and either methylmercury or stable isotopes while removing any differences in mercury concentrations caused by possible differences between the top and bottom of the feather (Lewis *et al.* 1993). All feathers were washed vigorously with deionized water, washed again with acetone, rinsed with deionized water, and air dried in order to remove any gross dirt particles and surface oils (Applequist *et al.* 1985, Burger 1993).

3.4 Total mercury analysis

Biological samples (all samples except soil and water) were digested using concentrated ultra-trace metal grade 7: 3 ratio of nitric (HNO_3) and sulfuric (HSO_4) acid

solution at 100^{o}C for 4 hours. Soil was digested using concentrated ultra-trace metal grade 1: 3 ratio of hydrochloric (HCl) and nitric acid solution at 100^{o}C for 4 hours. The biological and soil samples were further digested using a 20% BrCl solution overnight at room temperature. Water samples were digested via overnight UV radiation to break down any organic bonds (Olson *et al.* 1997). Total mercury concentrations were determined using cold vapour atomic fluorescent spectophotometry (CVAFS) involving the use of a Tekran 2600.

3.5 Methylmercury analysis

The Bloom method was used for methylmercury analysis of the adult 5th greater covert feathers (Liang *et al.* 1994). Feathers used in methylmercury analysis were digested in Teflon containers using a 25% solution of potassium hydroxide (KOH) overnight at 80^{o}C. The feathers were further digested using concentrated methanol (CHO_4) for 1 hour at room temperature. One milliliter of sample was diluted with deionized water and adjusted to pH 4.9 using acetate buffer in Teflon containers. The diluted sample was ethylated using sodium tetraethyl borate (NaTEB) for 15 minutes and purged with argon gas for 20 minutes so the gaseous mercury forms could adhere to the graphite traps. Argon gas was used as the carrier gas. Methylmercury is separated from the other forms of mercury using a gas chromatograph phase separator (GC column) interfaced to a CVAFS Tekran Model 2500 and pyrolyzed so the methylmercury concentration can be calculated from the resulting peak areas (Montuori et al 2004).

3.6 Quality control

The precision of total and methylmercury analyses was assessed using National Research Council Canada (NRC) certified dogfish muscle reference material (DORM-2) for all samples except soil and water. The precision of total mercury analysis of soil was assessed using National Research Council Canada (NRC) certified marine sediment reference material (PACS-2). Total mercury analysis was calibrated using standard American Chemicals Ltd. (A&C) mercury standard solution M-195 (1000 ppm) and methylmercury analysis was calibrated using Alfa Aesar The Right Chemistry certified Methylmercury (II) Chloride (CH3HgCl) standard # 33553 (1000 +/- 10 ug/ml). Feather, blood, water, and guano samples are reported on a fresh weight basis (ng/g or ppb FW) and all other samples are reported on a dry weight basis (ng/g or ppb DW). All samples were run in batches that included blanks and calibration standards. Further quality control, in total mercury analysis, included periodic inter-lab (Canada-wide) comparisons of an aliquot of a large sample of known concentration. The standard error of standard solutions ranged up to 15% in total mercury and 10% in methylmercury analyses. Detection limits in total mercury and methylmercury analysis are 0.1 ng.

3.7 Statistics

Analyses of variance (ANOVAs), repeated measures analysis of variance (ANOVARs), tables, and box plots were used to establish significant difference in mercury accumulations or transfers comparing species, locations, tissue types, age, gender, years, period in breeding season, and control site. Regression analysis and plots were used to assess any relationships between the tissue types, mercury, methylmercury, and stable isotopes. Significance was assessed using $\alpha = 0.05$.

4. Comparing Species, genders, and methylmercury

4.1. Introduction

The purpose of this chapter is to identify differences in mercury concentrations between the two species and between genders using the 5th greater covert feathers and blood. Another purpose of this chapter is to assess methylmercury concentration and the proportion of methylmercury to total mercury in the 5th greater covert feathers of both gull species.

Great black-backed gulls and herring gulls are similar gull species nesting in mixed colonies in the Bay of Fundy. Generally great black-backed gulls are considered to have a higher trophic level, although this study does not confirm this finding. Please refer to the introduction for species differences (Figure 1, table 1).

Female gulls have an elimination mechanism via egg laying which males do not. Therefore, male gulls should have higher mercury concentrations during the breeding season. Males may sequester more mercury into their first grown primary feathers than females because the lack of egg laying as an extra elimination mechanism. After breeding season the males' mercury levels should be similar to the females' mercury levels assuming male and female gulls eat similar diets.

Mercury accumulates in gulls from their diet and bioaccumulates in gulls because mercury is ingested faster than it is excreted. In seabirds, most of the bio-accumulated mercury is in the methylated form (Braune 1987). The percent of methylmercury generally depends on the tissue but mercury incorporated in the feathers is nearly 100% methylmercury (Thompson and Furness 1989).

4.2 Methods

Please refer to chapter 3 for laboratory methods.

Under federal and university permits, herring gull and great black-backed gull adults were trapped during incubation between May 1 and June 30 over a three year period (2001, 2002, and 2003). During 2001 and 2002, haphazard nests were nest trapped. During 2003, twenty nests of each species were staked and nest trapped. During trapping, the eggs were removed and kept warm in a padded egg box and replaced in the nest with decoy eggs. Only one member of the pair was trapped and the cages were covered to calm and protect the bird while waiting to be processed.

During 2001 and 2002, the 5th greater covert feathers and blood were sampled from adult gulls on nine islands in the Bay of Fundy (Figure2, Table 3). During 2003, all sampling was located on the Hospital Islands and Mink Island (Figure2). Each gull was banded on one leg with a "united states fish and wildlife service" (U.S.F.W.S.) metal band and on the other leg with a plastic field-readable colour band with a unique two alpha code. The colour band was placed on the right leg of males and the left leg of females. A 1-2cc blood sample was extracted using a 22-gauge needle from a leg or wing vein with a heparinized syringe and stored in glass vacuum containers. The tip of the outermost primary wing feather, the 5th greater covert wing feather, and 5-10 head feathers were removed and placed in a labeled plastic bag. Any regurgitation from the gulls produced during the trapping and handling process was collected in labeled plastic sample bags. Within 10 hours of sampling all feather and blood samples were stored at –20˚C until mercury analysis.

Blood and feather samples represent mercury burdens during specific times of the year. Blood reflects the current mercury burden and diet. The head feathers reflect mercury burden in winter (Dececember) when new head feathers are grown; the outer primary feather tip reflects mercury burden at end of the primary feather moult (October-November); and the 5th greater covert feathers reflect the mercury burden midway through primary moult (September) (Figure 1) (Pierotti and Good 1994, Good 1998). The 5th greater covert feathers and blood mercury concentrations are compared with those taken in previous years (2001 and 2002) to assess inter-annual variation.

Trapped adults were gendered by discriminant function analysis based on measurements of 'head and bill' and bill depth. Herring gulls were gendered using Fox *et al.*'s (1981) discriminant function model and the great-black-backed gulls were gendered using Mawhinney and Diamond's (1999) discriminant function model.

The 5th greater covert feathers of adult gulls (representing fall 2002 mercury burdens) were analyzed for methylmercury concentrations.

4.3 Results

4.3.1 Comparing species

Since all the regions gulls' (in 2001) had similar feather and blood mercury concentrations, the gulls' mercury concentrations (from all regions) were pooled and the two species were compared. The two species' 2001 mercury concentration, in the 5th greater covert and blood, were not significantly different (Figure 4, Table 6). In 2002, the gulls' mercury concentrations varied between regions; thus, data could not be pooled, but the species' mercury concentrations were compared within each of the three regions (Saint John area, Maces Bay, and Passamaquoddy Bay).

Mercury concentrations from the Saint John area and Maces Bay in great black backed gulls' 5th greater covert feathers (2002) were significantly higher than herring gulls, but at Passamaquoddy Bay there was no significant difference between the two species' feather mercury concentrations (Figure 4, Table 5). Blood mercury concentrations, collected during 2002, were not significantly different between the two species at Maces Bay and Passamaquoddy Bay (Figure 4, Table 5). In 2003 a species comparison was possible, but was limited to the Hospital Islands gull colonies' mercury concentrations. Herring gulls had significantly higher mercury concentration in blood and 5th greater coverts in 2003 (Figure 4, Table 5).

In each of the three years, the species had different relative mercury concentrations. During 2001 the species' mercury concentrations were similar during the breeding season (represented by blood) and fall (represented by 5th greater covert feathers), but in 2002 the great black-backed gulls had higher mercury concentrations during the fall in two regions (Saint John area and Maces Bay). In contrast to 2001 and 2002, the 2003 herring gulls had higher mercury concentrations during the breeding season and fall. Thus, the relative mercury concentrations in the two species varied erratically with no clear or consistent pattern.

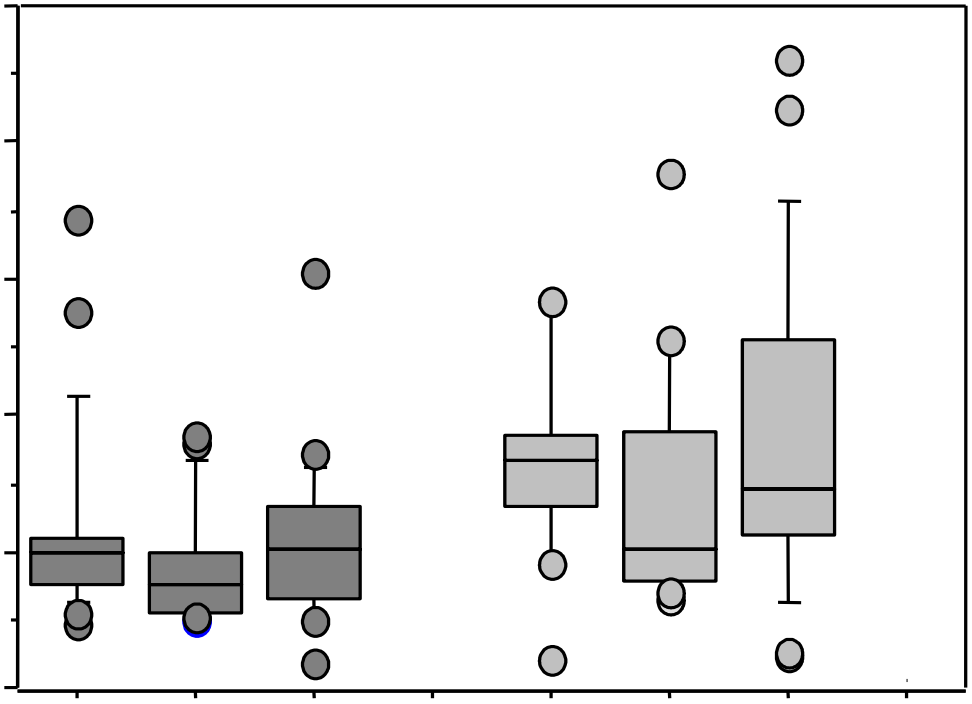


Table 5. Summary of adult gull 5th greater covert and blood mercury concentration ANOVAs. The regions are pooled for the 2001 analysis, in 2002 three regions are analyzed separately (STJ = Saint John area, MB = Maces Bay, and PQ = Passamaquoddy Bay), and only the Hospital Islands mercury concentrations are available in the 2003 analysis.

Comparison	Matrix [Hg]	P	Sample with higher [Hg]	Significant Difference between species Yes/No ($\alpha = 0.05$)	Effect Size
Species	5th Covert 2001	0.755	NA	No	NA
Species (STJ area)	**5th Covert 2002**	**0.036**	**GBBG**	**Yes**	2.18
Species (MB)	**5th Covert 2002**	**0.004**	**GBBG**	**Yes**	1.41
Species (PQ)	5th Covert 2002	0.080	NA	No	NA
Species	**5th Covert 2003**	**0.014**	**HERG**	**Yes**	0.64
Species	Blood 2001	0.808	NA	No	NA
Species (MB)	Blood 2002	0.371	NA	No	NA
Species (PQ)	Blood 2002	0.190	NA	No	NA
Species	**Blood 2003**	**0.002**	**HERG**	**Yes**	0.81

4.3.2 Comparing variability of mercury concentrations between genders

Figure 5 presents both the means and the ranges of mercury concentrations for each tissue type of each gender of each species. At a glance, it appeared the mercury concentrations in the tissues of the males, within each species, were more variable than females. Further analysis, using the two-tailed variance ratio test, corroborated this observation in all feather types of great black-backed gulls; however, herring gulls had significantly less variation, of mercury concentrations, in their primary feather #10 tip between the genders (Table 6, Table 8). Great black-backed gull males had more variable head feather, primary feather #10 tip, and 5th greater covert feather mercury concentrations compared to the females' (Table 6, Table 8). Herring gull males had more variable head feather and 5th greater covert feather mercury concentrations compared to female feather mercury concentrations (Table 6, Table 8). For great black-backed gulls and herring gulls, little variation in blood mercury concentrations between the genders was present (Table 6, Table 8).

4.3.3 Comparing mercury concentrations between genders

No difference in mercury concentrations between the genders, in each tissue type of each species, was observed (Figure 5). Further analysis using analysis of variance (ANOVA) confirms this observation (Table 7). There was no significant differences between the genders' mercury concentrations in head feathers (HF), primary feather # 10 tip (PT), 5th greater covert feather (GC), and blood in either great black-backed gulls or herring gulls (Table 7, Table 8). Since there were no significant differences between the genders' mercury concentrations, the genders were pooled for all following analyses.

For the current study, Burger and Gochfeld's (1997) general mercury level of 500-6000 ppb (WW) or 1500-18 000 ppb (DW) in eggs was considered the threshold mercury level causing effects in eggs and Eisler's (1987) general mercury level of 5000-40 000 ppb (DW) in feathers was considered the threshold mercury level causing effects in chicks as well as adults. Horizontal dashed lines in the figures represent the threshold mercury levels.

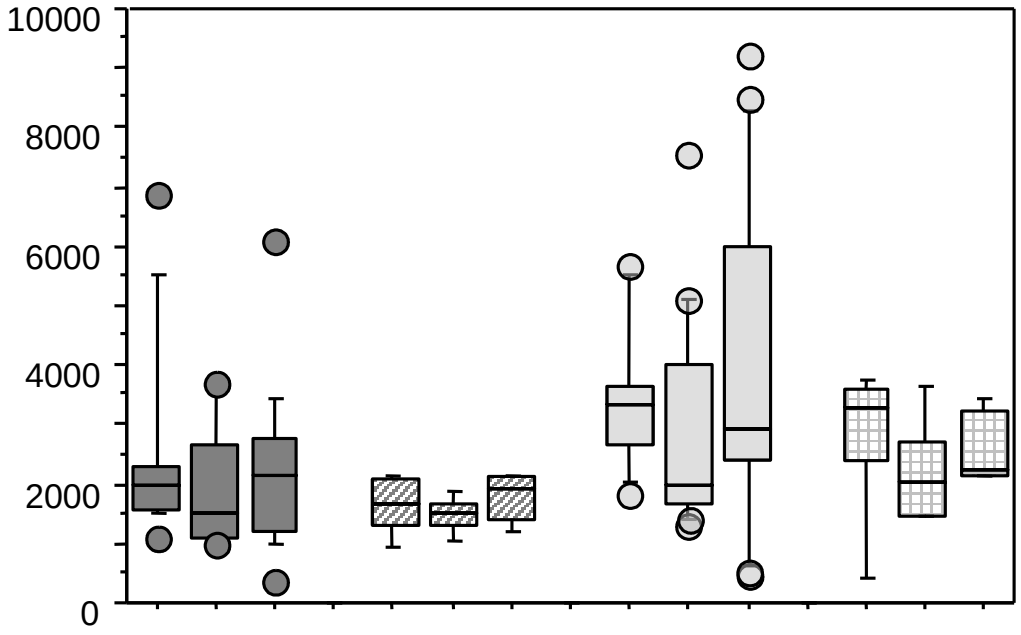


Table 6. Comparison of the variability of mercury concentrations between genders of adult great black-backed gull and herring gulls using the two-tailed variance ratio test.

Tissue Type	Species	F ($\alpha = 0.05$)	Significant Difference Yes/No (Fcrit. = 8.7)	Effect Size
Head feather	**GBBG**	**10.2**	**Yes**	0.52
Primary 10 Tip	**GBBG**	**10.7**	**Yes**	0.47
5th Covert	**GBBG**	**10.1**	**Yes**	0.35
Blood	GBBG	1.5	No	NA
Head Feathers	**HERG**	**10.3**	**Yes**	0.38
Primary 10 tip	HERG	3.9	No	NA
5th covert	**HERG**	**17.9**	**Yes**	0.52
Blood	HERG	3.7	No	NA

Table 7. Comparison of mercury concentrations between the genders of adult great black-backed gulls (GBBG) and herring gulls (HERG) using ANOVA.

Tissue Type	Species	P	Significant Difference Yes/No ($\alpha = 0.05$)
Head feather	GBBG	0.254	No
Primary 10 Tip	GBBG	0.268	No
5th Covert	GBBG	0.390	No
All Feathers	GBBG	0.096	No
Blood	GBBG	0.473	No
Head Feathers	HERG	0.424	No
Primary 10 tip	HERG	0.392	No
5^{th} covert	HERG	0.274	No
All Feathers	HERG	0.134	No
Blood	HERG	0.261	No

Table 8. Sample size, mean, and standard error of mercury concentrations in the feathers and blood collected from male and female great black-backed gulls and herring gulls on the Hospital islands during the 2003 field season.

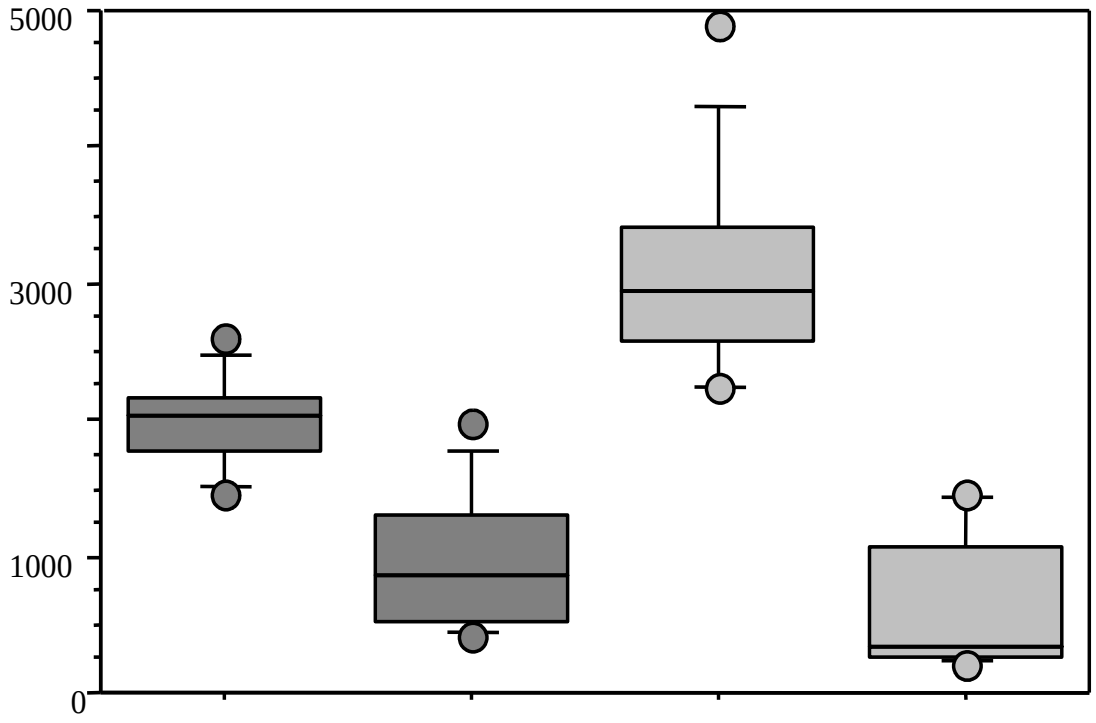
Tissue Type	Species	Mean Mercury Concentration (ppb fresh weight) (SE, N)	
		Male	Female
Head Feathers	GBBG	2484 (412, 15)	1653 (223, 5)
Primary 10 tip	GBBG	1928 (259, 14)	1478 (132, 5)
5th covert	GBBG	2259 (355, 15)	1776 (193, 5)
All Feathers	GBBG	2218 (203, 44)	1636 (105, 15)
Blood	GBBG	108 (14, 15)	97 (18, 5)
Head Feathers	HERG	4449 (1086, 16)	2816 (605, 5)
Primary 10 tip	HERG	3932 (448, 16)	2193 (408, 5)
5th covert	HERG	3967 (650, 16)	3625 (275, 5)
All Feathers	HERG	3783 (447, 48)	2545 (251, 15)
Blood	HERG	231 (34, 16)	156 (32, 5)

4.3.4 Methylmercury

Methylmercury was compared to total mercury concentrations in the 5th greater covert feathers. Herring gulls' 5th greater covert feathers had significantly higher concentrations of total mercury, but not methylmercury (Figure 6, Table 9, Table 10). Great black-backed gulls had a significantly higher ratio of methylmercury to total mercury compared to herring gulls (Figure 7, Table 9, Table 10).

Both species showed wide variations in methylmercury concentration and the percent methylmercury to total mercury in their 5th greater covert feathers. Methylmercury concentrations ranged between 421-1969 ng/g (ppb) (fresh weight) in great black-backed gulls and 196-1449 ng/g (ppb) (fresh weight) in herring gulls. Methylmercury as a percent of total mercury ranged between 20%-91% in great black-backed gulls and 6%-48% in herring gulls.

