QUANTIFYING TROPHIC TRANSFER OF MERCURY AND AROCLOR 1268 TO CLAPPER RAILS (*RALLUS LONGIROSTRIS*) IN A CONTAMINATED ECOSYSTEM USING SPATIALLY EXPLICIT SAMPLING METHODS

by

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(Under the Direction of I. Lehr Brisbin, Jr.)

ABSTRACT

Mercury and PCB concentrations were determined for sediments, crabs, clapper rail adults and chicks collected from a contaminated salt marsh in Brunswick, Georgia. Home ranges were established for fifteen adult rails. Sediment and crab samples were taken from each individual's range. The study was designed to accurately quantify the transfer factors of Aroclor 1268 and Hg from the soil to invertebrates and into adult clapper rails. We controlled for potential variability by studying and incorporating information regarding this species life history. Due to the heterogeneous nature of the sediment contamination, spatially explicit data collection was used to integrate the amount of contamination in the sediment matrix and the food items with the foraging range of the rails. Trophic transfer of mercury and PCBs were estimated for each sample type. Concentrations of these contaminants were shown to increase with each trophic level.

INDEX WORDS: Mercury, Aroclor 1268, Trophic Transfer, Spatially Explicit Data Collection

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DEDICATION

I would like to dedicate this work to my loving wife, Nancy, who probably learned more about clapper rails and contaminants than she bargained for. I am eternally grateful for her boundless support and encouragement.

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I would like to thank every one who gave freely of their time and experience to help with this project. I am especially grateful for my mentor and friend Karen Gaines. She believed in me from day one and showed me what it means to be a true professional. I would also like to thank everyone who helped with the fieldwork and data analysis, in particular Warren (Cub) Stephens, Stephanie Murray, Angel Kelsey-Wall, Heather Brant and Noel Garvin. Also I would like to thank my major advisor I. Lehr Brisbin Jr., as well as Gary Mills and Cham Dallas for helping me put this thesis together. I would like to thank Greg Masson and Keith Hastie with the U.S. Fish and Wildlife Service, Brunswick, Georgia for their support with this project. Field studies were supported in part by a grant from the M.K. Pentecost, Trust Fund of the Savannah Presbytery of the Presbyterian Church (USA). This research was also supported by the Environmental Remediation Sciences Division of the Office of Biological and Environmental Research, U.S. Department of Energy, through Financial Assistance Award No. DE-FC09-96-SR18546 to the University of Georgia Research Foundation.

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in order to establish the clapper rail as an indicator species of estuarine marsh health in a disturbed estuary.In coastal Georgia, there are large expanses of salt marsh that have abundant populations of clapper rails throughout the year. In particular, because of the presence of major shipping lanes, the city of Brunswick (Glynn County), Georgia has a large amount of industry in close proximity to the marshes. A superfund site located on the Turtle River in Brunswick shows elevated levels of mercury (Hg) and the polychlorinated biphenyl (PCB) Aroclor 1268 in the resident biota. This study quantified the trophic transfer of these toxins using clapper rails as the endpoint indicator species. To best understand the movement of contaminants through the food web, data collection should be spatially explicit to relate the amount of contamination in the sediment matrix and the food items within the foraging range of the rails, due to the heterogeneous nature of the sediment contamination in this area [4].

This study was designed to quantify the trophic transfer of contaminants from the sediment into prey items (fiddler crabs, *Uca spp.*) to the clapper rail by determining: (a) home ranges of individual clapper rails and (b) the contaminant contents of the sediment, fiddler crabs, clapper rail adults and their offspring. Studying the fate of these contaminants in abundant east coast populations will provide better information to study endangered west coast populations and may aid in their recovery. By modeling the trophic transfer of contaminants, studies investigating the use of clapper rails as indicators of estuarine marsh health will better be able to contribute to the conservation of these fragile ecosystems.

Clapper Rails as an Indicator Species

Bioavailability is the extent to which compounds may be taken-up from the environment by an organism. The bond between the contaminant and sediment matrix, route of exposure, and the way in which each organism responds to the presence of the pollutant are some of the

variables that can influence bioavailability. When a contaminant is introduced into the sediment and becomes tightly bound to the sediment matrix, it may not be available for accumulation by primary consumers. Microbial activity in the sediment could transform an otherwise inert contaminant into a form that is readily available for accumulation by the primary consumers. Once the contaminant is transferred from the sediment to the primary consumer many factors may influence the efficiency of transfer to higher trophic levels.

PCBs were first produced in 1881, and since 1930 have been in general use in many types of products. Because PCBs are completely man-made, any trace amount found in any sample type is a result of some type of manufacturing process [5]. PCBs tend to partition strongly to particulate organic matter associated with soils and sediments of lakes, estuaries, and rivers. They are extremely stable compounds and are slow to chemically or biologically degrade under environmental conditions [5, 6, 7]. PCBs are complex mixtures of bi-aromatic ring compounds with various degrees of chlorination. Each specific chlorinated isomer is called a congener and there are 209 possible congeners of PCBs. Moreover, the positioning of the chlorines on the rings affects the way the congener reacts with the environment as well as its potential toxicity. Congeners that are chlorinated in positions such that the rings are co-planar are the most toxic. Aroclor 1268, the congener mixture of concern for the LCP site, is part of the toxic co-planer family [8]. Unfortunately co-planer congeners tend to bind to receptor sites in many organisms disrupting endocrine systems and causing both hepatotoxicity and immunotoxicity. PCBs are both hydrophobic and lipophilic and their very high octanol-water partitioning coefficients lead to low water concentrations and strong binding to suspended particles and the sediment [9]. This makes them extremely bioavailable and therefore extremely dangerous in the LCP marsh since they can be volatilized or taken up by benthic organisms

living in the sediments. Volatilization of these compounds has led to worldwide distribution by wind, rain, snow and aerosol [5, 10]. Trace amounts of PCB congeners have been detected in otherwise pristine areas far removed from the production and use of these compounds [10]. PCB concentrations from 50 to almost 800 ppm dry weight have been detected in the sediments associated with a variety manufacturing facilities [5, 9, 11]. However, any detection of Aroclor 1268 in the present study can be attributed to the LCP site in Brunswick because it was the only producer of this congener mixture in the southeast [12].

Mercury has a great affinity for particulate matter and has a tendency to form insoluble sulfides in sulfur-reducing environments. Estuaries like the Turtle River become sedimentary traps for Hg released by industrial activities. Inorganic mercury is not readily bioavailable because it is sequestered as insoluble salts; however, Hg can be transformed into the very toxic methylated form through bacterial processes in salt marsh sediments. Methylmercury (MeHg) is readily bioavailable and bioaccumulated since it can easily pass through membranes and be stored in lipids. MeHg can have toxic effects in many ways including disrupting components of the central nervous, respiratory, immune, cardiovascular, hematologic and reproductive systems. Estimated residence half-times for Hg are 11 days in the atmosphere, 1,000 years in terrestrial soils, and >250 million years in oceanic sediments [13].

Bioaccumulation and the transfer of contaminants depend on many interacting variables. Risk assessment is the process in which information on the hazardous properties of chemicals and the extent of exposure, results in a statement as to the probability that exposed populations will be harmed. By reducing the amount of variance associated with this process, more accurate risk probabilities can be calculated to protect vulnerable species and natural resources. Including life history and behavioral information about the target species can also lead to higher quality

data and improve the understanding of the transfer of contaminants in disturbed as well as natural systems.