The lack of relationship between total mercury and methylmercury, in the gulls' 5th greater covert feathers, was further evident in the regression analyses. In great black-backed gulls and herring gulls, no significant relationships were found between total mercury and methylmercury, or between total mercury and the ratio of methylmercury to total mercury.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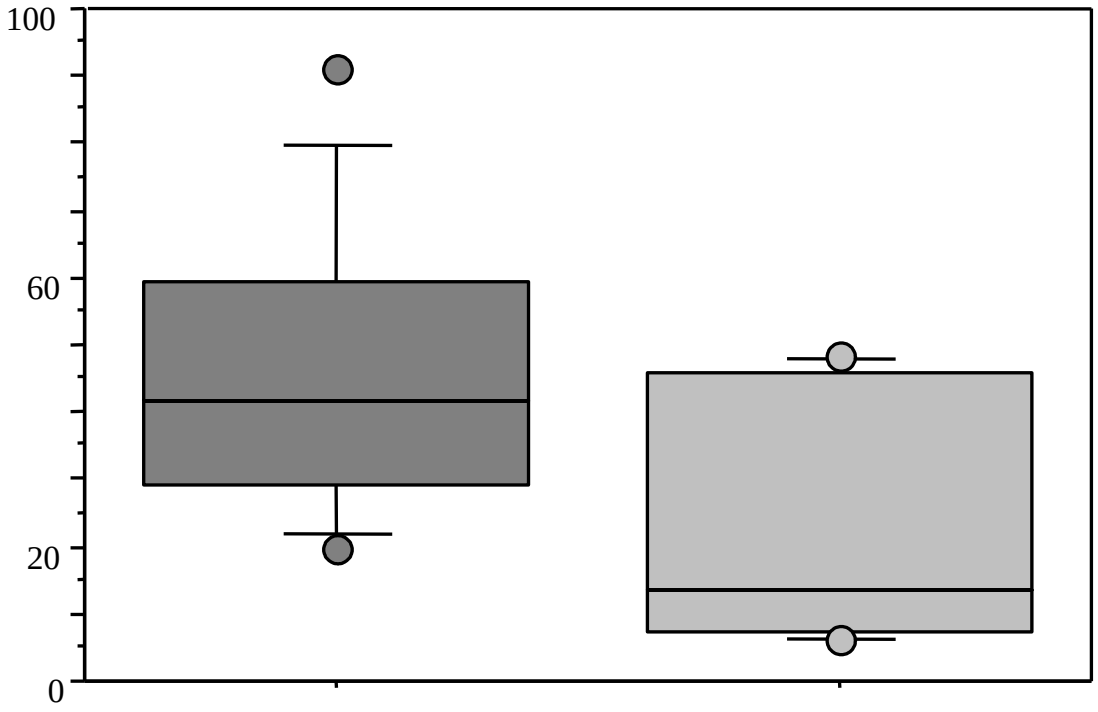


Figure 7. Comparison of the percent methyl-mercury to total mercury in great black-backed gulls' and herring gulls' 5th greater covert feathers (collected in 2003).

Table 9. Summary of total mercury (THg), methylmercury (MeHg), and percent MeHg to THg ANOVAs comparing the 5th greater covert feathers of great black-backed gulls and herring gulls (collected in 2003).

Comparison	P	Sample with higher [Hg]	Significant Difference between species Yes/No ($\alpha = 0.05$)	Effect Size
THg	**0.001**	**HERG**	**Yes**	0.81
MeHg	0.202	NA	No	NA
Percent MeHg to THg	**0.019**	**GBBG**	**Yes**	1.04

Table 10. Sample size, mean, and standard error of 5th greater covert feathers' total mercury and methylmercury concentrations ng/g (ppb) (fresh weight).

Matrix	Mean Mercury Concentration (ppb fresh weight) (SE, N)	
	GBBG	HERG
Total Hg	2006 (110, 10)	3088 (248, 10)
Average MeHg	938 (165, 10)	636 (157, 10)
Average % MeHg/THg	46 (7, 10)	22 (6, 10)

4.4 Conclusion

4.4.1 Comparing species

The lack of blood-feather relationship in great black-backed gulls, but presence in herring gulls, may indicate different mercury detoxification mechanisms in herring gulls compared with great black-backed gulls, or unpredictable mercury deposition from the internal organs. The lack of feather-feather relationship in herring gulls, but its presence in great black-backed gulls, lends further support to the hypothesis that the two species have different mechanism of mercury elimination and sequestration.

Great black-backed gulls and herring gulls had similar mercury concentrations during most of the time periods tested in this study. The gull species had similar mercury concentrations in fall and spring 2000-2001. Herring gulls have elevated mercury concentration in fall and spring 2003 compared to great black-backed gulls, and great black-backed gulls had elevated mercury concentrations during fall 2002 compared to herring gulls. Burger *et al.* (2000) found differences in mercury concentrations between herring gulls and great black-backed gulls, although their study compared heart, kidney, liver, breast muscle, and salt gland mercury concentrations. Since most mercury enters the gulls via food, great black-backed gulls during fall 2002, and herring gulls during fall and spring 2003, are expected to have higher trophic positions. The stable isotope results confirm these expectation except that herring gulls during spring 2003 did not have a higher trophic position than great black-backed gulls (please refer to stable isotope discussion).

4.4.2 Comparing genders

Male and female gulls, of both species, have similar mercury concentration in all feathers tested (head feathers, 5th greater covert feathers, and primary feather #10 tip) and blood. This finding agrees with that of Braune and Gaskin (1987) regarding Bonapart's gulls and of Lewis *et al.* (1993) regarding European herring gulls. Mercury concentrations in head feathers are similar between the genders because head feathers are grown during the winter period when the genders are assumed to have similar diets and are not affect by egg laying.

The effect of egg laying, on mercury concentrations in the females' feathers, is only seen in the first few primary feathers. This is because the males eliminate a large proportion of their mercury load into the first grown primary feathers until their levels are similar to those of the female gulls (Braune and Gaskin 1987). Since my study uses primary feather #10 (last primary feather grown) and 5th greater covert feathers (grown after the first primaries) it is not possible to test Braune and Gaskin's (1987) findings using feathers but is possible to test using blood samples.

Blood collected during the incubation period (at least two eggs present in nest) and prior to the 4th primary feather moult should have higher mercury concentrations in males than females. I found no gender-related trend in blood mercury concentrations of either species.

Further analyses of variance within each gender indicate that males have more variable mercury concentrations than females in all feather types in both species, with the exception of the primary feather #10 in herring gulls. Since males have more variable mercury levels, the eggs act as both a mercury elimination and stabilization mechanism, which does not decrease the mercury body burden of females more than

males. Little difference in blood mercury concentrations between the genders is present in either species. Male gulls do not have more variable blood mercury concentrations than female gulls, perhaps because mercury in the blood is sequestered into the other tissues (feathers or internal organs).

4.4.3 Methylmercury

Herring gulls had higher total mercury concentration, during fall 2002, as compared to great black-backed gulls, but methylmercury concentrations were similar in both species. Great black-backed gulls had a higher percentage of methylmercury in their feather (20%-91%) compared to herring gulls (6%-48%). The percentage of methylmercury, in both species, is lower in this study compared to other studies, which found between 70-100% of feather mercury is methylmercury (Thompson and Furness 1989, Burger 1993, Lewis and Furness 1991).

There were large variations in the percentage of methylmercury in feathers in both species. The lack of total mercury-methylmercury relationship and methyl-mercury-percent methylmercury relationship may be due to individual variations in internal demethylation mechanisms, efficiency of these mechanisms, and level of contamination.

5. Mercury Concentrations in Gull Chicks

5.1 Introduction

This chapter compares mercury levels between variouse chick feathers in both herring gull and great black-backed from the Hopital Islands. The percent body burden differs between adults and chicks (Burger 1993). The chicks have a short period of feather growth and generally sequester a lower percent of their mercury body burden in feathers (Braune and Gaskin 1987).

Various feathers were collected from the chicks during the 2003-breeding season, which represented mercury concentrations at different developmental stages. **Down feathers** represented egg mercury concentrations, **scapulars feather tips** (first grown feathers) represented mercury concentrations after an intense period of feeding and growth, **full scapulars feathers** were the same as scapular tips except they were fully grown at the time of collection, and **head feathers** (last grown feathers) represented pre-fledging mercury concentrations.

5.2 Methods

During 2003, chicks were sampled from the Hospital Islands. Gull chicks were trapped by pursuit and sampled for 5 down feathers, 2-3 scapular feathers, spontaneous regurgitation, and induced regurgitation (if spontaneous not provided). Gull chicks were handled three times when possible, once after hatching, once during the first feather growth (scapular feathers), and again just before fledging. The chicks were web-tagged on first capture (Blums *et al.* 1994), and on second capture banded on the right leg with a U.S.F.W.S. metal band. Once chicks begin to hatch, gullet samples were collected

from chicks belonging to the 20 staked nests (of each species). Diet samples were extracted by inserting an index finger down the throat of chicks and sweeping out the gullet contents (Ref). All regurgitation and gullet samples from adults and chicks were sorted to food type. Within 10 hours of sampling all chick samples (feathers, regurgitation, and guano) were stored at –20˚C until analyzed.

The various feathers sampled from the chicks represent mercury burdens during different periods in their development. Down feathers represent mercury levels in the eggs; scapular feathers are grown within 15 days of hatching and reflect the first grown feather mercury levels; and head feathers are grown 5-6 weeks after hatching and represent the pre-fledging mercury burden.

5.3 Feather types

Since no significant difference was found between scapular tip mercury concentrations and fully grown scapular feathers mercury concentrations, the two categories of scapular feathers were pooled and referred to simply as scapular feathers in great black-backed gulls and herring gulls (Table 11, Table 12, Table 13, Table 14). Great black-backed gull and herring gull chicks' scapular feathers had significantly higher mercury concentrations than down feathers (Figure 8, Table 11, Table 12). In herring gulls, scapular feather had significantly higher mercury concentrations than head feathers but there was no significant difference in mercury concentrations between down and head feathers (Figure 8, Table 13, Table 14). Head feathers were not tested in great black-backed gull chicks because only one sample was available.

Neither species showed any pattern of mercury concentrations between feather types. There was a significant relationship between chick weight (a measure of chick age) and the chicks' ratio of scapular feather tip mercury to down mercury. As the great black-backed gull chicks' weight (age) increased, the ratio of scapular tip mercury to down mercury decreased (Figure 10, Figure 9). In contrast, herring gull chicks showed no significant relationship between weight and the ratio of scapular tip mercury to down mercury (Figure 10). Great black backed gull and herring gull chicks both showed no significant relationship between wing chord (a measure of chick age) and the ratio of scapular tip mercury to down mercury (Figure 9).

5.4 Eggs in relation to down feathers

Mercury concentrations of great black-backed gull down were not significantly different from egg albumen and homogenized egg mercury concentrations (Table 11, Table 12). Down mercury concentrations were significantly higher than egg yolk mercury concentrations in great black-backed gulls (Table 11, Table 12). Mercury concentrations in herring gulls' down and egg albumen were not significantly different (Table 13, Table 14). Herring gulls' down mercury concentrations were significantly higher than egg yolk and homogenized egg mercury concentrations (Table 13, Table 14).

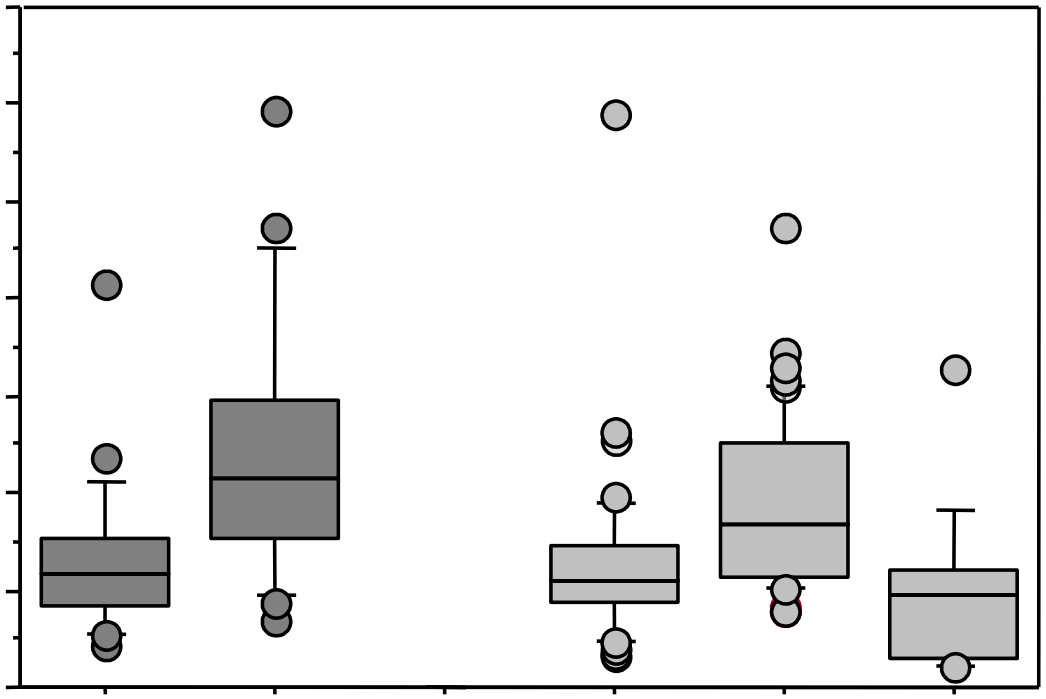


Table 11. Summary of great black-backed gull chicks (2003) ANOVARs and ANOVAs comparing feather mercury concentration and egg mercury concentrations.

Comparison	P	Sample with higher [Hg]	Significant Difference Yes/No ($\alpha = 0.05$)	Effect Size
^Down, Scapulars Tips, and Full Scapulars	0.202	NA	No	NA
^Scapulars Tips and Full Scapulars	0.606	NA	No	NA
^Down and Scapular Feathers	**0.001**	**Scapulars**	**Yes**	0.78
***Down and Albumen	0.156	NA	No	NA
***Down and Yolk**	**0.042**	**Down**	**Yes**	0.93
***Down and Homogenized Egg	0.195	NA	No	NA

*** = Egg samples and feather samples not from the same birds
^ = ANOVAR

Matrix	Mean Mercury Concentration (ppb fresh weight) (SE, N)
Guano	77 (28, 21)
Down	1307 (165, 23)
Scapular Tips	2453 (328, 20)
Full Scapulars	2454 (333, 3)
Scapular	2453 (286, 23)
Feathers	
Egg Albumen	1789 (248, 7)
Egg Yolk	570 (217, 6)
Egg	937 (181, 10)
Homogenized	
Egg Shell	32 (11, 10)
Egg Membrane	283 (99, 9)

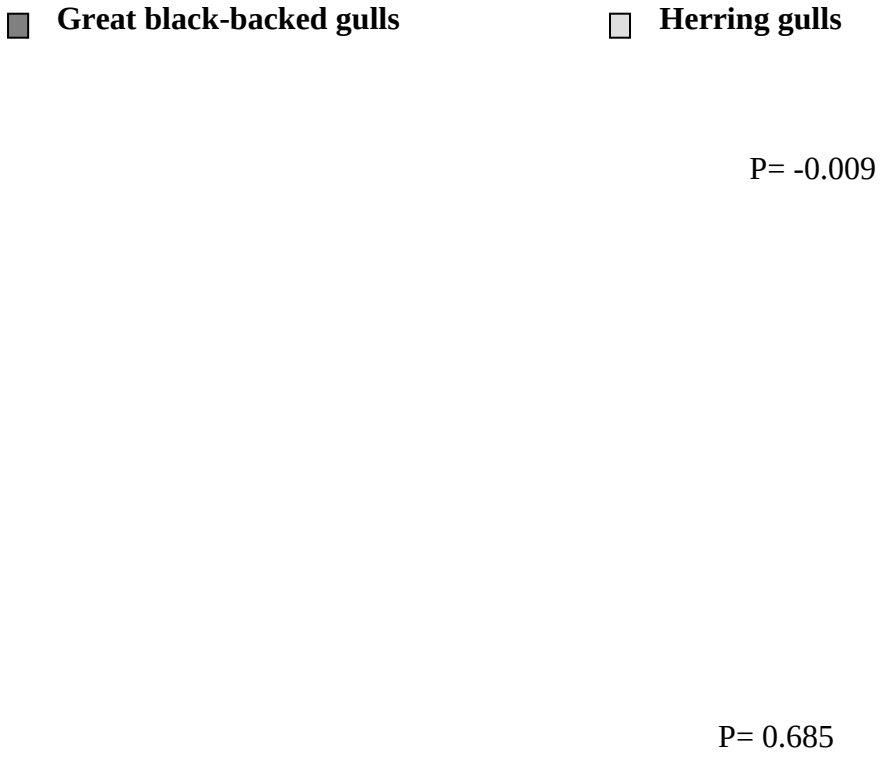
Table 13. Summary of herring gull chicks (2003) ANOVAs and ANOVARs comparing feather mercury concentration and egg mercury concentrations.

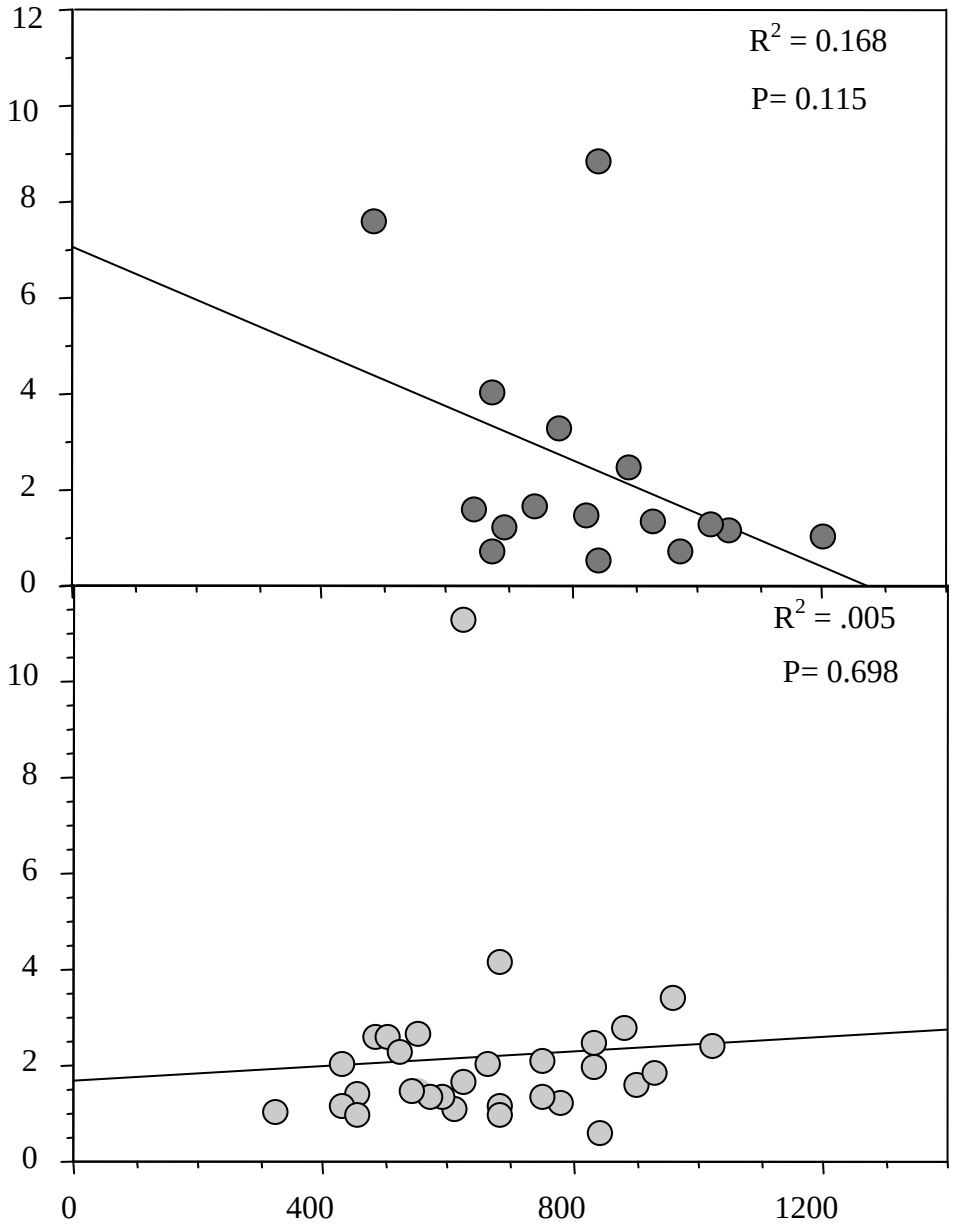
Comparison	P	Sample with higher [Hg]	Conclusion (α = 0.05) Significant Difference Yes/No	Effect Size
^Down, Scapulars, Full Scapulars, and Head	**< 0.001**	**Scapulars**	**Yes**	NA
^Scapular Tips and Full Scapulars	0.057	NA	No	NA
^Down and Scapular Feathers	**0.001**	**Scapulars**	**Yes**	0.55
^Scapular Feathers and Head	**0.002**	**Scapulars**	**Yes**	0.87
^Down and Head	0.815	NA	No	NA
***Down and Albumen	0.167	NA	No	NA
*****Down and Yolk**	**0.001**	**Down**	**Yes**	1.30
*****Down and Homogenized**	**0.007**	**Down**	**Yes**	0.91

*** = Egg samples and feather samples not from the same birds
^ = ANOVAR

Table 14. Sample size, mean, and standard error for 2003 herring gull chicks' guano, feather and egg mercury concentrations

Matrix	Mean Mercury Concentration (ppb fresh weight) (SE, N)
Guano	89 (16, 32)
Down	1265 (134, 44)
Scapular Tips	2040 (158, 31)
Full scapulars	1464 (187, 15)
Scapular Feathers	1852 (128, 46)
Head Feathers	987 (225, 13)
Egg Albumen	814 (141, 8)
Egg Yolk	112 (21, 8)
Egg Homogenized	455 (73, 10)
Egg Shell	21 (8, 9)
Egg Membrane	124 (18, 10)


Great black-backed gulls
Herring gulls
P= -0.009
P= 0.685


12
10
8
6
4
2
0
R^2 = 0.168
P= 0.115
10
8
6
4
2
0
R^2 = .005
P= 0.698
0
400
800
1200

5.5 Comparison of species

There was no significant difference between the two species chicks' mercury concentrations with regard to down and guano (Table 15). Great black-backed gulls' scapular feathers had significantly higher mercury concentrations compared to herring gulls' full scapular feathers (Table 15).