Even though the clapper rail is known for its secretive nature, there has been a substantial amount of research done over the years to better understand the life history of this species. Research has established the rail's distribution, habitat, feeding habits, reproduction and contaminant burdens found in some populations. There are 20-27 different clapper rail subspecies recognized. The endangered California, Light footed (*Rallus longirostris levipes*), and Yuma (*Rallus longirostris yumanensis*) clapper rails are found on the Pacific Coast [3]. This study will only focus on the Wayne's clapper rail (*Rallus longirostris waynei*) during the breeding season, this being the only subspecies which breeds in southern Georgia [14]. This subspecies' feeding habits have been well documented, with 75 – 90% of the diet consisting of fiddler crabs, [14, 15, 3]. However, rails are opportunistic feeders eating almost anything they can catch, which results in trace amounts of insects and plant material also being incorporated into their diets. Since fiddler crabs are deep below the surface during the coldest months, studies have shown that rails may rely on marsh snails (*Littorina irrorata*) as a secondary source for food [14].

Initial pair-bonding occurs in late February. Nest construction and egg laying are usually not initiated until the middle of April [16]. In Georgia, the nest is a platform built with dead *Spartina alterniflora* (hereafter Spartina) stalks and is elevated to protect it from tidal flooding. A canopy of live Spartina grass usually covers the nest to protect it from avian predators and most nests have a ramp leading to the edge of the platform [17]. Rails will typically lay up to nine eggs per clutch and under good conditions up to two clutches per breeding season [18]. Incubation lasts as long as 20 days with both male and female participating [3]. Contaminant

levels in rails, their food items, and their habitat have been established for these birds throughout their range [19, 20]. In many estuaries near Brunswick, Georgia, high levels of Hg have been found in rails and their food items. In the early 1970's, Hg levels were found to be higher than the 0.5 ppm Food and Drug Administrations (FDA) limit for human consumption [21]. However, until now, using clapper rails as indicators of environmental health has not been pursued. Determining the trophic transfer of Hg and Aroclor 1268 from sediment through prey items to clapper rails during the nesting season using a spatially explicit sampling regime will provide a realistic measure of what the transfer factors of these toxicants are within this ecosystem. The information collected in this study could describe a framework to establish rails as potential indicators of estuarine marsh health in other regions of the country. Thus, understanding the transfer factors of both Hg and PCB's in the species can help in the conservation of the endangered subspecies of the clapper rail in California.

Three separate marsh areas around the Brunswick area were chosen for use as control sites (Figure 1). Troupe Creek, Frederica Island and Blythe Island were all similar to the LCP estuary in habitat type and structure. These marshes consisted primarily of Spartina interspersed with patches of needle rush (*Juncus roemerianus*) and were inundated with tidal brackish water twice a day. The degree of flooding depended on moon phase and weather patterns. In Georgia, the tidal amplitude in one six-hour period can be as much as 3 m during a spring tide. This fluctuation of water into and out of the marsh plays an important role in determining the distribution and fate of contaminants released into the tidal marsh ecosystem.

Capture of Rails

Clapper rails (n = 52) were captured from the LCP marsh between February 2002 and March 2002 when they could be caught by hand or with a dip net from an airboat during the highest tides of the month. During these high tides, rails were forced to swim or take refuge on racks of dead cordgrass leaving them few places to hide. With two researchers positioned on the front deck of the airboat, clapper rails could be readily caught as the boat approached the swimming rails at idle speeds. After a bird was caught it was immediately placed in a holding cage in the boat. When 10 – 15 rails had been captured they were weighed (g), banded and had the length (mm) of the bill, tarsus, middle toe, keel and right wing recorded using dial calipers. A subset of rails (n = 25) was fitted with 7.9 g backpack radio transmitters, (Holohil Systems Ltd., Ontario, Canada; model RI-2CM). These transmitters did not exceed approximately 3-5% of the rails body weight in order not to affect their behavior. All birds were released within one hour and 500 m of the point of capture. All clapper rails captured in this study were handled according to the guidelines set forth by the State of Georgia scientific collecting permit (29-

WMB-03-96). All rails were handled according to the guidelines set forth by the University of Georgia IACUC (#A2003-10017-0).

Home Range

Telemetered adults rails (n = 15) were monitored between February 2002 and June 2002. Transmitters were attached to the rails in a backpack fashion by tying an elastic string over the hips and looping it around the legs. This allowed the bird to fly normally while keeping the transmitter in place for the duration of the study. In order to provide useful home range analyses a telemetered rails had to have at least 15 locations evenly distributed between all hours of the day and tide levels. Furthermore, the bird had to be recaptured after radio monitoring, so that contaminant levels in its tissues could be compared to those of sediment and crab samples taken from within its home range

Clapper rails fitted with backpack transmitters were located a total of 213 times between March 2002 and June 2002. Birds were located both day and night, and during high and low tides, by approaching them on foot using a portable telemetry receiver (Telonics Corporation, Mesa, Arizona, USA) coupled with a flexible H-style antenna (Telonics Corporation, Mesa, Arizona, USA). Clapper rail locations were recorded using a handheld Global Positioning System (Garmin Corporation, Olathe, Kansas, USA). To ensure independence of successive locations, only one location was taken per bird per tidal cycle, and a minimum of 12 hours was allowed between consecutive locations for any given rail. Each individual was located at least twice a week until transmitter failure or it was recaptured and sacrificed once sufficient data had been collected (n > 15 locations).

Individuals that met the home range criteria to be used in contaminant analyses were recaptured and sacrificed. The rail was then dissected to determine sex and collect tissue

samples. The whole liver (3 – 6 g fresh weight) was taken and divided equally for metal and PCB analyses. Muscle samples (5 – 10g fresh weight) where excised from the right breast muscle using a surgical scalpel. Each sample was placed into a 30 ml vials, labeled and kept in an upright commercial freezer (-10 – 0 degrees C°) for later analysis of PCBs and heavy metals.

Collection of Sediment and Prey Items

Sediment and fiddler crabs were collected from within each of the radio telemetery determined or estimated home ranges. Within each home range, feeding areas were divided into two categories: tidal creeks and pools. Tidal creek areas were those areas where a small steep-banked tidal drain passed through the home range. Tidal pools were those areas that commonly flooded at high tide, but consisted of an exposed mud flat with short (< 20 cm) exposed vegetation at low tide [22]. Twenty fiddler crabs (ten creek; ten pool) and ten sediment samples (five creek; five pool) were collected from each type of feeding area. Sediment samples were collected by hand (± 500g fresh weight) from the top ten centimeters of sediment and mixed together (by hand) in one bag for each location. Fiddler crabs were collected by hand from the surface of the exposed tidal pools and creeks at low tide. All ten crabs from each type of feeding area were mixed and ground together to comprise one composite sample from each type of feeding area from every home range.

Collecting Eggs and Chicks

During the breeding season of 2000, nest searches were conducted at LCP and Blythe Island to collect eggs for laboratory incubation studies. If a nest was found with 4 or more eggs, the eggs were removed from the nest and brought back to the Savannah River Ecology Laboratory (SREL) within 4 hours. If nests had fewer than 4 eggs, the location was recorded and revisited within a few days to collect a bigger clutch. Eggs were marked in the field using a #2

pencil identifying the nest they were associated with. Upon arrival at SREL, the width (mm), length (mm) and weight (g) of each egg were measured and each egg was then immediately put into an incubator. The eggs were incubated (99° F and 87° F relative humidity) and rotated automatically every 12 hours. Eggs were monitored on a daily basis and the time was recorded when piping initiated. After a chick successfully hatched and remained out of its shell for at least 12 hours, it was weighed (g), euthanized, and placed in a freezer for trace metal and PCB analyses.

Metal Analyses

Liver, muscle, chick, crab and sediment samples were freeze-dried prior to microwave digestion. Wet weights (g) were taken to account for percent moisture for each sample and then placed in a LABCONCO freeze dry system for approximately 7 days and reweighed upon removal from the freeze-drier. After the samples were dried they were homogenized using a SPEX CertiPrep© 6750 Freezer/Mill (all ppm were calculated on a dry weight basis).

For heavy metal analysis approximately 100mg of homogenized, freeze-dried, tissue/organ sample was weighed and digested separately, using 2.5 ml of trace metal grade HNO_3 (Fisher Scientific), and placed into a Teflon microwave digestion vessel. The vessel was then capped and digested in a CEM MDS-2000 microwave using a variable-powered program with increasing microwave power applied over a 45-minute program. After cooling, the vessels were uncapped and 1 ml of 30% H_2O_2 (Fisher Scientific) was added. The vessels were then recapped and placed into the microwave for a repeat of the previous procedure. Once the samples were cooled, each digestion was brought up to a final volume of 25 ml using volumetric flasks. Within each digestion set of liver or muscle, there was a duplicate set of samples, a blank sample, and a standard reference sample (DORM-2, DOLT-2, or TORT-2; National Research

Council Canada, Ottawa, Canada). The digested samples were analyzed for Al, Ti, V, Cr, Fe, Co, Ni, Cu, Zn, As, Se, Rb, Sr, Mn, Mo, Sb, Cd, Cs, Ba, Pb, U, Hg, and Tl (See Appendices). Samples were analyzed by using an Inductively Coupled Plasma Mass Spectrometer (ICP-MS) using a Perkin Elmer SCIEX (ELAN DRC plus) in standard operating mode. Samples were analyzed using an external calibration.

PCB Analysis

PCB's were extracted from the tissue using ultrasonic extraction (EPA Method 3550B). Tissues were freeze dried and macerated prior to extraction. For chicks, the whole chick was ground since they were too small to dissect individual tissues. Dibromooctofluorobyphenyl and tetrachlorometa zylene were added as internal surrogate standards. The extractions were performed by sonicating the tissues in 150 ml of acetone: hexane (1:1v/v) using a Tekmar Sonic Disruptor operated at 100% power in the pulsed mode with a 50% duty cycle for 3 minutes. The mixture was filtered and the extraction repeated twice with fresh solvent. The combined solvent extracts were dried with Na_2SO_4 solvent exchanged, and concentrated. Lipids were removed by treatment with 1:1 sulfuric acid solution and the solution back-extracted into hexane. The aqueous phase was discarded and the procedure repeated until a clear hexane extract was obtained.

The hexane extracts were concentrated to about 1 ml and then charged onto a precleaned silica gel column to isolate the PCB's from other organic contaminants. The column was sequentially eluted with a series of organic solvents and the PCB fraction collected. The isolated fraction was then concentrated and analyzed using gas chromatography (GC) and gas chromatography- mass spectrometry (GC-MS).

PCB analyses were performed on a Hewlett Packard (Atlanta, GA) 6890 gas chromatograph equipped with an electron capture detector (ECD), splitless injection, electronic pressure control (EPC), and autoinjector. Separation of PCB congeners was achieved using a capillary chromatographic column (30 m DB-5, 0.025 mm I.D., 0.25 um film thickness; J &W Scientific, Folsom, CA). Samples were quantified as Aroclor 1268 using a five-point calibration curve derived from dilutions of certified standards. Six characteristic peaks were selected from the Aroclor mixtures. All selected congener peaks were at least 25% of the highest Aroclor component. A Hewlett Packard 5890 Series II gas chromatograph with splitless injection, EPC, and a 5972 mass spectrometer (GC-MS) was used to confirm GC-ECD identifications. All samples were analyzed by GC-MS using the selected ion monitoring (SIM) acquisition mode. Selected samples were also analyzed using full scan acquisition in a separate sample injection/analysis. All of the 12 congeners in the Aroclor 1268 mixture were determined in the GC-MS analysis. Selected ions in the SIM mode for different retention time windows were determined from the analysis of an Aroclor 1268 standard. Analyses of spectra obtained in the full scan mode (mass 50 –550) were performed by comparing the mass spectra with Aroclor 1268 standards as well as the NIST reference library.

Transfer Factors

Transfer factors for mercury and PCB concentrations were calculated between trophic levels. These factors were determined my dividing the concentration of a trophic level by the trophic level below it. To calculate the transfer factors from the sediment to fiddler crabs the amount found in fiddler crabs were divided by the concentrations found in the corresponding sediments. Then the concentrations found in the adult rails' muscle or liver samples were divided by the amount found in the corresponding fiddler crabs.

Statistical Analysis

We first examined metal and PCB distributions using Shapiro-Wilk statistics (PROC UNIVARIATE, version 8.1; SAS Institute©). This tested the hypothesis that these data were random samples from normal distributions, which was rejected at $\alpha = 0.05$. Stem-and-leaf plots suggested a log-transformation, which successfully transformed the data to a normal distribution in all cases.

To examine the relationship between Hg and PCB burden in the different sampling locations (creek or pool) and sample types (sediment, crabs or adults), we used analysis of variance models (ANOVA; PROC GLM; SAS Institute©). For all tested models, Type III (partial) sums of squares and associated *F*-statistics were interpreted and least-squares means procedures were used to provide estimates of dependent variables that were adjusted for all effects in the models and to provide mean separation tests. All statistical tests were considered significant at $P<0.05$. Means and standard errors were presented as geometric means (i.e., back-transformed values of log least-squares means estimates).

Contaminant Levels (Sediment, Crabs, Adult Rails and Chicks)

Levels of PCBs and Hg found in all sample types (sediment, crabs, adult rails and chicks) are presented in Figures 2.a-b. Descriptive statistics for all contaminants tested in all sample types can be found in the appendices. The detection limit for the mercury concentrations in all samples was 0.004 ppm. The detection limits for the PCB analysis was 0.04 ppm. All samples analyzed for Hg and PCBs from LCP and the control sites were above these detection limits. Hg levels in the sediments were found to be significantly higher at LCP than at the control sites ($F = 65.31$, $P \leq 0.0001$). Sediment PCB concentrations were also significantly higher at LCP ($F = 92.74$, $P \leq 0.0001$).

Concentrations of Hg and PCBs of crabs were also found to be significantly higher at LCP than at the control sites ($F_{Hg} = 86.13$, $P \leq 0.0001$; $F_{PCBs} = 65.36$, $P \leq 0.0001$). Mercury levels in the sediments from LCP were significantly higher than those in the crabs ($P = < 0.0001$). However, PCB concentrations did not differ between sediment and crabs ($P = 0.7365$).

Muscle and liver samples from adult birds were significantly higher in both Hg and PCBs than were either the sediment or crab samples from the LCP site ($P \leq 0.0001$). Mercury concentrations in chicks from LCP were also significantly higher than in the chicks from the control site ($P \leq 0.0001$), and were also significantly higher than those found in the crabs and sediments from the same site ($P \leq 0.0001$). PCB concentrations were significantly higher in chicks from LCP than in those from the control marsh ($P \leq 0.0001$). PCB levels in chicks were significantly higher than in adult muscle but not liver ($P_{muscle} \leq 0.0001$; $P_{liver} = 1.000$).