Comparison	Feather type	P	Sample with higher [Hg]	Significant Difference Yes/No ($\alpha = 0.05$)	Effect Size
Species	Guano	0.669	NA	No	NA
Species	Down	0.852	NA	No	NA
Species	**Scapular Feathers**	**0.030**	**GBBG**	**Yes**	0.39

5.6 Conclusion

Becker *et al.* (1994) found more contaminated herring gull chicks have a significant differences between their down and side feather mercury concentrations as well as between their side and back feather mercury concentrations, but no significant differences between feather types exist in less contaminated chicks. The present study finds significant differences exist between down and scapular tips in both species and between scapular tips and head feathers in herring gulls, which may indicate the gull chicks are contaminated. Mercury in the diet is likely to be more damaging to chicks because they are in a developmental stage (Furness 1993).

Becker *et al.* (1994) also found more contaminated chicks eliminate mercury more quickly than less contaminated chicks. In great black-backed gulls the mercury concentrations in the first grown feathers (scapular feather tips) increased by 53% from the down mercury levels, whereas in herring gulls the mercury concentrations in the first grown feathers increased by 63% from the down mercury levels. Since the herring gulls have a greater rate of eliminating into their first grown feathers, they may be more contaminated compared to great black-backed gull chicks. Chicks with higher mercury concentrations in their down have higher mercury concentrations in their internal tissues and are probably at greater risk (Becker *et al.* 1994).

Both species' chicks have similar mercury concentrations in their down and scapular feather tips. Herring gulls down mercury concentration (from chicks on the Hospital Islands) are similar to chicks from Long Island, NY and slightly lower than chicks from the Wadden Coast, Germany. The fledging feather mercury concentrations are similar to those found in a variety of locations in the U.S.A. and the Wadden Coast, Germany (Table 16).

Table 16. Mean levels of mercury found in feathers, eggs, and blood of herring gull chicks from other locations.

Location	Tissue	Year	Mercury concentration (ppb)	Standard error or range	Reference
Hospital Islands, NB	Down	2003	1265	± 134 (1131-1399)	This study
Long Island, NY	Down	1993	1105	± 200	Burger 1993
German North Sea Coast	Down	1991	1420	± 590 (380-2870)	Becker *et al.* 1994
Hospital Islands, NB	Fledging Feathers	2003	2040	±158 (1882-2198)	This Study
Hospital Islands, NB	Head Feathers	2003	987	± 225 (762-1212)	This Study
Long Island, NY	Fledging feathers	1993	1799	± 105	Burger 1995
Long Island, NY	Fledgling Feathers	1993	1799	± 105	Burger 1993
Wadden Coast, Germany	Chick Shoulder Feathers	1991	1310	± 620 (490-2890)	Becker *et al.* 1994
Wadden Coast, Germany	Back Feathers	1991	1270	± 600 (490-2980)	Becker *et al.* 1994
Long Island, NY	Fledgling Feathers	1990	2592	± 275	Burger 1997
Long Island, NY	Fledgling Feathers	1990	1399	± 271	Burger 1997
Long Island, NY.	Fledgling Feathers	1990	1644	± 264	Burger 1997
Huckleberry Harbor, NY	Fledgling Feathers	1990	2833	± 267	Burger 1997
Prall's Island Harbor, NY	Fledgling Feathers	1990	811	± 115	Burger 1997
Lavalette, NJ	Fledgling Feathers	1990	1764	± 350	Burger 1997
Harvey Sedge, NJ	Fledgling Feathers	1990	2581	± 226	Burger 1997
Chincoteaque, Virginia	Fledgling Feathers	1990	761	± 108	Burger 1997

* Converted to dry weight from reported wet weights

Wing chord and weight are used as measures of chick age. There was no relationship between chick age and mercury concentrations in herring gulls or great black-backed gulls using wing chord as a measure of the chick's age. There was a negative relationship between chick age and mercury concentrations in great black-backed gulls using the chick's weight as a measure of age. This finding of no age-mercury trend (with the exception of the great black-backed gull chicks using weight) agrees with findings in great skua chicks by Thompson *et al.* (1991). The lack of relationship between chick age and mercury concentration may be due to a balance between increasing mercury intake via increased food intake and the chick's increasing size (Thompson *et al.* 1991). As great black-backed gull chicks age (weight) increases, the mercury concentrations in their scapular feather tips decrease. The age-mercury trend in great black backed gull chicks (using weight) may not be real because no age mercury trends exist when wing chord represents chick age.

6. Egg Mercury Concentrations

6.1 Introduction

The objective of this chapter is to compare egg mercury concentrations between the two species and between different parts of the eggs (albumen, yolk, shell, and shell membrane). Egg mercury concentrations are a good way to assess mercury concentrations of the local ecosystem. Egg mercury concentrations are indicative of dietary mercury concentrations in the female gull during the egg developmental stage but may not reflect the body burden of the female gull (Lewis *et al.* 1993). Egg laying sequence must be known because egg mercury concentrations decreases with laying order (Becker *et al.* 1989, Becker 1992). Analyzing only addled eggs may be biased because mercury concentrations may be a reason the eggs are not viable. Using viable eggs hinders the ability to follow the breeding success of the clutch, but eliminates the bias of using addled eggs (Thompson *et al.* 1991).

6.2 Methods

During 2003, 10 eggs of each species were collected from the Hospital Islands prior to visible embryo development. Great black-backed gull eggs were collected on the 14th of May and herring gull eggs on the 5th of June. The largest egg from 10 clutches of each species was removed. The largest egg, which is presumed to be the first laid was chosen because it contains the most mercury, it will give the best indication of the percent of the female gull's total body burden being deposited in the first laid egg, and removes the bias of laying order (Becker *et al.* 1989). Taking only the first-laid egg will not seriously jeopardize a colony's reproductive success since gulls have the capacity to

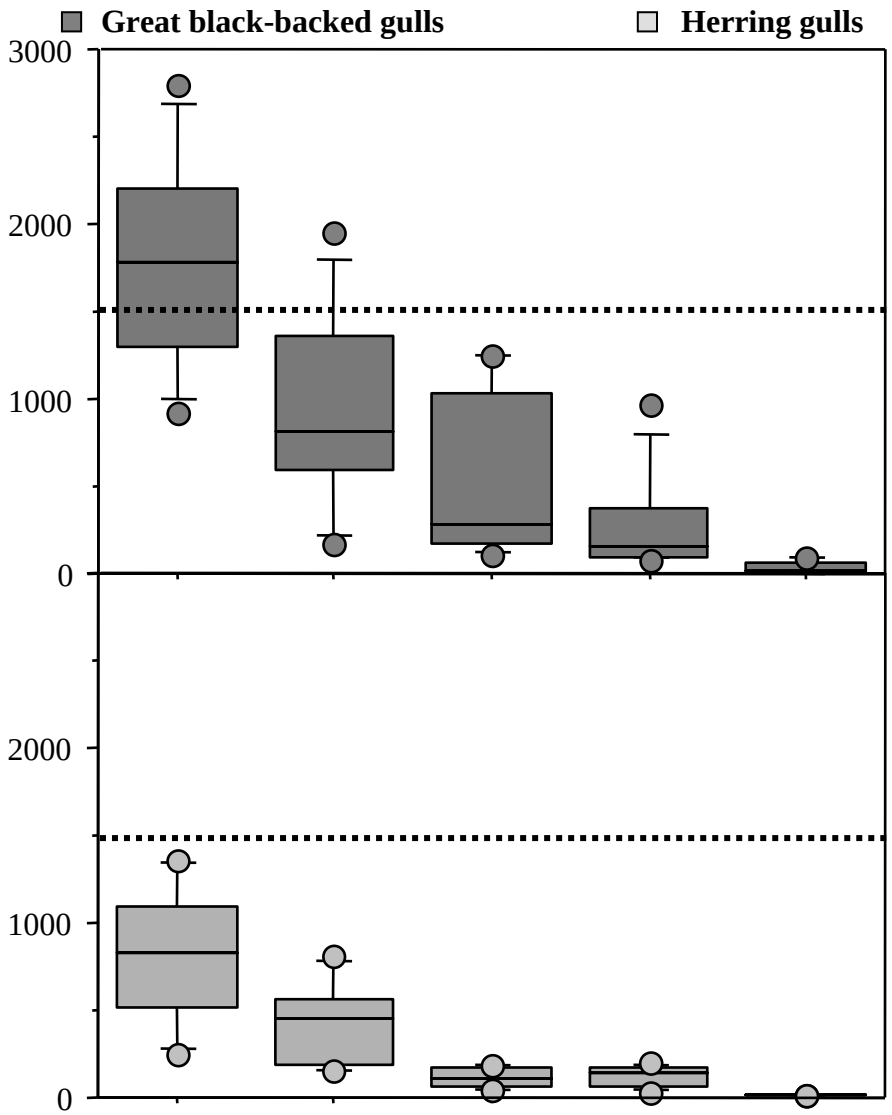
re-lay (Baerends and Drent 1970). Using only the mercury concentration of the first-laid egg leads to an underestimate of total mercury deposited in a clutch. Within 10 hours of sampling the eggs were stored at 0˚C until analyzed. The eggs were dissected into eggshell, eggshell membrane, yolk, and albumen prior to mercury analysis.

6.3 Comparing mercury concentrations between the egg components

Egg mercury concentrations were determined in homogenized egg, albumen, yolk, shell membrane, and shell. Both species of gulls showed similar patterns of mercury concentrations in their egg components. Albumen had the highest mercury concentration, followed by yolk, shell membrane, and shell (albumen > homogenized > yolk > shell membrane > shell) (Figure 11, Table 15, Table 17). In great black-backed gulls however, there was no significant difference in mercury concentrations between the yolk and homogenized egg contents (Table 17). Also, great black-backed gulls' eggs and herring gulls' eggs yolk mercury concentrations were similar to their shell membrane mercury concentrations (Table 17).

6.4 Comparing egg- mercury concentration between the species

The two species had similar mercury concentrations in their eggs' shell and shell membrane (Table 18). Great black-backed gulls had higher mercury concentrations than herring gulls in their homogenized eggs' contents (Figure 11, Table 18). The concentration of mercury in albumen and yolk was significantly higher in great black-backed gulls than in herring gulls (Figure 11, Table 18).


Great black-backed gulls
Herring gulls
3000
2000
1000
0
2000
1000
0

Tissue Type	Species	P	Sample with higher [Hg]	Significant Difference Yes/No ($\alpha = 0.05$)	Effect Size
Albumen and yolk	**GBBG**	**0.001**	**Albumen**	**Yes**	1.90
Albumen and homogenized	**GBBG**	**0.012**	**Albumen**	**Yes**	1.30
Yolk and Homogenized	GBBG	0.163	NA	No	NA
Shell and shell membrane	**GBBG**	**0.016**	**Membrane**	**Yes**	0.85
Albumen and shell	**GBBG**	**< 0.001**	**Albumen**	**Yes**	2.67
Albumen and shell membrane	**GBBG**	**< 0.001**	**Albumen**	**Yes**	2.30
Yolk and shell	**GBBG**	**0.004**	**Yolk**	**Yes**	1.02
Yolk and shell membrane	GBBG	0.169	NA	No	NA
Shell and homogenized	**GBBG**	**< 0.001**	**Homogenized**	**Yes**	1.58
Shell membrane and homogenized	**GBBG**	**0.008**	**Homogenized**	**Yes**	2.20
Albumen and yolk	**HERG**	**< 0.001**	**Albumen**	**Yes**	1.76
Albumen and homogenized	**HERG**	**0.029**	**Albumen**	**Yes**	0.90
Yolk and Homogenized	**HERG**	**0.001**	**Homogenized**	**Yes**	0.22
Shell and shell membrane	**HERG**	**< 0.001**	**Membrane**	**Yes**	1.84
Albumen and shell	**HERG**	**< 0.001**	**Albumen**	**Yes**	1.98
Albumen and shell membrane	**HERG**	**< 0.001**	**Albumen**	**Yes**	1.72
Yolk and shell	**HERG**	**0.001**	**Yolk**	**Yes**	1.54
Yolk and shell membrane	HERG	0.663	NA	No	NA
Shell and homogenized	**HERG**	**< 0.001**	**Homogenized**	**Yes**	5.95
Shell membrane and homogenized	**HERG**	**< 0.001**	**Homogenized**	**Yes**	4.53

Table 18. Summary of egg component ANOVAs comparing the species.

Comparison	Egg Section	P	Species with high [Hg]	Significant Difference Yes/No (α = 0.05)	Effect Size
Species	Membrane	0.171	NA	No	NA
Species	Shell	0.422	NA	No	NA
Species	**Albumen**	**0.004**	**GBBG**	**Yes**	1.48
Species	**Homogenized**	**0.023**	**GBBG**	**Yes**	0.84
Species	**Yolk**	**0.037**	**GBBG**	**Yes**	0.86

6.5 Conclusion

6.5.1 Mercury concentration in the egg components

Egg mercury concentrations represent the mercury deposited into the chick by the female gull (Burger and Gochfeld 1985, Braune 1987, Braune and Gaskin 1987, Lewis and Furness 1991, Burger 1994). Most studies use homogenized egg content to assess mercury levels in gulls and the local environment, but in the present study the eggs were dissected into albumen, yolk, shell, and shell membrane for separate analysis of mercury in each egg component as well as assessing the homogenized mercury concentrations.

Burger (1994) found herring gull eggshell is 7-8% of the total egg by weight and the mercury in the shell was less than 1 % of the total egg mercury burden, which is exactly the same as this study's findings. The low egg mercury burden in the shell suggests that eggshells do not provide a method of mercury excretion.

In this study the egg albumen and yolk had different mercury concentrations, which may be due to the albumen and yolk having different nutrient and chemical

compositions. Generally the yolk has more proteins and lipids than albumen (Burley and Vadehra 1989). Herring gull egg yolk and albumen are 90-91% of the total egg by weight (Baerends and Drent 1970). In laughing gulls, yolk is 33.2 % of the whole egg, 54.5% moisture, and 29.1% lipid, while albumen is 57.7% of the whole egg, 87.5 % moisture, and no lipids (Burley and Vadehra 1989). Assuming herring gulls and great black-backed gulls have similar yolk and albumen proportions as laughing gulls, the egg mercury burdens in both species are higher in albumen and yolk compared to shell and shell membrane (Table 19). Female gulls seem to use their egg contents as a method of mercury excretion, although depositing mercury into eggs may be detrimental to their reproductive success.

Table 19. Average mercury burdens in the egg components of great black-backed gulls and herring gulls. The average mercury burden was calculated using the average egg weight of great black-backed gulls (113.3 g) and herring gulls (91.8 g).

Egg Component	Species	Average % of Total Egg by Weight (WW)	Average % Moisture	Average [Hg] ng/g (WW)	Average Hg Burden
Albumen	GBBG	*58	86	1539	88
Yolk	GBBG	*33	68	356	12
Shell membrane	GBBG	2	55	156	0.3
Shell	GBBG	7	24	8	0.06
Homogenized Egg	GBBG	90-91	76	1014	100
Albumen	HERG	*58	81	659	93
Yolk	HERG	*33	68	76	6
Shell membrane	HERG	2	57	71	0.3
Shell	HERG	8	17	5	0.1
Homogenized Egg	HERG	90-91	75	409	100

* Values from laughing gull eggs (Burley and Vadehra 1989)

Since sulfur and selenium have possible detoxification properties; thus, the relative concentrations of these two elements in the egg albumen compared to the yolk may be important factors affecting mercury concentrations in the egg components. Large amount of sulfur are present in hen egg albumen (0.195%) as compared to the yolk (0.016%) (Romanoff and Romanoff 1949). In hen eggs, selenium from the diet is preferentially deposited into the albumen compared to the yolk (Romanoff and Romanoff 1949). Selenium and sulfur may be higher in the egg albumen in gulls as an adaptation to the higher mercury concentrations in the egg albumen although how this would act as a detoxification mechanism for the embryo is not clear.

6.5.2 Eggs in relation to down feathers

Down mercury concentrations are derived from the female gull sequestering mercury into her egg (Burger and Gochfeld 1985, Braune 1987, Braune and Gaskin 1987, Lewis and Furness 1991, Burger 1994); thus, down mercury concentrations should be similar to the mercury concentration of the egg. In great black-backed gulls mercury concentrations in the down and homogenized egg are similar, but in herring gulls the down is higher than the homogenized egg mercury concentrations. Thus, mercury concentrations in the down do not represent egg mercury concentrations in herring gulls. Further analysis comparing the mercury concentrations in down to albumen and yolk find in both species down mercury concentrations are similar to egg albumen but not yolk mercury concentrations. Mercury concentration in down representing the albumen mercury concentrations is expected since the majority of mercury deposited in the egg is deposited in the albumen.

6.5.3 Comparing mercury concentration between the species

Great black-backed gulls have higher mercury concentrations in their eggs than do herring gulls. A possible reason for this difference may be that female great black-backed gulls eliminate more of their mercury body burden into their eggs. The mercury concentrations in the eggshells and shell membranes of both species are similar. A possible reason for this similarity is that low mercury concentrations in these egg components represent only a small proportion of the total egg mercury burden. The homogenized egg mercury concentration of herring gulls in the study area is similar that in all other parts of North America, but lower than the value for Europe (Wadden Sea, Germany, 1430 ppb DW) (Table 20). The great black-backed gulls have a higher average homogenized egg mercury concentration (mean 1014 ppb WW or 1353 ppb DW) than herring gulls from all locations except the Wadden Sea.

Table 20. Mean levels of mercury found herring gull eggs from other locations in North America.

Location	Tissue	Year	Mercury concentration (ppb) (DW)	Standard error or range	Reference
Hospital Islands, NB	Homogenized Egg	2003	455	± 73	This Study
Long Island, NY	Homogenized Egg Contents	1992	230	± 50	Burger 1994
Long Island, NY	Shell	1992	10	± 0	Burger 1994
Long Island, NY	Homogenized Egg Contents	1989	172	NA	Burger and Gochfeld 1995
Long Island, NY	Homogenized Egg Contents	1991	370	NA	Burger and Gochfeld 1995
Long Island, NY	Homogenized Egg Contents	1992	121	NA	Burger and Gochfeld 1995
Long Island, NY	Homogenized Egg Contents	1993	248	NA	Burger and Gochfeld 1995
Long Island, NY	Homogenized Egg Contents	1994	458	NA	Burger and Gochfeld 1995
Great Slave Lake, NWT	Homogenized Egg Contents	1995	660	NA	Wayland 2000
Snake Island Lake, ON	Homogenized Egg Contents	1992	*856	NA	Koster *et al.* 1996
Lake Erie, ON	Homogenized Egg Contents	1992	*571	NA	Koster *et al.* 1996
Lake Ontario, ON	Homogenized Egg Contents	1975	638	(290-1470)	Gilman *et al.* 1977
Lake Erie, ON	Homogenized Egg Contents	1975	275	(110-350)	Gilman *et al.* 1977
Lake Huron, ON	Homogenized Egg Contents	1975	288	(110-500)	Gilman *et al.* 1977
Lake Superior, ON	Homogenized Egg Contents	1975	488	(160-630)	Gilman *et al.* 1977

Table 20 (continued)

Location	Tissue	Year	Mercury concentration (ppb) (DW)	Standard error or range	Reference
Huckleberry Harbor, New York, NJ	Homogenized Egg Contents	1990	*435	± 107	Gochfeld 1997
Canarise Pol, NJ	Homogenized Egg Contents	1990	*343	± 19	Gochfeld 1997
Ruffle Bar, NJ	Homogenized Egg Contents	1990	*338	± 21	Gochfeld 1997
Shooter's Island, NJ	Homogenized Egg Contents	1990	*308	± 46	Gochfeld 1997
Lavallette, NJ	Homogenized Egg Contents	1990	*558	± 102	Gochfeld 1997
Log Creek, NJ	Homogenized Egg Contents	1990	*384	± 54	Gochfeld 1997
Wadden Coast, Germany	Homogenized Egg Contents	1990	1430	580-3010	Lewis et al 1993
Long Island, NY	Homogenized Egg Contents	1989-1994	Average 250 (N=20)	NA	Burger and Gochfeld 1997

*Converted from reported wet weights to dry weight using 75% moisture

7. Mercury Transfers Between Adults, Their Chicks, and the Island Soil

7.1 Introduction

This chapter traces mercury from the adult to their eggs, chicks, and breeding islands's soil. In species where the chicks develop feathers later in their growth, the mercury must accumulate in the soft tissues until the first feathers are grown, which may result in the first-grown feathers having higher mercury levels compared to down (Monteiro and Furness 1995). Mercury levels are usually higher in adults compared with their chicks because mercury levels in the adult feathers represent a longer period of mercury accumulation (several months since the last moult) and chick mercury concentrations represent a shorter period of time (a few meals during their growth and from the egg) (Honda *et al.* 1986, Thompson *et al.* 1991).