Transfer Factors

Contaminant levels of both mercury and PCBs in the sediment samples were significantly different between the tidal creek and tidal pool feeding areas in LCP ($P_{PCB} = 0.0157$, $P_{Hg} =$

.0432). Mercury and PCBs were significantly higher in the tidal creeks (P_{PCB} = 1.04, P_{Hg} = 0.67). However, crab samples from the two types of feeding areas were not significantly different (P_{PCB} = 0.3711, P_{Hg} = .9903). Because the contaminant concentrations of crabs from creek vs. pool locations were not significantly different, transfer factors (Table 4.a-d) for the creek and pool samples were combined. The average transfer factors of PCBs and Hg in sediment vs. crabs, crabs vs. muscle and crabs vs. liver in the creek and pool samples increased with every trophic level. The average transfer factor for PCB from the sediment to the crabs was 0.8, from crabs to muscle was 15 and from crabs to liver was 119. The average transfer factor for Hg from the sediment to the crabs was 0.4, from crabs to muscle was 14.8 and from crabs to liver was 50.1.

were found in the sediments sampled at LCP (0.43 – 20 ppm). Concentrations of Aroclor 1268 were also found at the control sites in relatively small amounts (< 0.5 ppm).

Since fiddler crabs are the major food source for clapper rails [14], sampling them helped control for diet variability when establishing transfer factors. These invertebrates feed on the detritus found in the sediments and will accumulate both Hg and Aroclor 1268 by digesting contaminated detritus or from directly ingesting the sediment during normal feeding activities [27]. Hg levels reported in fiddler crabs from Georgia range from 0.04 – 1.8 ppm [13, 19, 26], with 45 – 75% of the Hg found in the crabs sampled being in the methylated form [19, 26]

This relationship between sediment contamination and fiddler crab contaminant burden was similar for Aroclor 1268. However, there was a slight decrease in Aroclor 1268 levels in fiddler crabs as compared to the sediment. The strong association of PCBs with detrital carbon in sediments increases its availability for accumulation through trophic levels. Reported levels in crabs and various invertebrates range from 0.4 – 33 ppm [5]. The levels of PCBs found in the sediment and macroinvertebrates of the Lower Hudson River in New York were also found to be closely related. The PCB concentration of those sediments was found to be between 1 – 15 ppm and the invertebrates ranged from 1 – 13 ppm [5]

Unlike the relationship between contaminant levels of sediments and fiddler crabs, both Hg and Aroclor 1268 biomagnified between fiddler crabs and the adult rails, (Figures 2.a-b) with mercury levels being significantly higher in liver than in muscle tissues. This finding is consistent with another clapper rail study from the same area which showed MeHg to be significantly higher in muscle tissue than in liver [19]. This may be an indication that inorganic Hg builds-up in the liver where it is metabolized and eliminated, with MeHg crossing biological

membranes more easily and accumulating in the muscle [19]. The study reported here did not differentiate between MeHg and total Hg in rail tissues.

PCBs may accumulate in the adult clapper rails in high concentrations due to this species' relatively long life expectancy (5 – 10 years) [3] and high fat content within their tissues. PCBs tend to deposit in fatty tissues and do not depurate. Thus, they can accumulate to high levels over extended periods. The population of clapper rails nesting in the Brunswick estuary is likely one of year-round residents. Although these birds will extend their home ranges during the nonbreeding season [14], they are still likely to utilize their nesting habitats for food during this time period thus continuing to expose themselves to toxicants. Transformation of PCBs to metabolites by the cytochrome P450 system is the major pathway of PCB metabolism. This metabolization occurs mainly in the liver and this may be the reason that concentrations are higher there than in the muscles [5]. Normal metabolic processes such as calcium regulation and potassium pumps can have an effect on the levels of inorganic toxicants that are closely associated with essential elements. Moreover, organic chemicals that are hydrophobic can still easily pass through membranes and tend to collect in the fat deposits of an organism [8].

Whole body concentrations of Hg and PCBs in clapper rail chicks indicated that both contaminants were actively passed to the chicks. Whole body concentrations of Hg in the young were similar to concentrations in the adult's muscle, but were much lower than liver concentrations (Figure 2.b). Elevated levels of Hg in eggs have been reported to cause low reproductive success and behavioral abnormalities in several species of waterfowl, fish-eating predators and songbirds [13, 21]. Behavioral studies conducted on mallard ducklings (*Anas platyrhynchos*) showed a change in avoidance responses with an increase in Hg levels. These changes occurred when parents were fed a diet containing 0.5 – 3 ppm Hg [28]. Rail chicks

hatched from the eggs from the LCP marsh in this study have been shown to have both behavioral and physical abnormalities [29], which could have been caused by the mixture of toxicants that the parents were exposed to.

PCBs were found in high concentrations in the clapper rail chicks (control < 40 ppm, LCP >100 ppm). The fact that adult PCB muscle concentrations were lower than those of the whole chicks while the adult liver concentrations were higher (Figure 2.a) was most likely due to the higher fat content of the liver as well as the aforementioned physiological responses to PCB metabolism. These data suggest that reproduction may be a significant pathway of elimination of PCBs from adult females. An increased concentration of organochlorides in bird eggs has been related to lower reproductive success and interference with developmental processes [5].

Contaminant Transfer

The bioaccumulation and trophic transfer of pollutants in the environment is complex and it is influenced by a variety of factors. The chemical characteristics of the contaminant, environmental conditions, behavior and physiology all play important roles in regulating the transfer of pollutants through food chains. Collecting prey and sediment samples from the delineated home range of each individual rail helped to variability in and between home ranges that is often overlooked in trophic transfer studies. By using clapper rails as indicator species, we were able to control for large movements and diet variability, improving our ability to quantify the transfer factors of the target contaminants. Although we were not able to quantify toxicant levels in the young that came from the same female rails that were sampled, this study did show that females most likely depurated contaminants into their young through the laying of eggs. Females also tended to have lower average concentrations of contaminants than males even though they were not significantly different. Studies on other wildlife species have shown

that a significant amount of contamination can be passed from the female to its offspring. Snakes naturally contaminated with radiocesium have been shown to transfer 6.47% of their total body burden to their offspring [30].

In general, the accumulation of Hg and PCBs by aquatic biota is rapid, and depuration is slow. In 1999, over five ha of the most contaminated portions of the LCP marsh were remediated by the dredging of marsh sediments and replanting of Spartina. However, this study showed that both Hg and Aroclor 1268 are still bioavailable and occur at levels that may be harmful to both clapper rails and their young. PCB concentrations in failed eggs of the California clapper rail (*Rallus longirostris obsoletus*) ranged from 0.65 to 5.01 ppm with an average of 1.30 ppm [20]. Rails from the LCP site have been shown to have elevated levels of double-stranded DNA breaks and there was a relationship between those breaks and contaminant levels within the rails [29].

Understanding the movement, feeding, breeding and social characteristics of the target species will lead to more accurate assessment of exposure tailored to specific species or populations. This study was designed to accurately quantify the transfer factors of Arolchlor 1268 and Hg from the sediment to invertebrates and into clapper rails. We provided a better description of the variability in contaminant transfer by studying and incorporating information regarding the spatial characteristics of the contamination in the marsh and thus in these birds' home ranges. Without this additional spatial dimension, the strength of these data would not have been as great. Specifically, the information found in this study can be used to better understand the impacts that these contaminants are having on the LCP marsh. The use of spatial analysis should be an important component of future studies of trophic transfer and ecological risk assessment. The current models being used almost always assume homogeneous exposures

and responses. This study shows that there is a large amount of spatial and individual variability in clapper rails from the LCP marsh. Consideration of these effects will only improve future risk assessment and trophic transfer models.