Eggs and chicks represent more local food source mercury contamination because adults usually obtain food within 10Km of their breeding site and because they can switch food sources if a prey type becomes scarce (Morris and Black 1980). Pressure to feed on more local prey items may be increased because herring gulls are territorial of their nesting area and one parent usually remains behind to guard the territory, while the other parent forages for themselves, their partner, and their chicks (Gochfeld 1997).

Herring gulls being omnivorous may be a confounding factor in assessing local ecosystem mercury pollution levels. Garbage is not a natural food source. Parsons and Duncan (1978) concluded that landfills are used mainly to sustain young birds through

the winter. However, gulls feed mostly on natural and high quality prey items during the breeding season and when providing food for their young (Pierotti and Annett 1991).

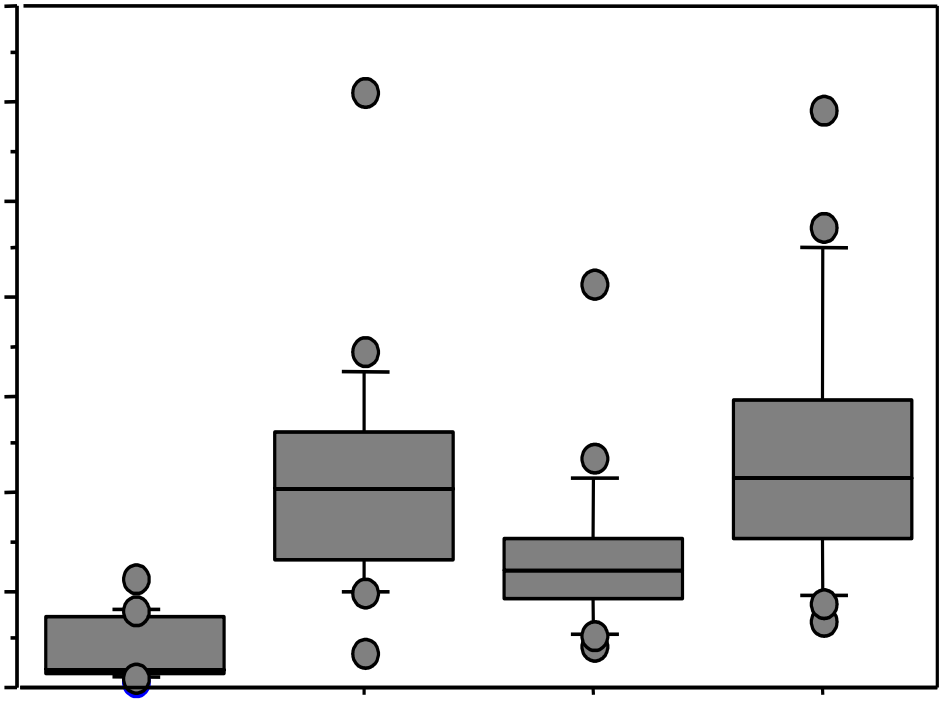
7.2 Methods

Please refer to chapter 3 for laboratory methods, chapter 4.1.2 for adult sampling methods, chapter 5 for chick sampling methods, and chapter 10 for soil sampling methods.

7.3 Results

Hospital Island soil mercury concentrations (from the mid-breeding period) were compared to mercury transfers from the parent gulls to their chicks. The Northwest (NW) Hospital Island soil, surrounding the nests, had lower mercury concentrations than adult and chick feather mercury concentrations. Adult great black-backed gulls' 5th greater covert feather mercury concentrations were higher than their eggs and their chicks' scapular feather mercury levels (Figure 12). The same trend, as described above on NW Hospital Island (in great black-backed gulls), was present on the Southeast (SE) Hospital Island (in herring gulls). In addition herring gull chicks' last grown feathers (head feathers) mercury concentrations decreased to approximately the same mercury level as the eggs (Figure 13). Great black-backed gulls showed no significant difference, in mercury concentration between adult 5^{th} greater covert feathers and chick scapular feathers (Table 21, Table 22). In herring gulls mercury concentrations were not significantly different between chick head feathers and down (Table 21, Table 22). Soil mercury concentrations were always lower than mercury concentration in the gulls (Table 21, Table 22).

Regression plots of adult mercury concentrations with their corresponding chicks' mercury concentrations had R^2 values ranging from 0.001-0.038 and 0.006-0.639 in great black backed gulls and herring gulls respectively (please refer to appendix 3 for regression R^2 values). Sample size was too small in great black-backed gulls to compare adult mercury concentrations with their chicks' head feather mercury concentrations. The regression plots indicated parent mercury concentrations were not related to their eggs and chicks' mercury concentration (Appendix 3).



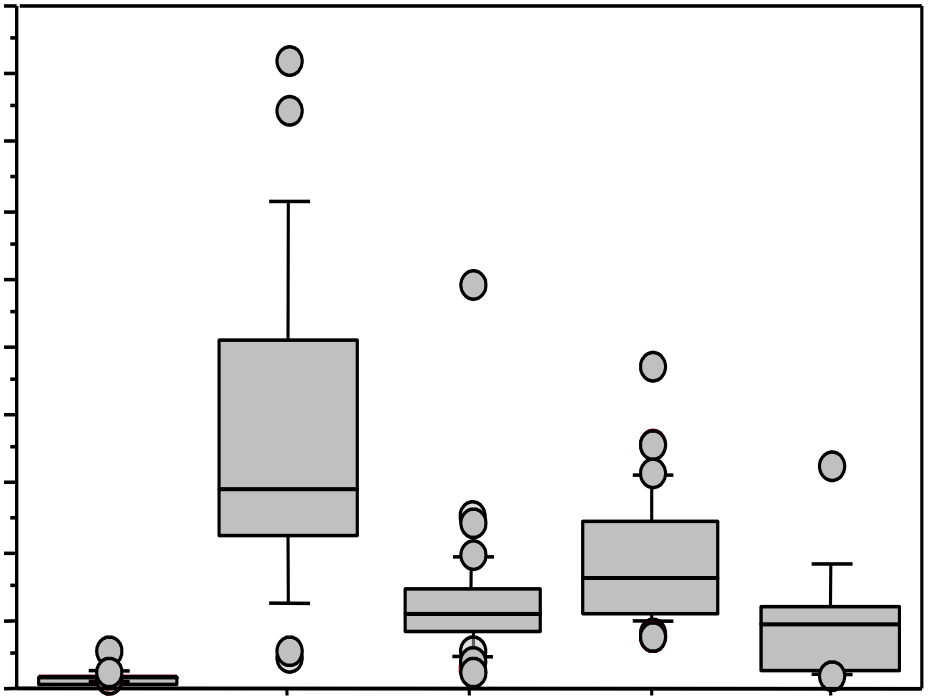


Table 21. Summary of mercury transfer ANOVAs. The soil samples were collected during mid-breeding season. Adult 5th greater covert feathers represent the adults' fall mercury concentrations, down is used as a measure of mercury concentration in the egg, and the chicks' scapular tips represent mercury concentrations in the first grown feathers.

Comparison	Species	P	Sample with higher [Hg]	Significant Difference Yes/No ($\alpha = 0.05$)	Effect Size
Soil and adult 5th greater covert feathers	**GBBG**	**< 0.001**	**Adult 5th greater covert**	**Yes**	**1.45**
Soil and chick down	**GBBG**	**< 0.001**	**Down**	**Yes**	**1.17**
Soil and chick scapular feathers	**GBBG**	**< 0.001**	**Chick scapular feathers**	**Yes**	**1.51**
Adult 5th greater covert and down	**GBBG**	**0.010**	**Adult 5th greater covert**	**Yes**	**0.68**
Adult 5th greater covert and chick scapular feathers	GBBG	0.433	NA	No	NA
Down and chick scapular feathers	**GBBG**	**0.001**	**Chick scapular feathers**	**Yes**	**0.83**
Soil and adult 5th greater covert feathers	**HERG**	**< 0.001**	**Adult 5th greater covert**	**Yes**	**6.78**
Soil and chick down	**HERG**	**< 0.001**	**Down**	**Yes**	**1.22**
Soil and chick scapular tip	**HERG**	**< 0.001**	**Chick scapular tip**	**Yes**	**1.99**
Adult 5th greater covert and down	**HERG**	**< 0.001**	**Adult 5th greater covert**	**Yes**	**2.68**
Adult 5th greater covert and chick scapular feathers	**HERG**	**0.000**	**Adult 5th greater covert**	**Yes**	**1.99**
Down and chick scapular feathers	**HERG**	**0.003**	**Chick scapular feathers**	**Yes**	**0.73**
Chick head feathers and soil	**HERG**	**< 0.001**	**Chick head feathers**	**Yes**	**0.99**
Chick head feathers and adult 5th greater covert	**HERG**	**< 0.001**	**Adult 5th greater covert**	**Yes**	**3.28**
Chick head feathers and down	HERG	0.301	NA	No	NA
Chick head feathers and chick scapular feathers	**HERG**	**0.002**	**Chick scapular feathers**	**Yes**	**1.06**

Table 22. Sample size, mean, and standard error for soil, adults, and chicks' 2003 mercury levels ng/g (ppb) fresh weight.

Sample Type	Mean Mercury Concentration (SE, N) (ppb)	
	GBBG	HERG
Mid-breeding soil	380 (58, 24)	184 (13, 22)
Adult 5th greater covert	2138 (272, 20)	3647 (511, 21)
Down	1307 (165, 23)	1281 (140, 42)
Chick scapular feathers	2453 (186, 23)	1852 (128, 46)
Chick head feathers	NA	987 (26, 13)

7.4 Conclusion

An age-related trend is present in both species. Mercury concentrations, in great black-backed gulls, are generally: down < first grown feather = adult feathers. Similarly in herring gulls the mercury concentrations generally are: down < first grown feather < adult feathers and first grown feather > last grown feather. The first grown feathers have increased mercury levels compared to the egg (down) levels because once feather growth starts the body burden and current dietary input of mercury is deposited in the feathers (Monteiro and Furness 1995). The mercury in the down is from the female depositing mercury in her egg, while the chick's feather mercury concentrations are from mercury ingested via food (Becker *et al.* 1994). The decrease in mercury concentrations in the last grown feathers (head feathers) of herring gulls compared to the first grown feather is due to the growth dilution effect. As the chick grows rapidly (prior to fledging) the mercury intake via their diet is distributed throughout their body and growing feathers, depleting the body burden to levels similar to mercury levels in the egg.

Adult feather mercury concentrations are significantly higher than egg and chick feather mercury concentrations in herring gulls, which agree with the findings of Thompson *et al.* (1991) and Burger (1995). Adult gulls have higher mercury concentrations compared with their chicks because mercury in adults represent a longer period of mercury accumulation (since the last moult) and chick mercury concentrations represent only the accumulation period during their growth and from the egg (Honda *et al.* 1986, Thompson *et al.* 1991). Adult great black-backed gulls also have significantly higher mercury concentrations than their eggs, but unlike herring gulls their chicks have

similar mercury concentrations as adults. Great-black-backed gull chicks may have a mechanism increasing their feather mercury elimination efficiency as an adaptation to a traditionally higher trophic level diet than herring gulls, although this study did not find a difference in trophic levels between adults of the two species.

In both species, scapular feather tips and fully grown scapular feathers have a similar mercury concentration, which agrees with Hahn *et al.*'s (1993) finding that mercury concentrations are homogeneously distributed in feathers. Chicks of both species have higher mercury concentrations in their first grown feathers as compared to egg mercury levels (represented by down). The chicks' first feathers are grown 15-20 days after hatching (Pierotti and Good 1994), but prior to feather growth ingested mercury must be stored in the internal organs. Once feather growth begins, the chick's body burden of mercury is sequestered into the newly forming feather, thereby increasing mercury concentrations in first-grown feathers compared to their egg mercury levels.

Herring gulls have higher mercury concentrations in their scapular feathers compared with head feathers, and there is no trend in mercury concentrations between head feathers and scapular feathers. The lower head feather mercury concentration, lack of relationship with scapular feathers, and the fact head feathers are grown after a period of rapid growth, indicate that head feather mercury concentrations may represent the chick's body burden of mercury once stabilized (deposited in the other feathers) to mercury levels similar to concentrations in their eggs (down).

8. Stable Isotopes and Diet

8.1 Introduction

8.1.1 Carbon and Nitrogen

The objectives of this chapter is to determine the trophic position using nitrogen isotopes (^{15}N) and carbon isotopes (^{13}C) to establish the source of nutrients in diets of herring gulls and great black-backed gulls. In addition the mercury concentrations in the gulls'diet are compared between species and with the isotope levels.

The standard for carbon is the PeeDee belemnite (PDB), which results in ^{13}C analyzed samples with negative numbers, because PDB is usually enriched with ^{13}C compare to the sample. Samples analyzed for ^{15}N are typically positive because the standard is atmospheric air (AIR) (Hobson 1999).

Carbon isotopes are subject to little change through the food web; thus, they are ideal for tracing the origin of nutrients (Hobson 1999). Marine food webs generally have more ^{13}C than terrestrial food webs (Hobson 1999). Thus, relative quantities of marine and terrestrial prey items to the consumer's tissue can be assessed (Hobson 1999).

Nitrogen isotope composition is also related to diet. ^{15}N is preferentially incorporated into tissue while the lighter isotope (^{14}N) is excreted (Minagawa and Wada 1984). In marine systems nitrogen isotopes are initially introduced as inorganic nitrogen which fractionates and enters the food chain via phytoplankton (Owens 1987). Since there is a linear relationship between ^{15}N levels and diet, ^{15}N is used to assess trophic levels (DeNiro and Epstien 1981, Owens 1987).

Carbon and nitrogen isotope analysis does not give the same dietary "snap shot" as stomach content analysis (Hobson 1999, Davenport and Bax 2002). Isotope

composition represents the assimilated diet. The dietary period which the isotope composition represents is determined by the metabolic rate of the tissue that is being sampled (Hobson 1999, Davenport and Bax 2002).

8.1.2 Isotope turnover rates and fractionation in body tissues

Isotope turnover rates depend on the tissue analyzed. Tissues with faster metabolism element isotopes more quickly reflecting a more recent diet, and tissues with a slower metabolism have isotope signatures reflecting the longer-term diet (Hobson 1999). A captive study on Japanese quail (*Cotumix japonica*) showed turnover rates of carbon in various tissues ranked liver>whole blood>muscle>bone collagen (Hobson and Clark 1992). Hobson and Clark (1992) suggest blood fraction carbon isotope analyses can give the same dietary information as muscle and liver (Hobson 1999).

The ecological interest of the present study involves estimating longer-term diet by analyzing carbon and nitrogen isotope signatures of feathers and shorter-term diet by determining the isotope signatures of blood. Isotope analysis of feathers and blood will assess the gulls' source of mercury and trophic position during two time periods in the year. The stable isotope and mercury analysis will also be used to determine the role of gulls in the marine mercury cycle.

The two species' trophic levels are assessed using stable isotope analysis of gull blood and feathers. Blood isotope ratios represent the immediate trophic position (using ^{15}N analysis) and the diet source (using ^{13}C analysis). The ^{15}N and ^{13}C isotope ratios of the 5^{th} greater covert feathers of adults determine the trophic position and diet source respectively during a period of approximately 2 weeks in the summer (fledging period).

Variations in stable isotope ratios within populations are not surprising because gulls are able to switch prey items readily.

8.1.3 Diet Composition

Gulls have a mid-range mercury level in seabirds. Herring gulls had lower mercury levels than double-crested cormorants and common terns (*Sterna hirundo*) and higher mercury levels than black-legged kittiwakes (*Rissa tridactyla*) and red-necked phalaropes (*Phalaropus lobatus*) in the same region. Gulls may have lower total mercury concentrations in their feathers, but because fish have a higher proportion of methylmercury than lower trophic level organisms, the gulls may still be at risk (Hildebrand *et al.* 1980, Schreiber 1983, Braune 1987). A reason why gulls have higher mercury concentrations than black-legged kittiwakes and red-necked phalaropes, is that gulls feed more inshore and inshore prey are generally more contaminated than offshore prey items (Braune 1987).

Mikac *et al.* (1985) found heavy metals are more concentrated in coastal and estuarine sediments as well as several orders of magnitude higher than the water above the sediment. Benthic organisms (especially mollusks) accumulate mercury from these sediments and then mercury is available to biomagnify up the trophic web (Mikac and Picer 1985). Since the gulls feed primarily on pelagic organisms and euphausiids, they have lower mercury concentrations than birds with a higher trophic level diet (Braune 1987).

Stomach content analysis accompanies stable isotope analysis well because it gives the immediate diet composition. Stomach content analysis is limited to recent diet and may be biased against quickly digested prey items (Davenport and Bax 2002).

Another confounding factor of stomach content examination is that identification to the species level is not always possible and prey species may be aggregated, therefore representing different trophic levels than nitrogen isotope trophic determination (Davenport and Bax 2002). Regurgitation samples and stable isotopes are used to identify the food sources that contribute mercury, and the relative contribution of terrestrial and marine sources of mercury to the gull's diet.

Herring gulls are opportunistic omnivores, which consume a wide variety of foods including fish, insects, marine organisms, garbage, small rodents, and other birds (Gilman 1977, Hahn *et al.* 1993). Herring gulls from the Dear Island area of the Bay of Fundy eat mostly herring *Clupea harengus* (a pelagic fish) and euphausiids *Meganyctiphanes norvegica* (crustaceans) (Braune 1987).

8.2 Methods

Feathers and blood were oven dried at 80˚C for 48 hours prior to analysis. Samples were prepared by packing a small (0.185-0.225g) part of the feather tip or powdered blood into tin capsules, and then palletized (Nisbet *et al.* 2002). The samples were analyzed for carbon (^{13}C and ^{12}C) and nitrogen (^{15}N and ^{14}N) stable isotope ratios at the Stable Isotope in Nature Laboratory, Canadian Rivers Institute, University of New Brunswick, using a Finnigan-Mat Delta Plus interfaced via continuous flow to an NC2500 elemental analyzer.

8.3 Comparing blood and 5th greater covert feather stable isotope levels

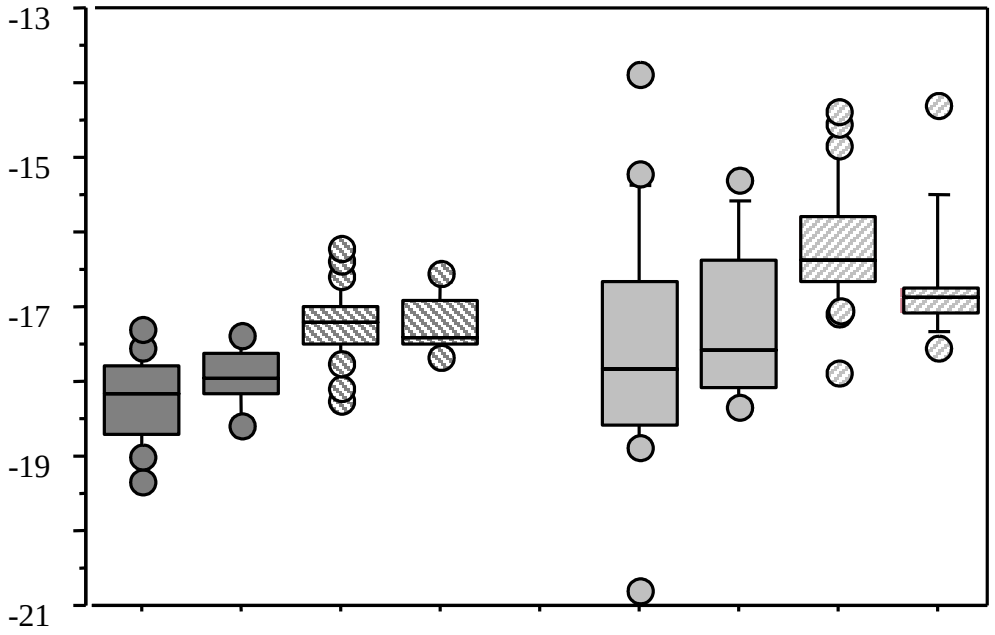
Stable carbon (^{13}C) and nitrogen (^{15}N) isotopes were used to assess the gulls' diet source and trophic position, respectively. ^{13}C and ^{15}N levels were compared in blood and 5th greater covert feathers of both species in 2002 and 2003. The **5th covert feathers**

represent late summer/early fall stable isotope levels of the year prior to collection and **blood** is a "snap shot" of stable isotope levels at the time of collection (spring).

In 2002, the summer/early fall ^{13}C and ^{15}N levels of great black-backed gulls and herring gulls were significantly higher than in spring (Table 23, Table 24). In 2003, great black-backed gulls' had similar ^{13}C levels in summer/early fall and spring were (in contrast to 2002), but the ^{15}N levels were significantly higher in the summer/early fall than their spring ^{15}N levels (similar to 2002) (Table 23, Table 24). The 2003 herring gulls followed the same trend as their 2002 stable isotope levels in that their ^{13}C and ^{15}N levels were significantly higher in the summer/early fall (Table 23, Table 24).