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Table 1: Sex, live whole body weights (g), number of telemetry locations and home range estimates (ha) of home ranges of adult clapper rails from the LCP marsh on the Turtle River in Brunswick, Georgia. Rails with only one location were collected from an active nest. In order to estimate a home range, from which to collect samples, for these eight birds, telemetry data from 16 that had more than 15 locations was used to estimate an average size and the median (0.28 ha) was used as a conservative estimate.

ID	Sex	Weight (g)	Locations	Home range (Ha)
219	F	270	19	0.19
255	F	240	18	0.21
337	F	225	25	0.33
358	M	270	15	0.27
501	M	260	25	13.3
567	M	350	13	0.28
970	F	280	16	0.77
640	F	260	1	0.28
102	M	290	1	0.28
103	F	220	1	0.28
104	F	230	1	0.28
105	M	270	1	0.28
106	F	210	1	0.28
107	F	220	1	0.28
108	M	310	1	0.28

Table 2: Descriptive statistics for the home ranges of the seven rails from the LCP marsh that had more than fifteen locations and were successfully recaptured at the end of the study. All calculations are reported in hectares.

	Size of Home Ranges
Mean	1.91
Standard Error	1.62
Median	0.27
Standard Deviation	4.59
Minimum	0.19
Maximum	13.27

Table 3: Descriptive statistics for the radio telemetry data collected for sixteen rails used to estimate the home ranges of the eight rails collected from known nesting locations. All rails used for this estimation had at least 15 locations evenly distributed between all hours of the day and tide levels. The median was used as a conservative estimation of the home ranges of the additional eight rails. All calculations are reported in hectares.

	Size of Home Ranges
Mean	1.26
Standard Error	0.81
Median	0.28
Standard Deviation	3.25
Minimum	0.06
Maximum	13.27
Count	16

Tables 4.a-d: Transfer factors for polychlorinated biphenyls (PCBs) and Mercury (Hg) between all sample types collected from the LCP marsh on the Turtle river in Brunswick, Georgia. All sediment and crab samples were taken from within the home range of the corresponding adult rail during the breeding season of 2002. Sediment, crab and tissue samples are reported in parts per million (ppm). Any values labeled "NA" were samples that were unable to be collected. Transfer factors for crabs were calculated as a function of the concentration of contaminant found in the sediment while muscle and liver transfer factors were calculated as a function of the concentration of contaminant found in the crabs.

Table 4.a: Concentration of PCBs found in all sample types (ppm dry weight).

Birds ID	Sediment	Crab	Muscle	Liver
102	11	3.4	13	32.3
103	1.3	0.8	9.4	NA
104	1.3	0.8	1.7	8.3
105	1.4	1.2	8.9	108
106	1.0	0.6	5.0	19.6
107	1.4	1.3	18	55.7
108	2.1	0.7	49	499
219	2.6	1.2	5.8	38.7
255	2.4	1.0	25	164
337	3.6	4.0	71	568
358	11	0.9	19	157
501	1.1	3.2	27	167
567	2.6	3.5	18	126
640	1.8	0.6	4.6	54.0
970	2.6	1.6	22	83.5
Means(SD)	***3.1 (3.1)***	***1.6(1.2)***	***21.9(18.5)***	***155.9(172.2)***

Table 4.b: Concentration of Hg found in all sample types (ppm dry weight).

Birds ID	Sediment	Crab	Muscle	Liver
102	3.3	0.6	4.7	20.2
103	2.3	0.3	3.5	NA
104	1.9	0.3	1.7	5.3
105	1.6	0.3	7.3	14.2
106	1.7	0.3	4.6	20.8
107	1.7	0.6	3.4	11.0
108	2.0	0.3	3.6	17.8
219	1.5	0.4	3.7	12.1
255	1.4	0.4	8.8	23.5
337	1.0	0.5	11	31.3
358	2.3	0.2	9.7	34.5
501	0.4	0.9	8.9	36.1
567	2.1	0.8	9.0	41.0
640	1.1	0.2	1.7	4.9
970	3.1	0.5	6.5	19.5
Means(SD)	***1.8(.07)***	***0.4(0.2)***	***5.9(3.1)***	***20.9(11.3)***

Table 4.c: Transfer factors for all sample types for PCBs.

Birds ID	Sediment to crab	Crab to Muscle	Crab to Liver
102	0.3	3.9	9.5
103	0.6	12.3	NA
104	0.7	2.0	9.9
105	0.9	7.1	87.3
106	0.6	8.9	34.6
107	0.9	14.4	43.5
108	0.3	73.4	744
219	0.4	5.0	33.5
255	0.4	24.6	162
337	1.1	17.9	144
358	0.1	21.5	178
501	3.0	8.5	52.7
567	1.3	5.2	36.3
640	0.3	7.3	85.3
970	0.6	13.5	51.1
Means(SD)	***0.8(0.7)***	***15.0(17.4)***	***119.4(187.8)***

Table 4.d: Transfer factors for all sample types for Hg.

Birds ID	Sediment to crab	Crab to Muscle	Crab to Liver
102	0.2	7.7	33.0
103	0.1	12.3	NA
104	0.1	6.3	19.5
105	0.2	27.0	52.7
106	0.2	15.6	70.2
107	0.4	5.6	18.2
108	0.2	10.9	53.5
219	0.3	8.5	28.3
255	0.2	25.1	67.2
337	0.5	22.3	63.6
358	0.1	39.5	141.0
501	2.1	10.4	42.0
567	0.4	11.8	53.7
640	0.2	6.9	20.3
970	0.2	12.5	37.6
Means(SD)	***0.4(0.5)***	***14.8(9.6)***	***50.1(31.6)***

Figure 1: Aerial photo of Glynn county southeastern Georgia. This figure shows the relationship of the LCP study site to the city of Brunswick and all control sites used in this study: (B.I. = Blythe Island State Park; F.I. = Frederica Island; T.C. = Troupe Creek). All control sites were similar to LCP in habitat type and structure.