8.4 Carbon

^{13}C is enriched in inshore feeders compared to more marine or offshore feeders; thus, relative protein contributions of the consumer can be assessed as marine or more inshore in origin (Hobson 1999, Nisbet *et al.* 2002). The species' ^{13}C levels were compared with each other. In 2002, ^{13}C was significantly enriched in herring gulls' 5^{th} greater covert feathers and blood, which indicated herring gulls were feeding on more inshore prey items in spring and fall than great black-backed gulls (Figure 14, Table 24, Table 25). This difference was not found in 2003 (Figure 14, Table 24, Table 25). ^{13}C levels in blood and feathers did not differ significantly between years in either species (Figure 14, Table 24).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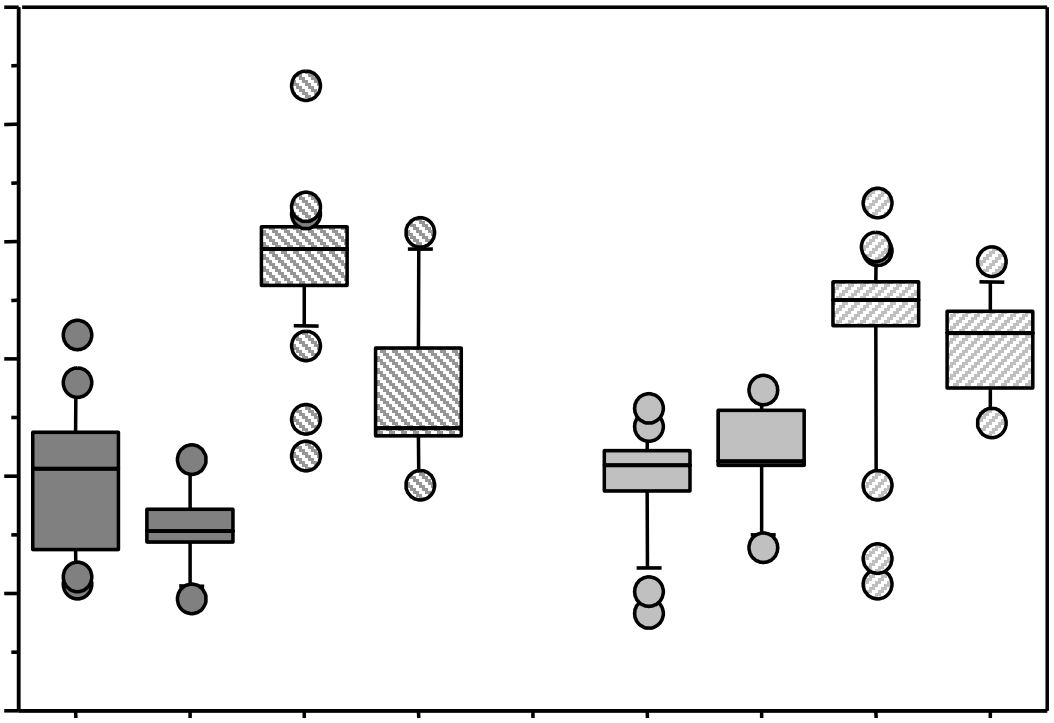
8.5 Nitrogen

^{15}N is used to assess trophic levels because there is a linear relationship between ^{15}N levels of the consumer and its diet (DeNiro and Epstien 1981, Owens 1987). Isotope turnover rates depend on the tissue analyzed; thus, different body tissues represent different diet periods. Tissues with higher metabolic rates have higher isotope turnover rates and represent more recent dietary averages (Hobson 1999).

The two species' ^{15}N levels were compared. In 2002, there was no significant difference between the two species' blood ^{15}N levels, but great black-backed gulls had significantly enriched ^{15}N in their 5^{th} greater coverts compared to herring gulls (Figure 15, Table 24, Table 25). In contrast to 2002, the 2003 herring gulls had significantly enriched blood ^{15}N and no significant difference between the two species' 5^{th} greater covert feather ^{15}N was found (Table 24).

^{15}N levels were compared between 2002 and 2003. The year 2002 blood ^{15}N levels were not significantly different from 2003 blood ^{15}N levels in great black-backed gull and herring gull (Table 24, Table 25). The 2002 great black backed gull 5^{th} greater coverts feathers had significantly enriched ^{15}N compared to 2003 ^{15}N levels while herring gulls had no significant difference between the two years ^{15}N levels in their 5^{th} greater feathers (Figure 15, Table 24, Table 25).



Comparison	Year	Stable Isotope	P	Sample with higher trophic level (D15N enriched) or inshore feeding (D13C enriched)	Significant Difference Yes/No ($\alpha = 0.05$)	Effect Size
Species (blood)	**2002**	**^{13}C**	**0.037**	**HERG**	**Yes**	0.32
Species (blood)	2002	^{15}N	0.743	NA	No	NA
Species (feather)	**2002**	**^{13}C**	**< 0.001**	**HERG**	**Yes**	1.05
Species (feather)	**2002**	**^{15}N**	**0.001**	**GBBG**	**Yes**	0.94
Sample Tissue (GBBG)	**2002**	**^{13}C**	**< 0.001**	**Feather**	**Yes**	1.79
Sample Tissue (GBBG)	**2002**	**^{15}N**	**< 0.001**	**Feather**	**Yes**	3.13
Sample Tissue (HERG)	**2002**	**^{13}C**	**0.001**	**Feather**	**Yes**	0.84
Sample Tissue (HERG)	**2002**	**^{15}N**	**< 0.001**	**Feather**	**Yes**	1.58
****Sample Tissue**	**2002**	**^{13}C**	**< 0.001**	**Feather**	**Yes**	NA
****Species**	**2002**	**^{13}C**	**< 0.001**	**HERG**	**Yes**	NA
**Sample Tissue * Species	2002	^{13}C	0.428	NA	No	NA
****Sample Tissue**	**2002**	**^{15}N**	**< 0.001**	**Feather**	**Yes**	NA
****Species**	**2002**	**^{15}N**	**0.029**	**HERG**	**Yes**	NA
****Sample Tissue * Species**	**2002**	**^{15}N**	**0.009**	**N/A**	**Yes**	NA

Table 23. Continued.

Comparison	Year	Stable Isotope	P	Sample with higher trophic level (D15N enriched) or inshore feeding (D13C enriched)	Significant Difference Yes/No ($\alpha = 0.05$)	Effect Size
Species (blood)	2003	^{13}C	0.073	NA	No	NA
Species (blood)	**2003**	**^{15}N**	**0.004**	**HERG**	**Yes**	0.68
Species (feather)	2003	^{13}C	0.083	NA	No	NA
Species (feather)	2003	^{15}N	0.163	NA	No	NA
Sample Tissue (GBBG)	2003	^{13}C	0.240	NA	No	NA
Sample Tissue (GBBG)	**2003**	**^{15}N**	**< 0.001**	**Feather**	**Yes**	1.63
Sample Tissue (HERG)	**2003**	**^{13}C**	**0.001**	**Feather**	**Yes**	0.50
Sample Tissue (HERG)	**2003**	**^{15}N**	**< 0.001**	**Feather**	**Yes**	2.11
****Sample Tissue**	**2003**	**^{13}C**	**0.016**	**Feather**	**Yes**	NA
****Species**	**2003**	**^{13}C**	**0.012**	**HERG**	**Yes**	NA
**Sample Tissue * Species	2003	^{13}C	0.748	NA	No	NA
****Sample Tissue**	**2003**	**^{15}N**	**< 0.001**	**Feather**	**Yes**	NA
****Species**	**2003**	**^{15}N**	**0.004**	**HERG**	**Yes**	NA
**Sample Tissue * Species	2003	^{15}N	0.487	NA	No	NA

** = Two-way ANOVA

Matrix	Species	Stable Isotope	P	Significant Difference Yes/No ($\alpha = 0.05$)	Effect Size
Blood	GBBG	^{13}C	0.136	No	NA
Blood	GBBG	^{15}N	0.081	No	NA
Feather	GBBG	^{13}C	0.776	No	NA
Feather	**GBBG**	**^{15}N**	**< 0.001**	**Yes**	1.77
Blood	HERG	^{13}C	0.609	No	NA
Blood	HERG	^{15}N	0.279	No	NA
Feather	HERG	^{13}C	0.116	No	NA
Feather	HERG	^{15}N	0.626	No	NA

Species	Year	Matrix	Isotope	Mean Isotope Level (‰) (SE, N)	
				GBBG	HERG
GBBG	2002	Blood	^{13}C	-18 (0.109, 24)	-18 (0.353, 19)
GBBG	2002	Blood	^{15}N	12 (0.236, 24)	12 (0.196, 19)
GBBG	2002	Feather	^{13}C	-17 (0.079, 37)	-16 (0.153, 27)
GBBG	2002	Feather	^{15}N	16 (0.169, 37)	15 (0.305, 27)
GBBG	2003	Blood	^{13}C	-18 (0.133, 9)	-17 (0.329, 10)
GBBG	2003	Blood	^{15}N	11 (0.244. 9)	12 (0.280, 10)
GBBG	2003	Feather	^{13}C	-17 (0.118, 10)	-17 (0.277, 10)
GBBG	2003	Feather	^{15}N	13 (0.453, 10)	14 (0.273, 10)

8.6 Relationship between mercury and stable isotopes

Out of 16 possible regression combinations between stable isotopes (^{15}N and ^{13}C) and mercury concentrations in blood and 5th greater covert feathers, only 4 combinations were significant. ^{15}N and mercury concentrations had a positive relationship in great black-backed gull blood collected in 2002 and 5th greater covert feathers collected in 2003. Therefore, as the trophic level increased, the mercury concentrations in great black-backed gull blood (2002) and 5th greater covert (2003) increased. Mercury concentrations, in herring gull blood collected in 2003, were positively related with ^{13}C and ^{15}N (Figure 16, Figure 17, Figure 18, Figure 19, Appendix 3). Thus, as herring gulls' (2003) trophic position and inshore feeding levels increased blood mercury concentrations increased.

8.7 Diet

In contrast to stable isotopes, regurgitation samples gave a snap shot of the chick's diet at the time of collection. In great black-backed gulls white fleshed fish and krill were present in 9 (47%) and 4 (21%) respectively of the 19 regurgitation samples. In herring gulls, white fleshed fish and krill were present in 13 (33%) and 19 (48%) respectively of the 39 regurgitation samples. Other items identified in great black-backed gulls were salmon pellets (16%) and birds (5%) while in herring gulls crustaceans (8%), human garbage (5%), and salmon pellets (3%) were identified (Figure 20, Appendix 4).

Figure 20. Diet samples from herring gull and great black-backed gull chicks as a percent of the total number of diet samples obtained from each species. A total of 19 diet samples were collected from great black-backed gull chicks and 39 diet samples were collected from herring gull chicks. WFF = White fleshed fish, SP = Salmon pellets, Crusta. = Crustaceans, and Anth. = Anthropogenic.

8.8 Conclusion

8.8.1 Comparing blood (spring) and 5th greater covert feather (fall)

During the spring breeding season (represented by blood isotope signatures), both species of gulls feed on more offshore food sources and are lower in trophic position in comparison to early fall (represented by the 5th greater covert feather isotope signatures). Thus, adult gulls switch from offshore sources (presumably more natural sources) during the breeding season to a more inshore food sources once their chicks have fledged (early fall).

In 2002, both species had similar trophic positions during the spring, but great black-backed gulls had a higher trophic position than herring gulls during the fall. In 2003, herring gulls had a higher trophic position during the spring than great black-backed gulls, but not in fall. Herring gulls fed on more inshore prey items in spring and fall of 2002 than great black-backed gulls, but in 2003 herring gulls fed on similar food sources as great black-backed gulls during spring and fall.

8.8.2 Comparing years and species

Herring gulls' spring and fall trophic positions, and great black-backed gulls' spring trophic positions, did not change between 2002 and 2003, but during 2002 great black-backed gulls had a higher fall trophic position than during 2003. Within each species, the inshore/offshore signal did not change between 2002 and 2003 during spring or fall. Generally, the trophic positions, inshore/offshore signal, and mercury concentrations remained consistent from one year to the next during spring and fall within each gull species with the exception of great black-backed gull fall 2002 trophic position.

If the primary source of mercury in gulls is through biomagnification up the food chain there should be a positive relationship between mercury concentrations and trophic position (as indicated by ^{15}N). However, out of 16 possible combinations, only four were significantly positive (Appendix 3). The lack of trophic position-mercury relationships is not consistent with the theory of mercury biomagnification. Since this section of the study is evaluating mercury and trophic levels between two sympatric gull species the differences in mercury, D15N, and D13C may be below the detectable difference levels.

8.8.3 Diet

The stomach content analyses found little difference between the two species diets (from the chicks) which supports the stable isotope findings. Both diet and isotope analyses indicate both species have similar diet sources during the breeding season (spring), assuming adult gulls have similar diets as their chicks. Krill (average mercury concentration = 95 ppb DW) and white fleshed fish (average mercury concentration =

108 ppb DW) were the predominant food items fed to the chicks (of both species) during 2003. Diet samples were not available for 2002.

9. Mercury in Feathers and Blood

9.1 Introduction

The purpose chapter 9 is to describes whether there are differences in the gull's mercury concentrations at different times of the year and location, by analyzing total mercury levels in feathers grown during different times of the year and from different breeding colonies alone the Bay of Fundy coast.

Blood is influenced mainly by dietary uptake of mercury and represents current mercury burdens (Kahle and Becker 1999). Whereas feather mercury concentrations reflect the dietary intake of mercury during the last moult and the sequestration of accumulated mercury in the internal organs since the previous moult (Burger 1993).

Much of the total mercury body burden, in gulls, is located in the feathers (Braune and Gaskin 1987). Mercury incorporated into the feathers is very stable; thus, feathers provide an ideal sampling matrix (Burger 1993). As moult progresses, the body burden of mercury decreases. The decrease in the body burden of mercury is generally reflected in the decrease in feather mercury concentrations as the moult progresses (Braune and

Gaskin 1987). Also, feathers give information about ecotoxic effects and incorporation paths of organic mercury in birds (Hahn *et al.* 1993).

9.2 Methods

Please refer to chapter 3 and chapter 4.1.2 for laboratory and adult collection methods respectively.

9.3 Collection dates and sampling matrix

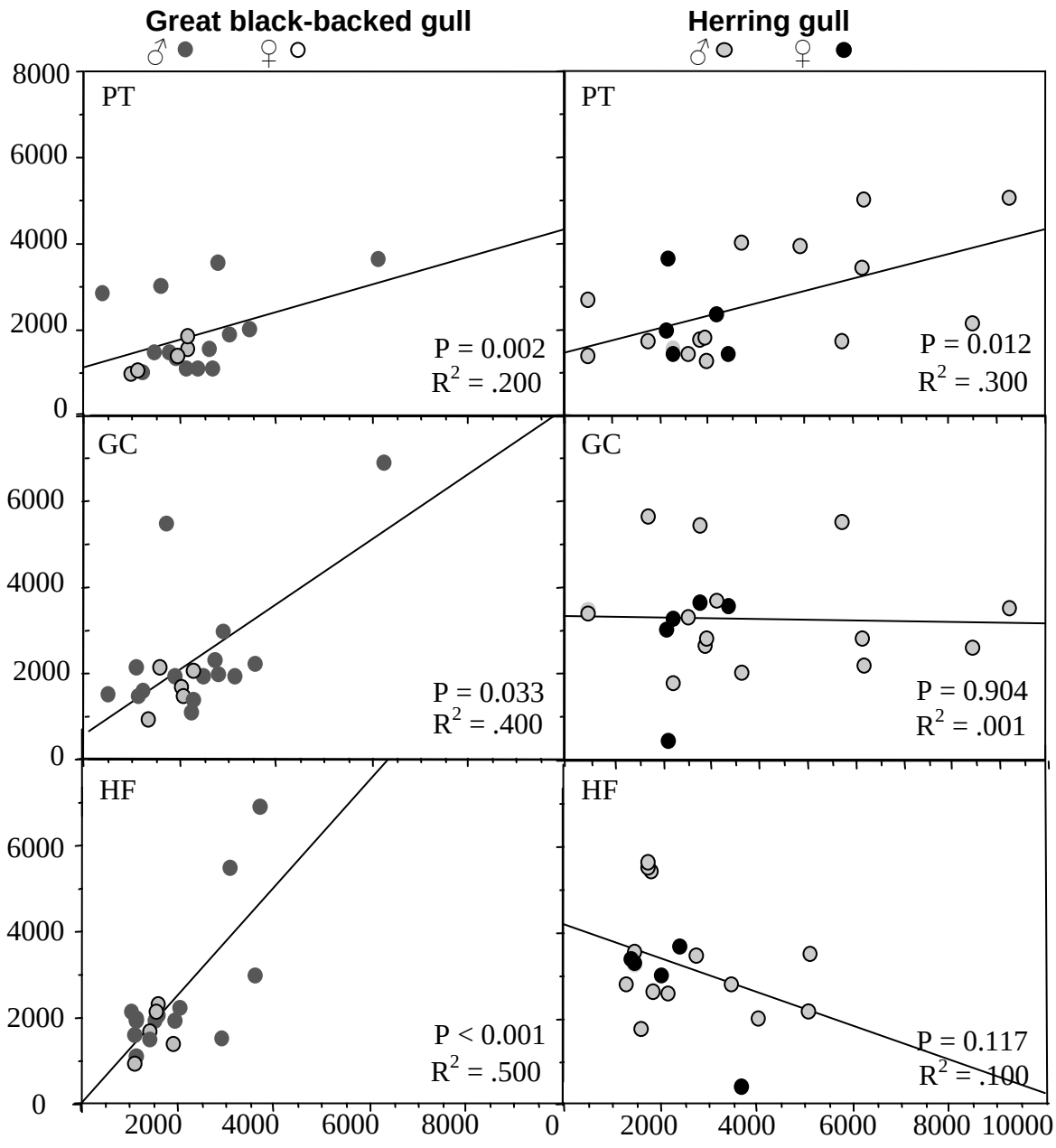
All dates are collection dates. The tissues collected represent mercury concentrations at different times of the year: the **10th primary feather tips** represent late fall mercury concentration of the year prior to collection (2002); the **5th covert feathers** represent late summer/early fall mercury concentration of the year prior to collection; the **head feathers** represent late fall/early winter mercury concentrations of the year prior to collection; and **blood** is a "snap shot" of mercury concentration at the time of collection (spring 2003).

9.4 Seasonal comparison of mercury concentrations using feathers

Since the three different feather types were grown during different seasons and accumulate mercury during their period of growth, the different feathers were used to compare mercury concentrations between the seasons. Since the feather types (head feather, 5th greater covert feather, and 10th primary feather tip) were collected from the same bird, repeated measures ANOVA tests were used to asses if the mean Hg concentration was the same in all three feather types. The mean Hg concentrations in the three feather types were the same in great black-backed gulls (P=0.115) and in herring gulls (P= 0.263).

Further regression analysis was used to compare mercury concentrations between each tissue type in order to determine whether any relationships exist between the three feather types and blood. Blood mercury concentrations (representing a "snap shot" of spring mercury concentration) of great black-backed gulls had no relationship with mercury concentrations in the 5th greater covert, 10th primary tip, or head feathers (Figure 21). However, the mercury concentrations of the three feather types did have a relationship with each other. There were significant relationships in mercury concentration between head feathers and 10th primary tip; 10th primary tip and 5th greater covert feathers; and head feathers and 5th greater covert (Figure 22).

In herring gulls, the blood mercury concentrations also had no relationship with mercury concentrations in the 5th greater covert feathers, but had a relationship with mercury concentrations in the 10th primary tip and head feathers (Figure 21). Unlike great black-backed gulls, the mercury concentrations of the three feather types had no relationship with each other in herring gulls. Mercury concentrations in the following herring gull feathers had no relationship with each other: head feather and 10th primary tip; 10th primary tip and 5th greater covert; head feather and 5th greater covert (Figure 22).


Great black-backed gull
♂ ♀
Herring gull
♂ ♀
PT
P = 0.002
R2 = .200
PT
P = 0.012
R2 = .300
GC
P = 0.033
R2 = .400
GC
P = 0.904
R2 = .001
HF
P < 0.001
R2 = .500
HF
P = 0.117
R2 = .100
0
2000
4000
6000
8000
10000

9.5 Comparing mercury concentrations with respect to collection year and location

Various tissue samples from both gull species were collected during 2001, 2002, and 2003 from four regions in the Bay of Fundy; namely, the Saint John area (STJ.), Maces Bay (MB), Passamaquoddy Bay (PB), and the Deer Island area (DI). Two similar collection habitats, Sandy Island during 2001 and the Hospital Islands during 2002 and 2003, represent the Deer Island area. These four regions were loosely grouped into two zones. The Saint John area and Maces Bay collection regions were classified as part of the inner Bay of Fundy, whereas Passamaquoddy Bay and Deer Island area were classified as part of the outer Bay of Fundy.

Of the various tissues sampled only two types were sampled consistently in all regions; namely, blood and the 5^{th} greater covert feathers. Blood and 5^{th} greater covert feathers from both great black-backed gulls and herring gulls were collected in all years from all regions with the following exceptions. No data was available for herring gulls from the Saint John area in 2001 and the Deer Island area in 2002. In 2003, samples were collected from only the Hospital Islands (Table 28).

9.6 Comparing regional differences within the collection year

In 2001, no regional differences in mercury concentrations were found in the 5^{th} greater covert feather and blood of either the great black backed gulls or herring gulls (Figure 23, Table 26, Table 27). In contrast, samples collected in 2002 showed significant regional differences in the mercury concentrations found in the 5^{th} greater covert feather and blood of both great black backed gulls and herring (Figure 23, Table 26, Table 27). The 2002 data was further characterized as part of the inner Bay of Fundy or outer Bay of Fundy. Further analysis comparing the inner Bay of Fundy (Saint John

area and Maces Bay) to the outer Bay of Fundy (Passamaquoddy Bay and Deer island area) indicated there were no significant differences in great black backed gull blood and feather as well as in herring gull blood mercury concentrations between the inner and outer Bay of Fundy (Figure 23, Table 26, Table 27). The only significant difference between the 2002 inner and outer bay's mercury levels was present in herring gull feathers where the outer Bay of Fundy had significantly elevated mercury concentrations (Figure 23, Table 26, Table 27). Thus, no significant difference existed between the regions' mercury concentrations in 2001 or between the inner to the outer Bay of Fundy in 2002 with the exception of higher feather mercury concentration in the outer Bay of Fundy's herring gulls during 2002.

9.7 Comparing mercury concentrations from year to year

Since the samples were collected from only the Hospital Islands in 2003, a direct comparison was possible only for the Deer Island area. Within this region the mercury concentrations in both the 5th greater covert feather and blood of herring gulls did not differ significantly between 2001 and 2003 (Figure 24, Table 26, Table 27) (2002 data unavailable). Similarly there was no significant difference in mercury concentrations in the 5^{th} greater covert feather of great black-backed gulls between 2001, 2002, and 2003, but the mercury concentrations in blood were significantly different (Figure 24, Table 26, Table 27). Blood mercury concentrations were significantly higher in 2001 than 2002 and 2003 (2001>2002, 2001>2003) and in 2003 as compared to 2002 (2003> 2002) (Figure 24, Table 26, Table 27). Further comparisons follow to validate whether the above results may be extrapolated to encompass other regions in the Bay of Fundy.

The mercury concentrations in the 2001 and 2002 Deer Island areas gull colonies were compared to all other regions to assess if the 2003 Hospital Island data (off Deer Island) were similar to the other Bay of Fundy (all other regions) gull colonies' mercury concentrations. In 2001, there was no significant difference in the great black-backed gulls' feather and blood mercury concentrations from the Deer Island area as compared with all the other regions (Table 26, Table 27). In contrast, the blood mercury concentrations of the Deer Island herring gulls, in 2001, were significantly elevated. Similar to the 2001 great black-backed gulls the 2001 herring gulls' feather mercury concentrations were not significantly different in the Deer Island area as compared with the other regions (Table 26, Table 27). Thus, in 2001 the only significant differences between the Deer Island gull colonies' mercury concentrations and the rest of the gull colonies' (all other regions) mercury concentration was herring gull blood.

In 2002, the blood mercury concentrations of the Deer Island great black-backed gulls were not significantly different from mercury concentrations in the gulls from colonies in the other regions of the Bay of Fundy. The Deer Island great black-backed gulls' feather mercury concentrations were significantly lower as compared with the other regions (Table 26, Table 27). No data was available for the Deer Island herring gulls in 2002. Since no consistent pattern between the Deer Island gulls' mercury concentrations and the other regions was present in 2001 or 2002, the Deer Island data did not represent any other region in the Bay of Fundy. Thus, the 2003 results are isolated to the Hospital Island area and can not be extrapolated to the other gull colonies in the Bay of Fundy.

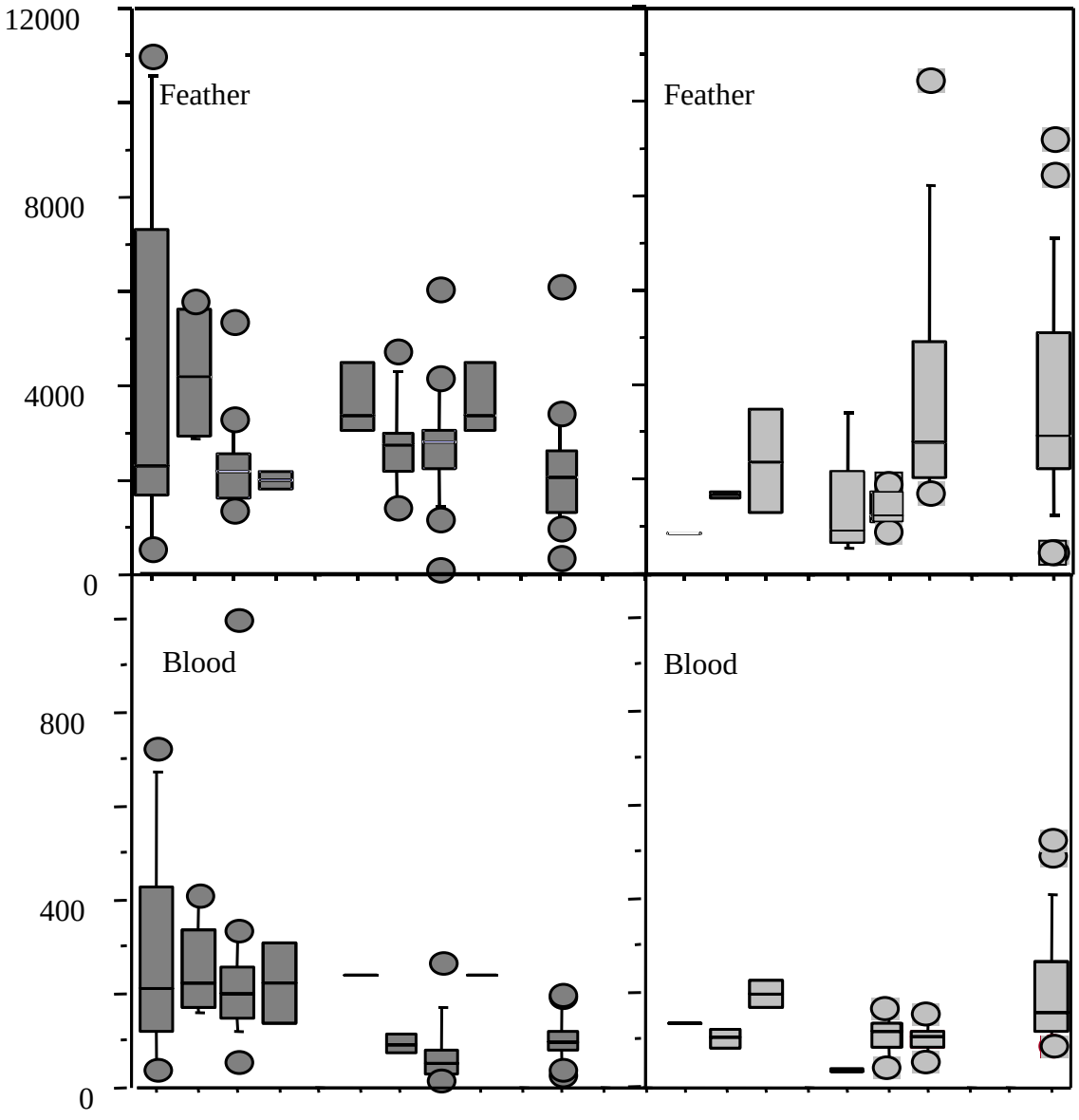

12000
8000
4000
0
Feather
Feather
800
400
0
Blood
Blood

Table 26. Summary of ANOVAs performed on regional differences and yearly differences (Deer Island area only) the mercury concentrations (ppb fresh weight) in the blood and 5th greater covert feathers of adult gulls collected during 2001, 2002, and 2003. Four regions in the Bay of Fundy are represented. STJ = Saint John area, MB = Maces Bay, PQ = Passamquoddy Bay, and DI = Deer Island area.

Comparison	Species	Year	Tissue type	P	Sample with higher [Hg]	Significant Difference Yes/No ($\alpha = 0.05$)
Regions (STJ, MB, PQ, and DI)	GBBG	2001	Blood	0.962	NA	No
Regions (STJ, MB, PQ, and DI)	GBBG	2001	Feather	0.192	NA	No
Regions (STJ, MB, PQ, and DI)	**GBBG**	**2002**	**Blood**	**0.050**	**STJ**	**Yes**
Regions (STJ, MB, PQ, and DI)	**GBBG**	**2002**	**Feather**	**0.025**	**STJ**	**Yes**
Inner bay Vs outer bay	GBBG	2002	Blood	0.092	NA	No
Inner bay Vs outer bay	GBBG	2002	Feather	0.173	NA	No
*DI area and all other regions	GBBG	2001	Blood	0.810	NA	No
*DI area and all other regions	GBBG	2001	Feather	0.530	NA	No
DI area and all other regions	GBBG	2002	Blood	0.326	NA	No
DI area and all other regions	**GBBG**	**2002**	**Feather**	**0.007**	**All other regions**	**Yes**
Years (DI)	**GBBG**	**NA**	**Blood**	**0.002**	**2001**	**Yes**
Years (DI)	GBBG	NA	Feather	0.350	NA	No
***2001 and 2002 (DI)**	**GBBG**	**NA**	**Blood**	**0.027**	**2001**	**Yes**

Table 26. Continued

Comparison	Species	Year	Tissue type	P	Sample with higher [Hg]	Significant Difference Yes/No (α = 0.05)
***2001 and 2003 (DI)**	**GBBG**	**NA**	**Blood**	**0.007**	**2001**	**Yes**
2002 and 2003 (DI)	**GBBG**	**NA**	**Blood**	**0.030**	**2003**	**Yes**
Regions (MB, PQ, and DI)	HERG	2001	Blood	0.108	NA	No
Regions (MB, PQ, and DI)	HERG	2001	Feather	0.476	NA	No
Regions (STJ, MB, and PQ)	**HERG**	**2002**	**Blood**	**0.013**	**MB**	**Yes**
Regions (STJ, MB, and PQ)	**HERG**	**2002**	**Feather**	**0.016**	**PQ**	**Yes**
Inner bay Vs outer bay	HERG	2002	Blood	0.450	NA	No
Inner bay Vs outer bay	**HERG**	**2002**	**Feather**	**0.004**	**Outer bay**	**Yes**
DI area and all other regions	**HERG**	**2001**	**Blood**	**0.035**	**DI**	**Yes**
DI area and all other regions	HERG	2001	Feather	0.291	NA	No
*2001 and 2003 (DI)	HERG	NA	Blood	0.889	NA	No
*2001 and 2003 (DI)	HERG	NA	Feather	0.474	NA	No

*Sample sizes small or very uneven

Table 27. Sample size, mean, and standard of mercury concentrations (ppb fresh weight) in blood and 5th greater covert feathers of adult great black-backed gulls and herring gulls collected during 2001, 2002, and 2003. Four regions in the Bay of Fundy are represented. STJ = Saint John area. MB = Maces Bay, PQ = Passamquoddy Bay, and DI = off Deer Island.

Matrix	Region	Mean Mercury Concentration (ppb fresh weight) (SE, N)	
		GBBG	HERG
Feather 2001	STJ	4123 (1540, 7)	NA
Blood 2001	STJ	293 (90, 7)	NA
Feather 2001	MB	4275 (770, 4)	900 (NA, 1)
Blood 2001	MB	255 (57, 4)	140 (NA, 1)
Feather 2001	PQ	2319 (243, 16)	1700 (58, 3)
Blood 2001	PQ	248 (53, 16)	107 (15, 3)
Feather 2001	DI	2000 (200,2)	2400 (1100, 2)
*Blood 2001	DI	225 (85, 2)	200 (30, 2)
Feather 2002	STJ	3738 (593, 3)	1494 (534, 5)
Blood 2002	STJ	241 (NA, 1)	36 (2, 3)
Feather 2002	MB	2721 (346, 8)	1377 (131, 7)
Blood 2002	MB	92 (12, 4)	114 (16, 7)
Feather 2002	PQ	2721 (283, 18)	4010 (741, 13)
Blood 2002	PQ	70 (20, 12)	107 (12, 8)
Feather 2002	DI	1307 (324, 5)	NA
Blood 2002	DI	48 (9, 4)	NA
Feather 2003	DI	2138 (272, 20)	3647 (511, 21)
Blood 2003	DI	105 (11, 18)	213 (128, 21)

9.8 Conclusion

9.8.1 Adult Mercury Concentrations

Feather mercury concentration is representative of the mercury concentration in the gull during the feather's period of growth, whereas the blood is an indicator of mercury concentration at the time of collection (Hahn *et al.* 1993). The feather mercury levels are higher than blood mercury concentrations both because feathers have many S-H bonds, which bind the mercury, and because the mercury in the blood and internal organs is sequestered into the growing feathers (Braune and Gaskin 1987, Lewis and Furness 1991, Lewis and Furness 1993). In both species, feathers grown at different seasons have similar mercury concentrations, which indicate the gulls have no major shifts between winter and fall mercury concentrations (head feathers versus primary feather #10 tips and 5^{th} greater covert feathers).

Further evidence of the mercury concentrations remain constant over time, in herring gulls, is presented in the feather-blood regression analyses. In herring gulls, the 2003 spring mercury concentrations (blood collected in 2003) had a relationship with the 2002 fall mercury concentrations (10^{th} primary feather tips representing fall 2002) and 2002 winter mercury concentrations (head feathers representing winter 2002). However, there was no trend between mercury concentrations in blood and 5^{th} greater covert feather. Overall, these relationships indicate mercury concentrations do not change greatly between years or between seasons.

The primary feather moult presumably eliminates most of the body burden of mercury built up between moults; thus, the three feather types (head feather, 5^{th} greater covert feathers, and 10^{th} primary feather tips) represent a period when the mercury concentrations are lower and potentially more steadily deposited. The feather types are

all collected after the first primary wing feathers are moulted. Evidence that mercury may be steadily deposited into the blood and feathers during the fall and winter in great black-backed gulls, is present in the feather-feather relationships and lack of significant difference in mercury concentrations between the feather types. The feather-feather relationships, in great black-backed gulls indicate fall mercury levels (10^{th} primary feather tips and 5^{th} greater covert feathers) have a positively relationship with winter mercury concentrations (head feathers).

The variable presence of feather-feather and feather-blood relationships may be due to gulls being opportunistic omnivores, eating a wide variety of food items containing diverse mercury concentrations. The high variability among individuals on the Hospital Islands may be due to individual specialization in diet, mercury excretion, and demethylation, or some combination thereof.

Generally, fall mercury concentrations, in both gull species, were consistent over the three-year period of 2000-2002 and mercury concentrations were more variable during the spring over a period of three years 2001-2003. In herring gulls, the 2001 and 2003 spring mercury concentrations were similar, and higher than in spring 2002. Great black-backed gulls showed different yearly trends; spring mercury concentrations were higher in 2001 than 2002 and 2003. Since samples from each species were collected from the same locations, the different trends in spring mercury concentrations, between the years, are not attributed to any point source or long range mercury influxes. The gull species showed different trends over the three years probably because of species or individual specializations in diet during the spring (breeding season) and a more predictable diet source in the fall (non-breeding season). The gulls are limited to a more local feeding range during the breeding season due to territoriality on the nesting

grounds; thus, they potentially have to forage on whatever the local ecosystem provides. In the fall, the gulls no longer have a territory and can forage over a larger area for preferred prey items.

Table 28. Comparison with other studies of mercury concentration (ppb fresh weight) in adult herring gull feathers and blood.

Location	Tissue	Year	Mercury concentration (ppb)	Standard error or range	Reference
Passamaquoddy Bay, NB	5th Greater Covert	2001	1700	± 58	This Study
Deer Island, NB	5th Greater Covert	2001	2400	± 1100	This Study
Passamaquoddy Bay, NB	Blood	2001	107	± 15	This Study
Deer Island, NB	Blood	2001	200	± 30	This Study
Saint John, NB	5th Greater Covert	2002	1494	± 534	This Study
Maces Bay, NB	5th Greater Covert	2002	1377	± 131	This Study
Passamaquoddy Bay, NB	5th Greater Covert	2002	4010	± 741	This Study
Saint John, NB	Blood	2002	36	± 2	This Study
Maces Bay, NB	Blood	2002	114	± 16	This Study
Passamaquoddy Bay, NB	Blood	2002	107	± 12	This Study
Deer Island, NB	5th Greater Covert	2003	3647	± 511	This Study
Deer Island, NB	Blood	2003	213	± 128	This Study
Long Island, NY	Breast Feathers	1993	3807	± 266	Burger 1995
Wadden Coast, Germany	Body Feathers	1990	5300	± 70	Lewis *et al.* 1993
Wadden Coast, Germany	Female Body Feathers	1990	4870	2150-9400	Lewis *et al.* 1993
Wadden Coast, Germany	Male Body Feathers	1990	6410	3650-10 940	Lewis *et al.* 1993
Wadden Coast, Germany	Female Primary #1 Feathers	1990	5840	3280-10 030	Lewis *et al.* 1993
Wadden Coast, Germany	Male Primary #1 Feather	1990	9590	4190-13 350	Lewis *et al.* 1993
German Bight	Body feathers	After 1940	7910	2150-21 180	Furness *et al.* 1995
German Bight	Body feathers	Before 1940	4560	1030-7830	Furness *et al.* 1995

9.8.2 Comparing Mercury Concentrations with Respect to Collection Year and Location

The three regional gull colonies, in the Bay of Fundy, were assessed for spring (blood) and fall (5^{th} greater covert feather) mercury concentrations in 2001 and 2002. The mercury concentrations in great black-backed gulls were similar in all three regions. Mercury concentrations in herring gulls were also similar between all regions in 2001 and during spring 2002, but the regions from the outer Bay of Fundy had higher mercury concentrations during the fall of 2002 than those in the inner Bay of Fundy. The regional similarities suggest that gulls from all regions have similar mercury inputs from their diet, similar diet sources throughout the bay, and there were no major changes in regional mercury concentration during 2001 and 2002.

In 2003, only the Hospital Islands gull colony was sampled. Unfortunately, the data from the Deer Island areas is comparable to the other regions in some cases, but significantly different (higher or lower depending on the comparison) in other cases; thus, the Deer Island data cannot be extrapolated to the rest of the Bay of Fundy. Therefore, the 2003 data are compared with 2001 and 2002 data only from the Deer Island area. Mercury concentrations in herring gulls were similar in 2001 and 2003 in the Deer Island area. Great black-backed gulls, from the Deer Island area, had similar mercury concentrations from 2001-2003 during the fall, but spring mercury levels varied between years. In 2002, there was a decrease in spring mercury concentrations and 2001 had the highest spring mercury concentrations of the three years. Thus small changes in spring mercury concentration in great-black-backed gulls were detectable. These changes in spring mercury concentration are attributed to changes in diet due to a more restricted foraging area during spring.

10. Island Parameters

10.1 Introduction

The purpose of chapter 10 is assess if gulls contribute mercury to the Hopital Islands (their nesting site) compared to Mink Island (control with no gulls). The potential mercury contributions to the islands are assessed by measuring mercury concentrations in the soil, vegetation, fresh water seeps, seaweed, and marine invertebrates.

The major excitatory paths of mercury in gulls are the feathers, eggs, and guano (Lewis and Furness 1993, Burger 1994). In the Bay of Fundy rockweed beds are a major source of nutrients, and are inhabited by many species of commercial interest (Coastal Zone Management Bay of Fundy New Brunswick 1979). Mercury and methylmercury concentration are measured from samples collected at low tide from the rockweed flora and fauna surrounding the gull colony. A control site excluding gulls, but with similar geology and marine flora and fauna, is compared to the gull colony's mercury levels. This, in turn, is used to establish whether gull colonies concentrate mercury on their breeding grounds, subsequently contribute to the local rockweed flora mercury levels and possibly lead to toxic levels.

10.2 Methods

Soil samples were collected around 20 staked nests on the Northwest (NW) Hospital Island (in the great black-backed gull breeding area), Southeast (SE) Hospital Island (in the herring gull breeding area), and Mink Island (no gulls) during the pre-breeding (14 May 2003), mid-breeding (23 June 2003), and fledging (29 June 2003)

periods. The staked nests were the same as those used for trapping adults and pursuing chicks. Soil was placed in labeled plastic bags and stored at –20˚C until mercury analysis.

Fresh water seepage was collected from the Hospital Islands and Mink Island during the same three days in the breeding season as the soil was collected. Seepage was collected in glass jars fixed with 1ml of HCl. In order to quantify any mercury contributions to the jars during transport and via the collection process, jars filled with deionized water and 1ml HCl (blanks) were exposed to the same field handling as the sample jars. The blank jars were opened (exposed to the atmosphere) for the same period of time as the sample jars. Within 10 hours of sampling all water samples and blanks were stored at –20˚C until mercury analysis. The Islands are very dry and have no standing water; thus, sufficient water samples for statistical analysis were not obtainable.

Marine vegetation was sampled in the high tide, mid-tide, and low tide zones on the same days the soil and water samples were collected. Random seaweed samples were placed in labeled plastic bags and stored at 0˚C until mercury analysis. The seaweed samples were identifies to the species level where possible using: The Illustrated Key to the Seaweeds of New England (Villalard-Boshnsack 1995) and Neas Key to Benthic Marine Algae of the Northeastern Coast of North America from Long Island South to the Strait of Belle Isle (Sears 1998).

The terrestrial vegetation species composition of the Hospital Islands and Mink Island were assessed using transects on July 29, 2003. The percent cover of each vegetation species was identifies within a $5m^2$ radius every 10m along each transect. Samples of each vegetation species on the NW Hospital, SE Hospital, and Mink Island

respectively were collected in labeled plastic bags and stored at 0˚C until mercury analysis.

10.3 Location

Great black-backed gull samples were collected from central NW Hospital Island and herring gull samples were collected from the SE Hospital Island. NW Hospital Island is a nesting colony for herring gulls and great black-backed gulls, although great black-backed gulls dominate the central portion of the island and had approximately 25-30 great black-backed gull nests. The SE Hospital Island was occupied predominantly by herring gulls and had approximately 60-80 herring gull nests. Soil mercury concentrations were significantly higher on NW Hospital Island during the mid-breeding and pre-breeding periods, but not during the fledging period (Figure 28, Table 35, Table 35).

10.4 Time

Soil mercury concentrations differed significantly among pre-breeding, mid-breeding, and fledging time periods, on both NW and SE Hospital Island (Figure 28, Table 35, Table 35).

On NW Hospital Island, no significant difference between pre-breeding and mid-breeding soil mercury concentrations was found, but there was a significant decrease in soil mercury concentrations during the fledging period compared to the pooled pre-breeding/mid-breeding soil mercury concentrations (Figure 28, Table 35, Table 35).