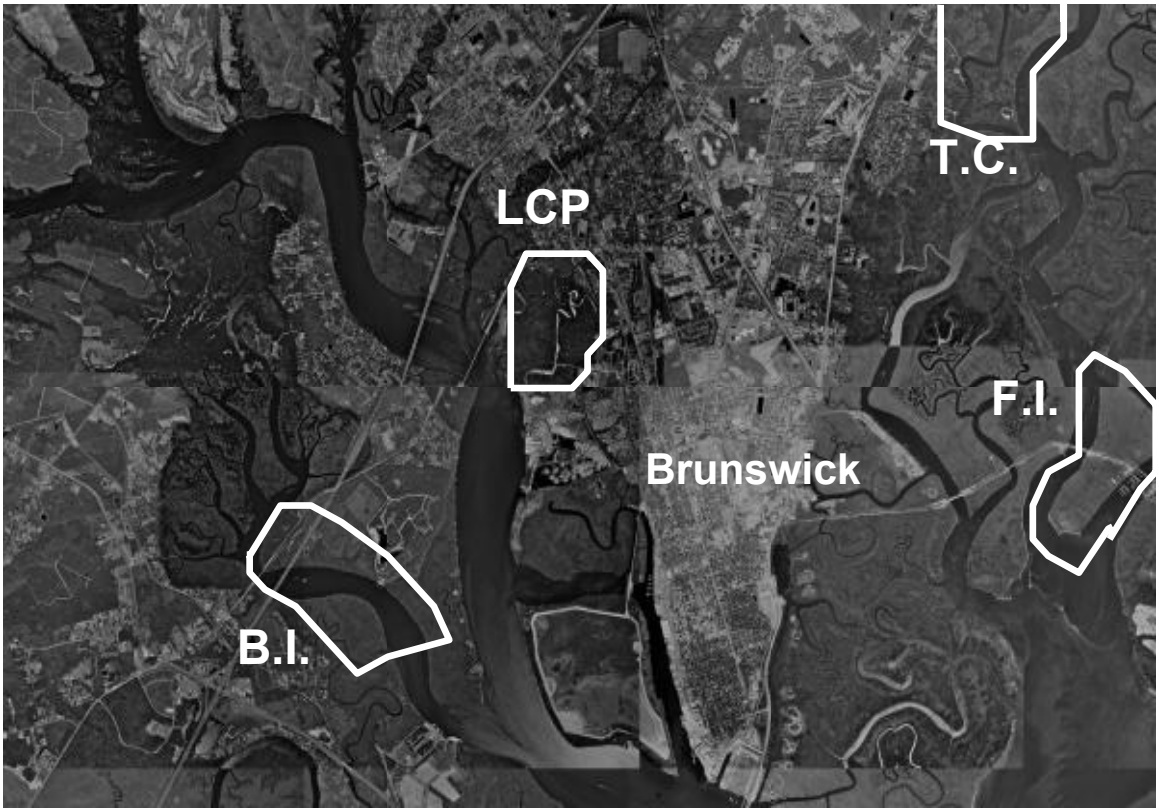


Figure 2.a: Geometric means and associated 95% confidence levels of polychlorinated biphenyl (PCB) concentrations found in all sample types from control and LCP sites collected during the breeding seasons of 2000 and 2002. Values are in parts per million (dry wt.).

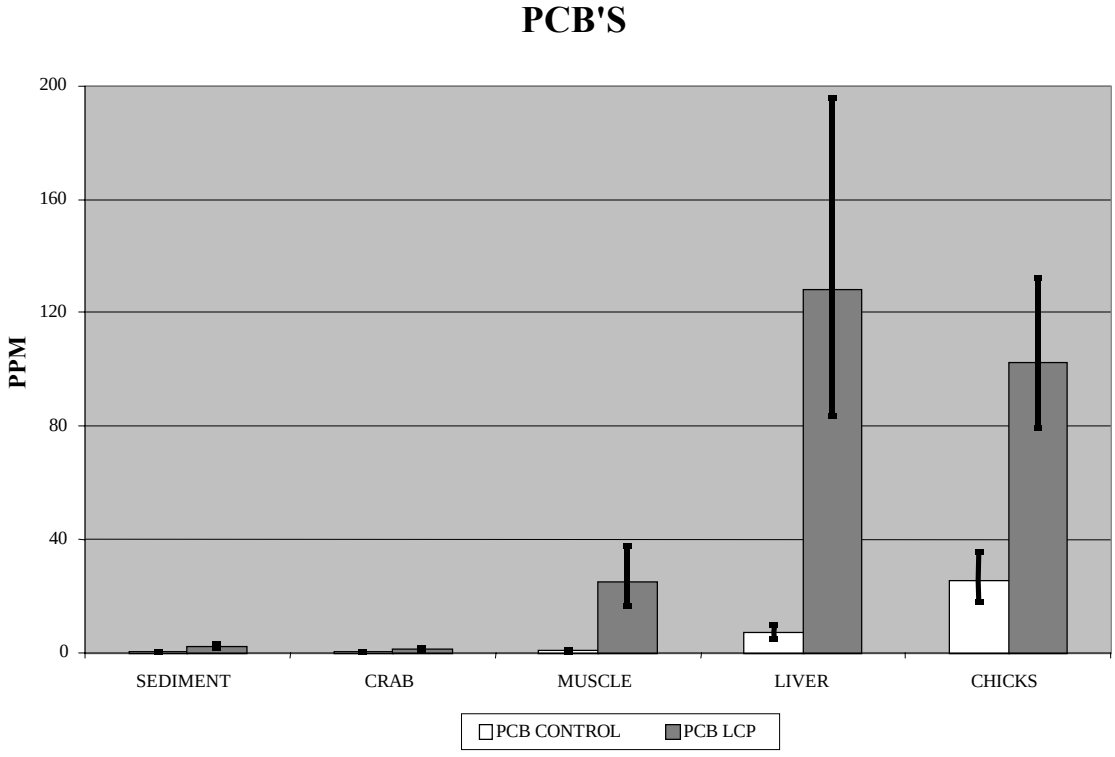


Figure 2.b: Geometric means and associated 95% confidence levels of mercury concentrations found in all sample types from control and LCP sites collected during the breeding seasons of 2000 and 2002. Values are in parts per million (dry wt.).

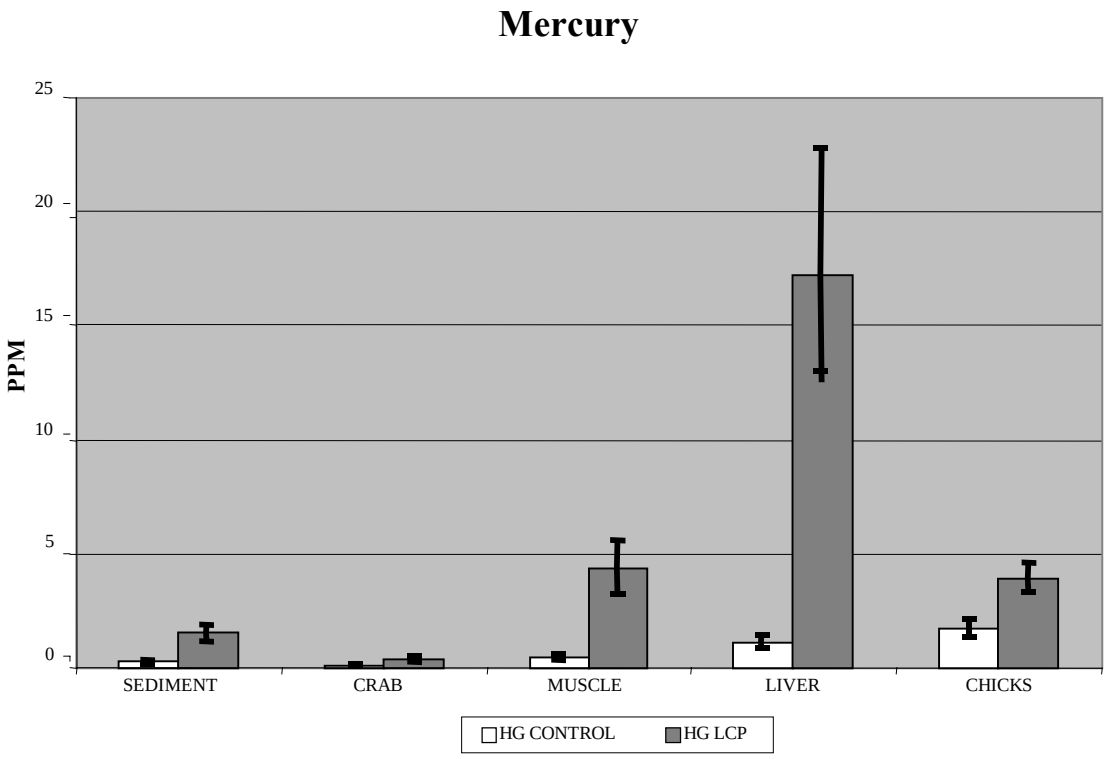
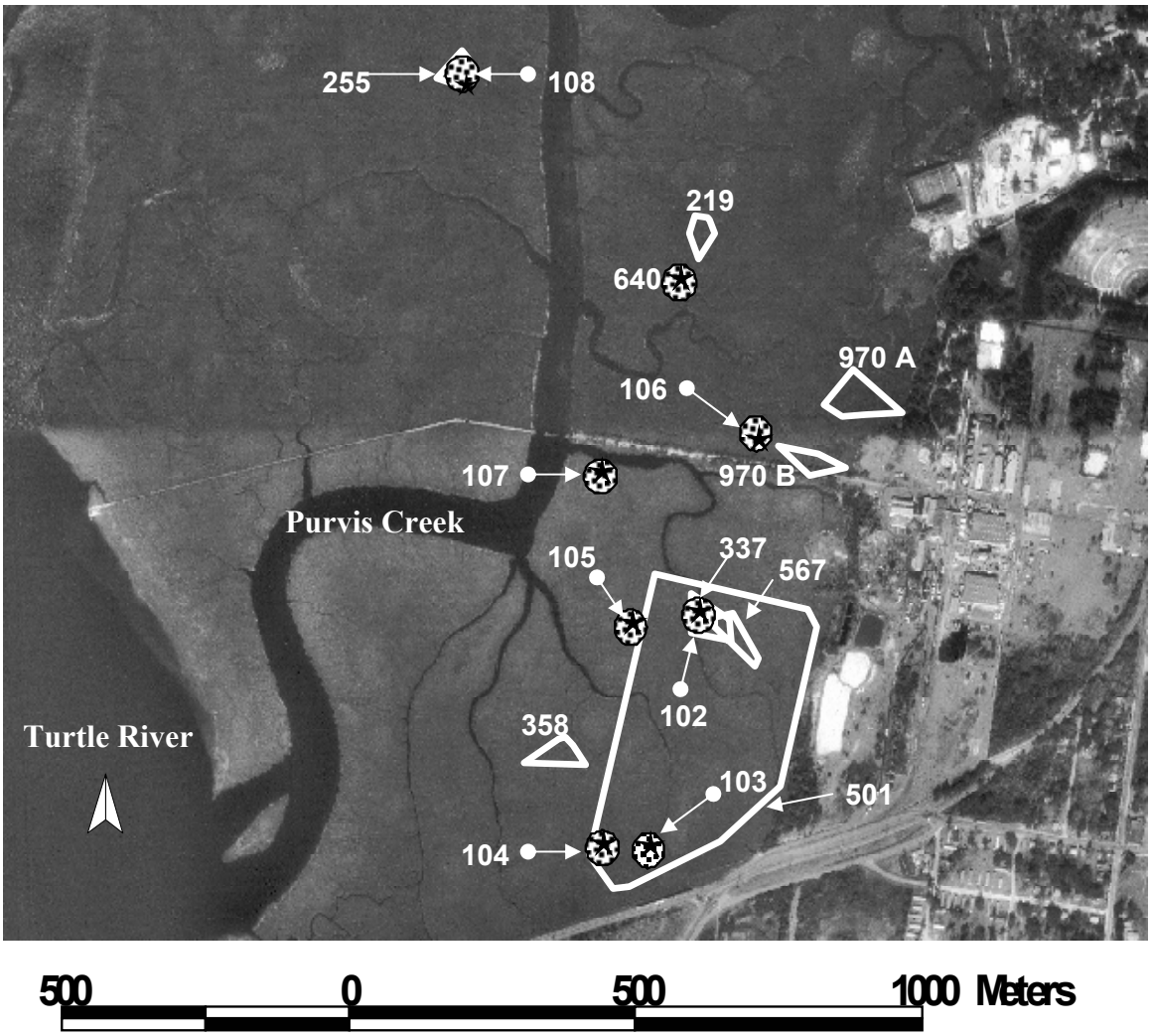


Figure 3: Known and estimated home ranges for clapper rails (n = 15) collected during the 2002 breeding season at the LCP study site. Outlined ranges represent clapper rails (n = 7) that had sufficient telemetry data (n > 15 locations) to establish their core home range using the Minimum Convex Polygon (MCP) method. Stars surrounded by buffers represent clapper rails (n = 8) taken from know active nesting locations. These home ranges were estimated by calculating the median of the known home ranges (n = 16) and applying a buffer of that area around the nest.



Appendices: Descriptive statistics for all samples collected from the control sites and LCP marsh. All LCP samples were collected during the breeding season between February 2002 and June 2002. Control adults were collected during the breeding season of 2001 and the chicks were collected during the breeding season of 2000.

Control Creek Sediments ppm dry wt. (n = 10) Date :05/2002

Contaminant	Mean	Standard Error	Median	Standard Deviation	Range	Minimum	Maximum
PCB	0.35	0.03	0.33	0.09	0.30	0.20	0.50
Hg	0.18	0.02	0.18	0.07	0.20	0.07	0.27
Al	33495	2020	33854	6386	19591	21522	41113
V	54.84	1.33	55.69	4.22	15.67	45.68	61.35
Cr	48.60	1.72	48.24	5.43	19.84	38.17	58.02
Fe	16821	827	17004	2617	9768	12083	21851
Co	2.79	0.76	4.46	2.40	5.04	0.01	5.05
Ni	22.49	0.66	23.04	2.10	7.04	18.19	25.22
Cu	12.18	0.52	12.47	1.64	5.86	8.34	14.19
Zn	62.43	2.64	66.71	8.35	21.65	49.42	71.07
As	11.29	0.61	11.34	1.93	6.34	7.39	13.73
Se	1.52	0.65	0.23	2.07	4.51	0.23	4.75
Rb	18.72	1.02	19.09	3.23	10.51	11.42	21.92
Sr	40.76	1.75	42.08	5.52	17.88	28.77	46.65
Mn	154	22.49	134	71.11	226	97.78	324
Ba	86.44	5.55	86.55	17.56	58.00	55.42	113
Pb	15.44	0.63	15.81	1.99	5.96	11.97	17.93

LCP Creek Sediments ppm dry wt. (n = 15) Date :05/2002

Contaminant	Mean	Standard Error	Median	Standard Deviation	Range	Minimum	Maximum
PCB	4.61	1.57	2.47	6.09	19.28	0.98	20.26
Hg	2.39	0.30	2.38	1.15	4.59	0.13	4.72
Al	13619	571	12469	2212	6562	12469	19031
V	41.85	5.38	38.40	20.82	67.57	15.12	82.69
Cr	41.16	5.86	35.57	22.71	67.17	11.15	78.31
Fe	12186	1618	9452	6266	22164	5068	27232
Co	2.56	0.59	2.45	2.28	6.59	0.01	6.60
Ni	14.62	2.44	10.19	9.43	29.45	5.16	34.61
Cu	13.67	1.80	16.86	6.97	21.13	0.02	21.14
Zn	69.73	6.03	77.00	23.34	73.95	27.84	102
As	10.57	1.24	11.61	4.81	19.02	0.13	19.15
Se	1.98	0.54	1.18	2.10	5.63	0.23	5.86
Rb	16.27	0.97	16.63	3.76	12.47	8.16	20.63
Sr	36.30	1.73	36.00	6.70	21.89	25.21	47.10
Mn	86.00	9.04	88.23	35.02	122	28.46	150
Ba	86.84	6.35	82.01	24.60	82.95	55.61	139
Pb	24.48	5.31	21.92	20.57	88.20	7.11	95.32