On the SE Hospital Island soil mercury concentrations during the fledgling period, were not significantly different from pre-breeding or mid-breeding soil mercury concentrations. Mid-breeding soil mercury concentrations were significantly higher than pre-breeding and pooled pre-breeding/fledgling soil mercury concentrations. The pooled mid-breeding/fledging soil mercury concentrations were significantly higher than pre-breeding soil mercury concentrations (Table 35, Table 26).

10.5 Mink Island soil (control)

The three Mink Island soil mercury concentrations were pooled and compared with mid-breeding soil mercury concentrations from NW and SE Hospital Island. During the mid-breeding season, "site" (i.e. island) was a significant factor affecting soil mercury concentrations (Figure 23, Table 35, Table 35). The power of the ANOVA was 0.97; thus, there was only a 3% chance of Type II error (unequal sample size modified power test) and the minimal detectable difference is 1.47 ng/g (ppb). Mink Island soil mercury concentrations were significantly lower than NW and SE Hospital Island soil mercury concentrations (using unequal sample size modified Tukey's test: Table 34) and NW Hospital Island had significantly higher soil mercury concentrations than SE Hospital Island (Figure 28, Table 34, Table 35).

Comparison	Island or time period	P	Sample with higher [Hg]	Significant Difference Yes/No ($\alpha = 0.05$)	Effect Size
***Location**	**All Time Periods**	**0.001**	**NA**	**Yes**	NA
Location	**Pre-breeding**	**< 0.001**	**NW**	**Yes**	1.42
Location	**Mid-breeding**	**0.003**	**NW**	**Yes**	0.67
Location	Fledging	0.091	NA	No	NA
***Time**	**Both Locations**	**< 0.001**	**NA**	**Yes**	NA
Time	**NW**	**< 0.001**	**NA**	**Yes**	NA
Time	**SE**	**0.015**	**NA**	**Yes**	NA
Pre-breeding vs. mid-breeding	NW	0.113	NA	No	NA
Pre-breeding vs. fledging	**NW**	**< 0.001**	**Pre-breeding**	**Yes**	0.39
Mid-breeding vs. fledging	**NW**	**< 0.001**	**Mid-breeding**	**Yes**	1.14
Pooled pre-breeding/mid-breeding vs. fledgling	**NW**	**< 0.001**	**Mid-breeding**	**Yes**	1.20
Pre-breeding vs. mid-breeding	**SE**	**0.009**	**Mid-breeding**	**Yes**	0.78
Pre-breeding vs. fledging	SE	0.206	NA	No	NA
Mid-breeding vs. fledging	SE	0.061	NA	No	NA
Pooled pre-breeding/fledging vs. mid-breeding	**SE**	**0.008**	**Mid-breeding**	**Yes**	0.60
Pooled mid-breeding/fledging vs. pre-breeding	**SE**	**0.024**	**Pooled mid-breeding/fledging**	**Yes**	0.57

Table 30. Results of the modified Tukey's test on log transformed one-way ANOVA data. The comparisons are of the means of the three locations: SE = South East Hospital Island; NW = North West Hospital Island; and MI = Mink Island (control).

Comparison	Difference	SE	q	$q_{0.05, 41, 3}$	Conclusions
MI vs. SE	0.487	0.069	7.113	3.486	Reject Ho
MI vs. NW	0.119	0.011	10.868	3.486	Reject Ho
NW vs. SE	0.368	0.981	3.753	3.486	Reject Ho

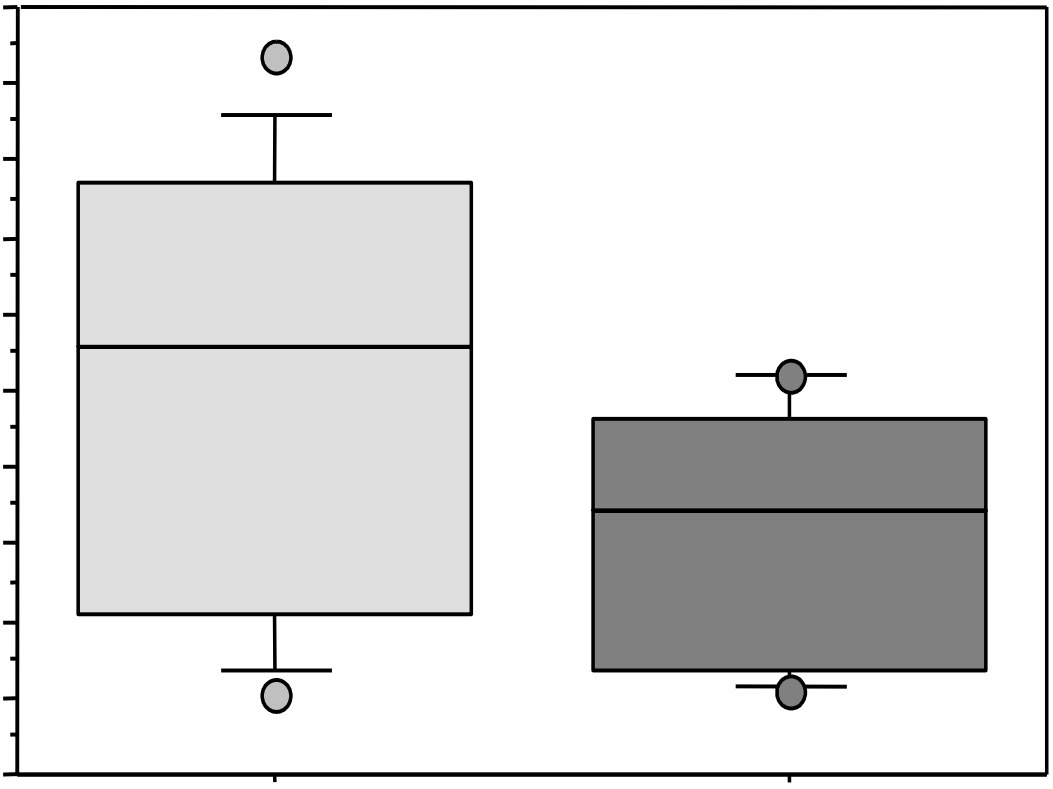
Table 31. Sample size, mean and standard error of soil mercury concentration ng/g (ppb) dry weight.

Time Period	Mean Mercury Concentration (SE, N)		
	NW Hospital Island	SE Hospital Island	Mink Island
Pre-breeding soil	217 (19, 20)	126 (9, 17)	52 (NA, 1)
Mid-breeding soil	380 (58, 24)	184 (13, 22)	109 (NA, 1)
Fledging soil	124 (11, 19)	144 (9, 23)	74 (NA, 1)

10.6 Terrestrial vegetation

Terrestrial vegetation on the Hospital Islands had significantly higher mercury concentrations than terrestrial vegetation on Mink Island (Figure 28, Table 34, Table 35). A variety of species of terrestrial vegetation were analyzed and the species composition differed between Hospital Islands and Mink Island (Table 35). All terrestrial vegetation was collected on July 29, 2003 and represented the mercury concentration during the fledging period.

The Hospital Islands and Mink Island had two species of terrestrial vegetation in common. Wild raspberry (*Rubus stigosus*) had a mercury concentration of 67 ng/g (ppb) dry weight from the Hospital Islands (N=1) and 28 ng/g (ppb) dry weight from Mink Island (N=1). The yarrow-aster family (*Asteraceae*) had a mercury concentration of 112 ng/g (ppb) dry weight from Hospital Islands (N=1) 104 ng/g (ppb) dry weight from Mink Island (N=1).



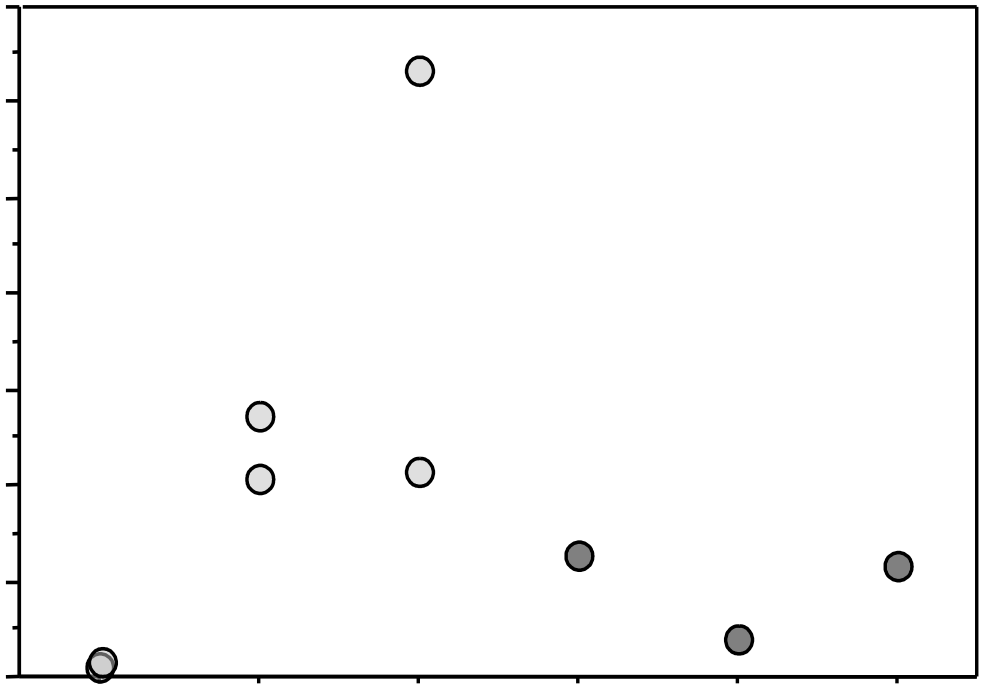
Vegetation Species	Island	Mercury concentration ng/g (ppb) dry weight
Common ragweed (*Ambrosia artemisiifolia*)	Hospital Island	71
Wild raspberry (*Rubus stigosus*)	Hospital Island	67
Common hemp nettle (*Galeopsis tetrahit*)	Hospital Island	152
Yarrow-Aster family (*Asteraceae*)	Hospital Island	112
Rough cinquefoil (*Poentilla sp*.)	Hospital Island	34
Common chickweed (*Stellaria media*)	Hospital Island	188
Grass family (*Poaceae*)	Hospital Island	155
New York aster (*Aster novi-belgii*)	Hospital Island	31
Dandelion *(Agoseris glauca)*	Hospital Island	162
Canadian thistle (*Cirsium avense*)	Hospital Island	148
Harebell (*Campanula rotundifolia*)	Hospital Island	21
Wild raspberry (*Rubus stigosus*)	Mink Island	28
Canadian gooseberry (*Ribes hirtellum*)	Mink Island	40
Grove sandwort (*Moehringia lateriflora*)	Mink Island	93
Sheep sorrel (*Rumex acetosella*)	Mink Island	104
Common eyebright (*Euphasia nemorosa*)	Mink Island	65
Yarrow-Aster family(*Asteraceae*)	Mink Island	104
Flat-topped white aster (*Aster umbellayus*)	Mink Island	75
Wild morning-glory (*Calysteyia sepium*)	Mink Island	74
Seaside plantain (*Plantago maritima*)	Mink Island	22

Table 33. Sample size, mean and standard error of terrestrial vegetation mercury concentration ng/g (ppb dry weight) from the Hospital Islands and Mink Island.

Island	Mean Mercury Concentration (SE, N)
Hospital Islands	104 (18, 11)
Mink Islands	67 (10, 9)

10.7 Water

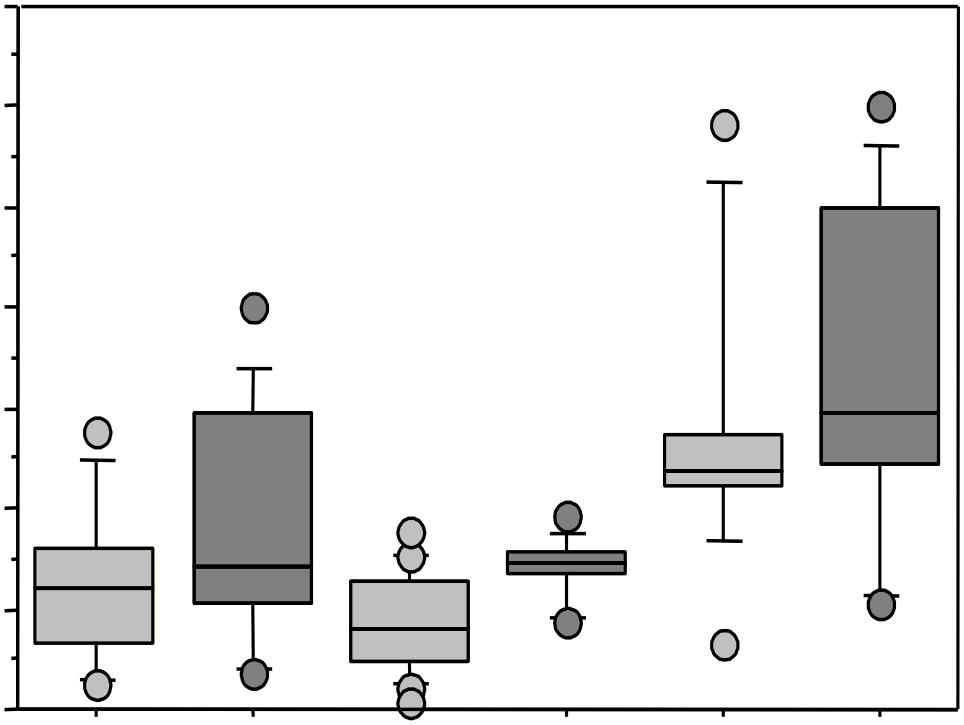
On the Hospital Islands, fresh water mercury concentrations generally increased as the breeding season progressed. The same trend was not present on Mink Island. Mink Island water mercury concentrations were lowest during the mid-breeding season and increased during the fledging period to a similar level as the pre-breeding mercury level (base level). Mercury concentrations were higher during the mid-breeding and fledging periods on Hospital Islands and higher during the pre-breeding period on Mink Island (Figure 28).



10.8 Seaweed

Seaweed mercury concentrations on the Hospital Island and Mink Island were affected by the time of sampling (pre-breeding, mid-breeding, and fledging periods), but not by the tidal zones (high tide, mid-tide, and low tide zones) (Table 34). Seaweed mercury concentrations were from a variety of species (please refer to Appendix 6a, 6b, and 6c for species composition during the three time periods). There was no significant difference between pre-breeding and mid-breeding seaweed mercury concentration on the Hospital Islands or Mink Island (Figure 28, Table 35, Table 35). Pre-breeding seaweed mercury concentrations were higher than fledging mercury concentrations on Mink Island, but the Hospital Islands showed the opposite trend (fledging mercury concentrations were higher than pre-breeding mercury concentrations) (Figure 28, Table 34, Table 35). On both the Hospital Islands and Mink Island seaweed mercury concentrations were higher during the fledging period than the mid-breeding period (Figure 28, Table 34, Table 35).

The mercury levels on Hospital Island were compared to mercury levels on Mink Island. There was no significant difference between the Hospital Islands and Mink Island seaweed mercury concentrations during the pre-breeding and fledging periods (Figure 28, Table 34, Table 35). Mink Island had significantly higher seaweed mercury concentrations during the mid-breeding period than the Hospital Islands (Figure 28, Table 34, Table 35). In general, the seaweed mercury concentrations during the three time periods did not follow the same trend as the soil mercury concentrations.



Comparison	Island or time period	P	Sample with higher [Hg]	Significant Difference Yes/No ($\alpha = 0.05$)	Effect Size
Tidal Zones	Hospital Island	0.260	NA	No	NA
Tidal Zones	Mink Island	0.263	NA	No	NA
Time Periods	**Hospital Island**	**< 0.001**	**Fledging**	**Yes**	NA
Time Periods	**Mink Island**	**0.001**	**Fledging**	**Yes**	NA
Pre-breeding vs. mid-breeding	Hospital Islands	0.094	NA	No	NA
Pre-breeding vs. fledging	**Hospital Islands**	**0.001**	**Fledging**	**Yes**	1.14
Mid-breeding vs. fledging	**Hospital Islands**	**< 0.001**	**Fledging**	**Yes**	1.45
Pre-breeding vs. mid-breeding	Mink Island	0.349	NA	No	NA
Pre-breeding vs. fledging	**Mink Island**	**0.004**	**Pre-breeding**	**Yes**	1.05
Mid-breeding vs. fledging	**Mink Island**	**0.001**	**Fledging**	**Yes**	1.28
Hospital Islands vs. Mink Island	Pre-breeding	0.194	NA	No	NA
Hospital Islands vs. Mink Island	**Mid-breeding**	**0.004**	**Mink Island**	**Yes**	1.14
Hospital Islands vs. Mink Island	Fledging	0.190	NA	No	NA

Table 35. Sample size, mean, and standard error of seaweed mercury concentrations ng/g (ppb) dry weight.

Time Period	Mean Mercury Concentration (SE, N)	
	Hospital Islands	Mink Island
Pre-breeding	25 (4, 13)	36 (6, 14)
Mid-breeding	17 (2, 16)	28 (2, 10)
Fledging	55 (7, 15)	59 (9, 13)

10.9 Conclusion

10.9.1 Control site

Many studies use gulls to monitor mercury levels of an area but few studies assess whether gulls contribute mercury to the local ecosystem (Fimreite *et al.* 1974, Gilman *et al.* 1977, Thompson *et al.* 1990, Burger 1993, Hahn *et al.* 1993, Lewis *et al.* 1993, Becker *et al.* 1994, Koster *et al.* 1996, Burger 1997, Burger and Gochfeld 1997, Gochfeld 1997, Wayland 2000). I measured contributions of nesting gulls to their local ecosystem by measuring mercury concentrations in soil, fresh water seeps, terrestrial vegetation, and marine vegetation around the breeding colony. A nearby island (Mink Island), with no gull colony but otherwise similar ecology, was used as a control site.

10.9.2 Soil

Soil mercury concentrations were assessed from both parts of the Hospital Islands and compared to the control. As expected, the Hospital Islands soil had higher mercury concentrations than Mink Island, indicating that gulls may be contributing mercury to the soil. Surprisingly, NW Hospital Island had greater soil mercury concentrations than SE Hospital Island during the pre-breeding and mid-breeding periods, but not during the fledging period. The above finding indicates that great black-backed gulls on NW Hospital Island contribute more mercury to the overall island soil than do herring gulls. The decrease and lack of difference in soil mercury concentrations between the two sides of the Hospital Islands during the fledging period indicates that mercury escapes from the islands' soil readily. Mercury may be evading due to the

Hospital Islands and Mink Island having no trees and a thin soil layer mostly composed of organic matter; thus, the island soil is exposed to a large amount of sunlight causing mercury to dissipate back into the atmosphere in the form of Hg^0.

10.9.3 Terrestrial Vegetation

The Hospital Island and Mink Island are both classified as coastal scrub environments (DNR 1982), but their terrestrial vegetation compositions differ; thus, it is difficult to assess if the differences in mercury concentrations of the terrestrial vegetation are due to the gulls, vegetation species composition, or other factors. The two species of terrestrial plants, which are common to the Hospital Islands and Mink Island, have elevated mercury concentrations on the Hospital Islands. As well, the mean terrestrial vegetation (all species pooled) mercury concentrations are higher on the Hospital Islands compared to Mink Island. However, the lack of replicates means these apparent differences could not be tested statically.

10.9.4 Water

Any mercury in the soil, vegetation, or other components of the islands, may be transported into the ocean via fresh water runoffs. A general trend on the Hospital Islands of increasing water seepage mercury concentrations as the breeding season progresses and decreasing mercury concentrations during the mid-breeding season (on Mink Island) may indicate the gulls are contributing some mercury to the water runoff. Since water seepage is so difficult to locate and collect on these very dry islands (which lack standing water and have shallow soil), very few samples were collected and further sampling is needed to assess the validity of the above conclusion.

10.9.5 Seaweed

Seaweed mercury concentrations are generally low, ranging between 4-120 ppb (DW) and independent of tidal zone. The Hospital Island and Mink Island have similar seaweed mercury concentrations during the pre-breeding and fledging periods, but unexpectedly Mink Island has higher mercury concentrations during the mid-breeding period. Any mercury entering the ocean from the gulls may be flushed or diluted by the ocean before being incorporated into the rockweed. Generally the Hospital Islands and Mink Island follow the same trends and have similar seaweed mercury concentrations; therefore, the measure of breeding gulls seem not to affect the mercury levels in the rockweed surrounding the Hospital Islands.

11. Risk Assessments, Conclusion, and Future Research

11.1 Introduction

The objectibve of chapter 11 is to asses the possible risks from mercury to both gull species, their breeding ground's ecosystem, and people.

11.2 Gulls

A clear risk assessment for either species of gull is difficult, especially for great black-backed gulls, because no studies have quantified what mercury concentrations in the feathers, blood, eggs, and diet of these two species cause sub-lethal or lethal effects. The literature shows a wide range of mercury tolerance in birds. Mercury tolerances are species-specific and possibly specific to individuals within a population.

Eisler (1987) found 5000- 40 000 ppb (DW) was the threshold mercury range causing detrimental effects in birds. The mean feather mercury concentrations in the adults and chicks are all below the threshold of 5000 ppb (DW). The minimum threshold mercury concentration causing effects in bird eggs is 1500-18 000 ppb (DW) (Burger and Gochfeld 1997). Great black-backed gull mean egg albumen mercury concentration (1789 ppb DW) exceeds the lowest threshold limit of 1500 ppb (DW), but all other mean mercury concentrations of egg components are below the threshold concentration range. The threshold ranges are conservative for gulls since much higher concentrations have been reported without any observable adverse effects to the gulls (Vermeer *et al.* 1973, Koster *et al.* 1996). Monteiro and Furness (1995) attribute this tolerance to relatively elevated mercury concentrations as an adaptation to a traditionally high mercury diet. The Hospital Island gulls are not considered at risk from mercury.

11.3 Local island ecosystem

Gulls contribute mercury to the breeding island via moulted feathers, guano, addled eggs, and carcasses of chicks and adults. During the breeding season a large influx of mercury was expected due to the gulls. The ecological pathway of mercury into the gulls via local food sources, onto the island via the above mercury outputs, accumulation in the island soil and vegetation, acquisition into fresh water runoff, and deposition into the rockweed ecosystem was not quantified in detail, but the soil and terrestrial vegetation mercury concentrations indicate that gulls are contributing only small amounts of mercury into their breeding colonies and the mercury is not entering the rockweed ecosystem surrounding the Hospital Islands. The lack of mercury input into the rockweed is attributed to mercury evasion. The Hospital Islands soils are shallow and exposed to large quantities of sunlight; thus, any mercury input from the gulls is readily transformed to Hg^0 and re-enters the atmosphere and global mercury cycle. Even though the Hospital Island soil and terrestrial vegetation mercury concentration are higher than on Mink Island the statistical and biological significance is not determined.

11.4 People

No greater risk to humans is expected from fishing activities in the rockweed habitats surrounding gull colonies compared with other rockweed habitats not associated with gull colonies. Unfortunately, the Hospital Islands data cannot be extrapolated to other regions in the Bay of Fundy since no trend was found in mercury concentrations between the Deer Island area and the other regions in the Bay of Fundy.

Even though the Migratory Bird Conservation Act does not allow egg collecting from gulls, some local inhabitants have a tradition of collecting gull eggs for consumption. The U.S. Food and Drug Agency (FDA) has established 1000 ppb as the limit allowed in fish intended for human consumption. This 1000 ppb level is not exceeded in any of the eggs analyzed (wet weight basis); thus, local people who may be consuming gull eggs are not at risk of mercury contamination from gull eggs. Herring gulls have lower egg mercury concentration than great black-backed gulls and the mercury deposition into the eggs decreases with laying order (Becker *et al.*1989); therefore, in order to further minimize human mercury intake the last-laid herring gull egg should be selected for consumption.

11.5 Conclusions

The major findings of this study are:

- Adult gulls of both species had higher mercury concentrations than chicks, and no difference was found between the genders of the adult gulls, although male gulls had more variable mercury concentrations in their feathers than females.
- Methylmercury concentrations as a percent of total mercury concentrations in
- Both species adult gulls' mercury concentrations generally remain constant during the year, but chicks' mercury concentration varied during the breeding season. Both gull species chicks had higher mercury in their first grown feather than egg and herring gull chicks' mercury concentrations decreased to levels similar to the egg during the intense period of growth before fledging.
- Regurgitation analysis results indicate the chicks of both species are fed mostly krill and white fleshed fish during the 2003 breeding season, but the stable isotope results for the adult gulls varied between years and between species with no clear pattern. Therefore, the sources of mercury to the chicks were clear but mercury sources to the adults needs further study.
- feathers ranged from 20-91% in great black-backed gulls and 6-48% in herring gulls.
- The gull colony did increase mercury concentrations in the soil and vegetation on their breeding island compared to the control site, but these higher mercury levels did not translate into higher mercury concentrations in the rockweed. Most of the mercury transferred to the breeding colony evidently evades before reaching the rockweed. Thus, the gull colony does not contaminate the marine ecosystem surrounding the nesting colony.

- The gulls do not appear to be at risk of mercury contamination, have similar levels as elsewhere in North America, and pose no risk to human health.

11.6 Future research

Future research should invole:

- Creating a bioinergetics model of mercury within the gulls in order to predict mercury cycling and body burden within the gulls.
- Creating an ecosystemic model of the gulls island ecosystem mercury cycle and fluxes in order to predict mercury levels on and around the gulls'breeding island during the breeding season.
- Obtaining more great black-backed gull and herring gull samples from the whole Bay of Fundy reagion in order to further assess if mercury levels vary between the inner and outer Bay of Fundy.
- Compare gull mercury levels to other sea and shore bird mercury levels in the Bay of Fundy.
- Assess was levels of mercury caise sub-lethal effects, what are the sub-lethal effects of mercury, and if sub-lethal levels will effect survival and reproctive success in gulls.

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Appendix 1. Summary of adult great black-backed gull and herring gull stable isotope and tissue mercury concentration regressions.

Comparison	Year	Species	R^2	P
^{13}C Blood and Blood [Hg]	2002	GBBG	0.013	0.611
^{15}N Blood and Blood [Hg]	**2002**	**GBBG**	**0.357**	**0.003**
^{13}C 5th Greater Covert Feathers and Greater Covert Feather [Hg]	2002	GBBG	0.092	0.082
^{15}N 5th Greater Covert Feathers and Greater Covert Feather [Hg]	2002	GBBG	0.044	0.235
^{13}C Blood and Blood [Hg]	2002	HERG	0.025	0.531
^{15}N Blood and Blood [Hg]	2002	HERG	0.209	0.057
^{13}C 5th Greater Covert Feathers and Greater Covert Feather [Hg]	2002	HERG	0.044	0.306
^{15}N 5th Greater Covert Feathers and Greater Covert Feather [Hg]	2002	HERG	0.101	0.114
^{13}C Blood and Blood [Hg]	2003	GBBG	0.095	0.459
^{15}N Blood and Blood [Hg]	2003	GBBG	0.055	0.576
^{13}C 5th Greater Covert Feathers and Greater Covert Feather [Hg]	2003	GBBG	NA	0.970
^{15}N 5th Greater Covert Feathers and Greater Covert Feather [Hg]	**2003**	**GBBG**	**0.762**	**0.001**
^{13}C Blood and Blood [Hg]	**2003**	**HERG**	**0.494**	**0.023**
^{15}N Blood and Blood [Hg]	**2003**	**HERG**	**0.444**	**0.035**
^{13}C 5th Greater Covert Feathers and Greater Covert Feather [Hg]	2003	HERG	0.069	0.464
^{15}N 5th Greater Covert Feathers and Greater Covert Feather [Hg]	2003	HERG	0.140	0.287

Appendix 2. Summary of herring gull and great black-backed gull regurgitation mercury concentrations (ppb DW) collected 2003. The avian dietary reference concentration is 33 ppb (CTRG 2000).

Type	# Collections/Species		Mean Mercury Concentration
	Chicks	Adults	
Krill	4 GBBG	0	81
	19 HERG	0	109
White fleshed fish	9 GBBG	0	134
	13 HERG	2 HERG	81
Salmon pellets	3 GBBG	0	74
	1 HERG	0	11
Crab	2 HERG	0	63
Periwinkle (no shell)	1 HERG	1 HERG	198
Sea cucumber	0	2 HERG	33
Egg with chick	1 GBBG	0	44
Anthropogenic	1 HERG	1 HERG	Variable
Miscellaneous	2 GBBG	0	Variable
	2 HERG	0	Variable
Total	19 GBBG		NA
	39 HERG	6 HERG	NA

Appendix 3. Summary of regression analyses of mercury concentrations in adult great black-backed gulls and herring gulls with their corresponding chick's tissue mercury concentrations.

Comparison	Species	R^2	P
Adult Blood and Chick Down	GBBG	0.038	0.468
Adult Blood and Chick Scapular	GBBG	0.067	0.417
Adult Primary Tip and Chick Down	GBBG	NA	0.991
Adult Primary Tip and Chick Scapular	GBBG	0.003	0.864
Adult Head Feather and Chick Down	GBBG	0.001	0.903
Adult Head Feather and Chick Scapular	GBBG	0.015	0.674
Adult 5th Greater Covert Feather and Chick Down	GBBG	0.002	0.866
Adult 5th Greater Covert Feather and Chick Scapular	GBBG	0.022	0.614
Adult Blood and Chick Down	HERG	0.018	0.551
Adult Blood and Chick Scapular	HERG	0.181	0.055
Adult Blood and Chick Head Feather	HERG	0.006	0.884
Adult Primary Tip and Chick Down	HERG	0.024	0.491
Adult Primary Tip and Chick Scapular	HERG	0.144	0.089
Adult Primary Tip and Chick Head Feather	HERG	0.177	0.406
Adult Head Feather and Chick Down	HERG	0.036	0.400
Adult Head Feather and Chick Scapular	HERG	0.106	0.161
Adult Head Feather and Chick Head Feather	HERG	0.154	0.442
Adult 5th Greater Covert Feather and Chick Down	HERG	0.024	0.490
Adult 5th Greater Covert Feather and Chick Scapular	HERG	0.033	0.434
Adult 5th Greater Covert Feather and Chick Head Feather	HERG	0.618	0.637

Appendix 4A. Pre-breeding seaweed species list and mercury concentrations (ppb DW) collected from the Hospital Islands and Mink Island on May 14, 2003.

Location	Zone	Species	Pre-Breeding Mercury Concentration
Hospital Islands	High	Ascophylum nodosum	32
Hospital Islands	High	Vertebrata lanosa	29
Hospital Islands	High	Fucus vesiculosus	24
Hospital Islands	Middle	Ascophylum nodosum	23
Hospital Islands	Low	Ulva lactuea	8
Hospital Islands	Low	Ascophylum nodosum	32
Hospital Islands	Low	Fucus edentatus	5
Hospital Islands	Low	Fucus vesiculosus	15
Hospital Islands	Low	Fucus evanescens	6
Hospital Islands	Low	Chondrus crispus	48
Hospital Islands	Low	Rhodymenia palmata	55
Hospital Islands	Low	Alaria sp.	21
Hospital Islands	Low	Cladophora sp. + Entomorpha sp. + diatoms	32
Mink Island	High	Fucus vesiculosus	9
Mink Island	Middle	Ascophylum nodosum	28
Mink Island	Middle	Fucus evanescens	41
Mink Island	Middle	Ulva lactuea	66
Mink Island	Middle	Ulva sp.	59
Mink Island	Middle	Enteromorpha Linza	80
Mink Island	Middle	Capsosiphon sp. + diatoms	63
Mink Island	Low	Rhodymen palmata	7
Mink Island	Low	Ulva lactuea	21
Mink Island	Low	Ulva sp.	8
Mink Island	Low	Polysiphonia lanosa	22

Appendix 4A continued

Location	Zone	Species	Fledging Mercury Concentration
Mink Island	Low	Ascophylum nodosum	23
Mink Island	Low	Punctaria sp.	30
Mink Island	Low	Majority Cladophora sp.	41

Appendix 4B. Mid-breeding seaweed species list and mercury concentrations (ppb DW) collected from the Hospital Islands and Mink Island on June 23, 2003.

Location	Zone	Species	Mid-Breeding Mercury Concentration
Hospital Islands	High	Ascophyllum sp.	30
Hospital Islands	High	Chaetomorpha sp.	25
Hospital Islands	High	Ulva sp.	26
Hospital Islands	High	Fucus sp. + Pulmaria sp.	33
Hospital Islands	High	Fucus sp. + Elachista sp.	30
Hospital Islands	Middle	Fucus sp.	9
Hospital Islands	Middle	Ralfsia verrucosa	11
Hospital Islands	Middle	Alaria sp.	12
Hospital Islands	Middle	Cladophora sp. + diatoms	21
Hospital Islands	Middle	Pulmaria sp.	4
Hospital Islands	Middle	Agarum sp.	5
Hospital Islands	Low	Ulva sp.	12
Hospital Islands	Low	Entomorpha sp.+ Cladophora sp. + diatoms	21
Hospital Islands	Low	Pulmaria sp.	10
Hospital Islands	Low	Fucus sp.	7
Hospital Islands	Low	Agarum sp.	21
Mink Island	High	Ascophyllum sp.	17
Mink Island	High	Entomorpha sp.	29
Mink Island	Middle	Ascophyllum sp.	32
Mink Island	Middle	Ulva sp.	27
Mink Island	Middle	Ulva sp.	39
Mink Island	Middle	Cladophora sp. + diatoms	31
Mink Island	Low	Ascophyllum sp.	28

Appendix 4B continued

Location	Zone	Species	Fledging Mercury Concentration
Mink Island	Low	Ulva sp.	29
Mink Island	Low	Kelp blade	19
Mink Island	Low	Vertebrata lanosa	31

Appendix 4C. Post-breeding seaweed species list and mercury concentrations (ppb DW) collected from the Hospital Islands and Mink Island on July 29, 2003.

Location	Zone	Species	Fledging Mercury Concentration
Hospital Islands	High	Ascophyllum nodosum	47
Hospital Islands	High	Fucus vesiculosus	47
Hospital Islands	High	Membranoptera denticulata	54
Hospital Islands	High	Acrosophonia sp.	117
Hospital Islands	Middle	Ascophyllum nodosum	41
Hospital Islands	Middle	Fucus spiralis	34
Hospital Islands	Middle	Rhodymenia palmata	46
Hospital Islands	Middle	Ulva sp.	43
Hospital Islands	Middle	Ulva sp.	47
Hospital Islands	Low	Ulva sp.	69
Hospital Islands	Low	Ascophyllum nodosum	105
Hospital Islands	Low	Fucus vesiculosus	13
Hospital Islands	Low	Polides sp.	50
Hospital Islands	Low	Mastocarpus sp.	55
Hospital Islands	Low	Chondrus crispus	54
Mink Island	High	Fucus vesiculosus	21
Mink Island	High	Ascophyllum nodosum	53
Mink Island	Middle	Ascophyllum nodosum	58
Mink Island	Middle	Fucus vesiculosus	23
Mink Island	Middle	Vertebrata lanosa	120
Mink Island	Low	Rhodymenia palmata	110
Mink Island	Low	Chaetomorpha Linum	100

Appendix 4c continued

Location	Zone	Species	Fledging Mercury Concentration
Mink Island	Low	Ulva sp.	100
Mink Island	Low	Fucus vesiculosus	38
Mink Island	Low	Ascophyllum nodosum	59
Mink Island	Low	Vertebrata lanosa	85
Mink Island	Low	Cladophora sp. + diatoms	57
Mink Island	Low	Ectocarpus sp.	80

Appendix 5. Levels of total mercury in body tissues (ppb) in a variety of gull species.

Species	Location and Year	Laboratory or Field Study	Tissue Type	Mercury Concentration ± SE or % Body Burden	Source
Herring gull adults (*Larus argentatus*)	Kent Island, NB (1991)	Field	Kidney	1800 (DW)	Fox *et al.* 2002
Herring gull adults	Kent Island, NB (1988)	Field	Kidney	1600 ± 350 (DW)	Elliott *et al.* 1992
Herring gull adults	Gull Island, NB (1988)	Field	Kidney	1950 ± 460 (DW)	Elliott *et al.* 1992
Herring gull adults	Magawagonish Island, NB (1988)	Field	Kidney	1110 ± 220 (DW)	Elliott *et al.* 1992
Herring gull adults	Kent Island, NB (1988)	Field	Liver	1500 ± 530 (DW)	Elliott *et al.* 1992
Herring gull adults	Gull Island, NB (1988)	Field	Liver	1700 ± 690 (DW)	Elliott *et al.* 1992
Herring gull adults	Magawagonish Island, NB (1988)	Field	Liver	690 ± 180 (DW)	Elliott *et al.* 1992
Herring gull adults	Quoddy region , NB (1978-1984)	Field	Muscle	101 (WW)	Braune 1987
Herring gull adults	Quoddy region , NB (1978-1984)	Field	Liver	482 (WW)	Braune 1987
Herring gull adults	Quoddy region , NB (1978-1984)	Field	Kidney	350 (WW)	Braune 1987
Herring gull adults	Quoddy region , NB (1978-1984)	Field	Brain	56 (WW)	Braune 1987
Herring gull adults	Wadden Coast, Germany (1990)	Field	Female Pectoralis Muscle	2000 (DW)	Lewis *et al.* 1993
Herring gull adults	Wadden Coast, Germany (1990)	Field	Male Pectoralis Muscle	2560 (DW)	Lewis *et al.* 1993

Appendix 5 continued

Species	Location and Year	Laboratory or Field Study	Tissue Type	Mercury Concentration ± SE or % Body Burden	Source
Herring gull adults	Wadden Coast, Germany (1990)	Field	Female Liver	4370 (DW)	Lewis *et al.* 1993
Herring gull adults	Wadden Coast, Germany (1990)	Field	Male Liver	4720 (DW)	Lewis *et al.* 1993
Herring gull adults	Wadden Coast, Germany (1990)	Field	Ovary	1870 (DW)	Lewis *et al.* 1993
Bonaparte's gull adults (*Larus philadelphia*)	Quoddy region, NB (1978-1984)	Field	Muscle	75 (WW)	Braune 1987
Bonaparte's gull adults	Quoddy region, NB (1978-1984)	Field	Liver	450 (WW)	Braune 1987
Bonaparte's gull adults	Quoddy region, NB (1978-1984)	Field	Kidney	418 (WW)	Braune 1987
Bonaparte's gull adults	Quoddy region, NB (1978-1984)	Field	Brain	101 (WW)	Braune 1987
Lesser black-backed gull (*Larus fuscus*)	East Scotland (after 1940)	Field	Body feathers	3790 (1860-11 490)	Furness *et al.* 1995
Yellow-legged gull (*Larus cachinnans*)	Azores, Mid-North Atlantic Ocean (1990-1992)	Field	Body feathers	4000 ± 680	Monteiro *et al.* 1995
Common gull chicks	Jade Bay, Germany (1996)	Field	Blood	59 ± 25	Kahle and Becker 1999
Mew gull chicks (*Larus canus*)	Jade Bay, Germany (1996)	Field	Down	1357 ± 282	Kahle and Becker 1999
Mew gull chicks	Jade Bay, Germany (1996	Field	Side feathers	1399 ± 374	Kahle and Becker 1999

Appendix 5 continued

Mew gull chicks	Elbe River Bay, Germany (1996)	Field	Blood	83 ± 56	Kahle and Becker 1999
Mew gull chicks	Elbe River, Germany (1996)	Field	Side feathers	2235 ± 1836	Kahle and Becker 1999
Prefeledgling herring gulls	Kent Island, NB (1991)	Field	Kidney	260 (DW)	Fox *et al.* 2002
Herring gull adults	Long Island, NY	Field	Heart	401 ± 58.7 (WW)	Burger *et al.* 2000
Herring gull adults	Long Island, NY	Field	Kidney	470 ± 191 (WW)	Burger *et al.* 2000
Herring gull adults	Long Island, NY	Field	Liver	838 ± 82.1 (WW)	Burger *et al.* 2000
Herring gull adults	Long Island, NY	Field	Breast muscle	379 ± 52.9 (WW)	Burger *et al.* 2000
Herring gull adults	Long Island, NY	Field	Salt gland	813 ± 115 (WW)	Burger *et al.* 2000
Great black-backed gull adults (*Larus marinus*)	Long Island, NY	Field	Heart	889 ±191 (WW)	Burger *et al.* 2000
Great black-backed gull adults	Long Island, NY	Field	Kidney	1236 ± 234 (WW)	Burger *et al.* 2000
Great black-backed gull adults	Long Island, NY	Field	Liver	1366 ± 163 (WW)	Burger *et al.* 2000
Great black-backed gull adults	Long Island, NY	Field	Breast muscle	722 ± 167 (WW)	Burger *et al.* 2000
Great black-backed gull adults	Long Island, NY	Field	Salt gland	1017 ± 268 (WW)	Burger *et al.* 2000
Juvenile Black-headed gulls (*Larus ridibundus*)	1989	Laboratory	Kidney (20ul, 100ul, 200ul)	0.58, 0.62, 0.68	Lewis and Furness (1991)
Juvenile Black-headed gulls	1989	Laboratory	Liver(20ul, 100ul, 200ul)	2.90, 3.20, 2.51	Lewis and Furness (1991)

Appendix 5 continued

Juvenile Black-headed gulls	1989	Laboratory	Carcass(20ul, 100ul, 200ul)	39.19, 28.84, 27.92	Lewis and Furness (1991)
Juvenile Black-headed gulls	1989	Laboratory	Feathers(20ul, 100ul, 200ul)	57.25, 67.34, 68.87	Lewis and Furness (1991)
Juvenile Black-headed gulls	1989	Laboratory	Primary Feathers(20ul, 100ul, 200ul)	8.47, 12.11, 11.89	Lewis and Furness (1991)
Juvenile Black-headed gulls	1989	Laboratory	Head Feathers(20ul, 100ul, 200ul)	0.80, 0.85, 0.85	Lewis and Furness (1991)
Juvenile Bonaparte's gulls	Quoddy region, NB (1978-1984)	Field (N=2)	*Kidney	6.2 ± 0.14	Braune and Gaskin (1987)
Juvenile Bonaparte's gulls	Quoddy region, NB (1978-1984)	Field (N=2)	*Liver	38.3 ± 9.90	Braune and Gaskin (1987)
Juvenile Bonaparte's gulls	Quoddy region, NB (1978-1984)	Field (N=2)	*Muscle	6.1 ± 2.26	Braune and Gaskin (1987)
Juvenile Bonaparte's gulls	Quoddy region, NB (1978-1984)	Field (N=2)	*Brain	1.4 ± 0.21	Braune and Gaskin (1987)
Juvenile Bonaparte's gulls	Quoddy region, NB (1978-1984)	Field (N=2)	*Carcass	48.10 ± 8.02	Braune and Gaskin (1987)
Juvenile Bonaparte's gulls	Quoddy region, NB (1978-1984)	Field (N=2)	Body	12.10 ± 3.32	Braune and Gaskin (1987)
Juvenile Bonaparte's gulls	Quoddy region, NB (1978-1984)	Field (N=2)	Feathers	88.00 ± 3.32	Braune and Gaskin (1987)

* % Distribution of mercury content in body tissues excluding feath