Control Pool Sediments ppm dry wt. (n = 10) Date :05/2002

Contaminant	Mean	Standard Error	Median	Standard Deviation	Range	Minimum	Maximum
PCB	0.29	0.03	0.26	0.10	0.32	0.19	0.51
Hg	0.51	0.04	0.47	0.13	0.35	0.36	0.71
Al	50205	2200	50792	6956	24025	34039	58064
V	52.25	1.72	52.01	5.44	17.63	42.60	60.23
Cr	53.87	1.51	53.10	4.78	17.09	47.92	65.02
Fe	14794	868	15190	2744	8624	9842	18466
Co	0.49	0.49	0.01	1.54	4.86	0.01	4.86
Ni	20.89	0.82	20.75	2.58	7.44	17.57	25.01
Cu	11.05	0.30	10.62	0.95	2.98	9.71	12.70
Zn	55.76	2.05	57.82	6.48	19.98	43.37	63.36
As	8.37	0.67	8.30	2.13	6.16	5.41	11.58
Se	1.17	0.62	0.23	1.97	4.85	0.23	5.08
Rb	29.18	1.33	30.24	4.20	14.72	17.53	32.24
Sr	52.70	1.71	52.62	5.41	17.39	45.69	63.08
Mn	113	13.10	109	41.43	123	50.06	173
Ba	101	5.33	101	16.84	58.51	63.13	122
Pb	15.14	0.55	15.59	1.73	5.77	11.72	17.50

LCP Pool Sediments ppm dry wt. (n = 15) Date :05/2002

Contaminant	Mean	Standard Error	Median	Standard Deviation	Range	Minimum	Maximum
PCB	1.65	0.27	1.23	1.04	3.35	0.47	3.82
Hg	1.30	0.19	1.06	0.75	3.03	0.48	3.51
Al	12469	.	12469	.	.	12469	12469
V	48.55	2.97	48.42	11.49	41.78	29.51	71.30
Cr	44.02	3.27	45.16	12.66	48.77	20.81	69.58
Fe	11483	991	12404	3836	11394	5996	17389
Co	1.63	0.45	1.86	1.75	4.73	0.01	4.74
Ni	15.08	1.77	15.74	6.85	19.91	5.33	25.24
Cu	12.96	0.68	12.13	2.64	8.10	9.08	17.17
Zn	66.90	4.10	63.10	15.87	66.74	41.09	108
As	9.49	0.76	9.39	2.93	11.05	5.70	16.75
Se	2.00	0.51	1.38	1.97	4.96	0.23	5.20
Rb	21.97	2.30	24.45	8.92	25.28	8.48	33.76
Sr	47.54	3.37	51.79	13.06	46.30	25.79	72.09
Mn	82.75	12.51	70.59	48.47	144	26.96	171
Ba	85.05	6.03	83.96	23.35	71.72	48.40	120
Pb	23.13	5.92	17.87	22.92	96.50	8.13	105

Control Creek Crabs ppm dry wt. (n = 10) Date :05/2002

Contaminant	Mean	Standard Error	Median	Standard Deviation	Range	Minimum	Maximum
PCB	0.33	0.06	0.28	0.18	0.66	0.14	0.81
Hg	0.14	0.01	0.13	0.04	0.15	0.09	0.24
Al	1116	117	1065	369	1126	516	1642
V	2.97	0.26	3.05	0.81	2.54	1.57	4.11
Cr	5.32	0.56	5.00	1.78	5.68	2.34	8.02
Fe	1265	65	1250	207	620	966	1586
Co	0.59	0.05	0.54	0.17	0.44	0.38	0.82
Ni	1.84	0.13	1.82	0.42	1.31	1.23	2.54
Cu	99.23	8.07	95.75	25.52	86.46	72.09	159
Zn	339	31.96	367	101	337	95.88	433
As	11.28	0.95	11.69	3.01	9.48	6.89	16.37
Se	4.15	0.46	4.43	1.46	4.01	1.95	5.96
Rb	3.20	0.11	3.24	0.34	1.22	2.45	3.67
Sr	1352	79	1416	249	851	866	1717
Mn	127	38.09	61.69	120	342	47.84	390
Ba	448	61.17	456	193	707	19.86	727
Pb	1.15	0.11	1.07	0.34	1.04	0.62	1.67

LCP Creek Crabs ppm dry wt. (n = 15) Date :05/2002

Contaminant	Mean	Standard Error	Median	Standard Deviation	Range	Minimum	Maximum
PCB	1.71	0.29	1.29	1.11	3.26	0.67	3.92
Hg	0.43	0.05	0.39	0.18	0.65	0.16	0.81
Al	995	92	1043	357	1233	326	1559
V	2.48	0.21	2.64	0.83	2.80	1.03	3.83
Cr	4.98	0.46	4.89	1.79	7.25	1.81	9.06
Fe	1258	80	1233	309	1119	701	1820
Co	0.48	0.04	0.46	0.14	0.55	0.28	0.83
Ni	4.44	1.76	1.54	6.83	24.99	0.08	25.07
Cu	91.11	7.07	94.86	27.37	95.28	39.04	134
Zn	340	28.16	345	109	426	68.50	494
As	10.39	0.51	10.59	1.99	6.62	7.22	13.85
Se	3.66	0.35	3.26	1.34	5.18	2.15	7.34
Rb	2.71	0.19	2.92	0.73	2.39	1.31	3.70
Sr	1474	67	1481	260	1096	847	1943
Mn	75.44	10.43	52.21	40.40	112.66	32.24	145
Ba	443	34.55	476	134	529	38.05	567
Pb	1.27	0.08	1.26	0.32	1.18	0.80	1.99

Control Pool Crabs ppm dry wt. (n = 10) Date :05/2002

Contaminant	Mean	Standard Error	Median	Standard Deviation	Range	Minimum	Maximum
PCB	0.29	0.03	0.27	0.10	0.31	0.14	0.45
Hg	0.14	0.01	0.12	0.04	0.10	0.11	0.20
Al	1750	166	1747	526	2005	831	2836
V	4.47	0.35	4.37	1.12	3.66	2.77	6.43
Cr	5.87	0.45	5.67	1.42	4.15	3.78	7.93
Fe	1728	97	1694	307	992	1177	2168
Co	0.72	0.09	0.63	0.27	0.95	0.47	1.42
Ni	2.08	0.20	2.28	0.62	1.61	1.29	2.89
Cu	84.06	6.67	84.32	21.09	68.73	53.98	123
Zn	267	31.59	301	99.91	280	86.95	367
As	10.66	0.65	11.10	2.04	7.26	6.61	13.87
Se	3.28	0.48	2.95	1.51	5.39	1.75	7.14
Rb	2.93	0.11	2.91	0.36	1.34	2.23	3.57
Sr	1421	43	1449	135	508	1146	1655
Mn	203	76.30	79.14	241	689	34.21	723
Ba	360	59.74	407	189	518	24.96	543
Pb	1.73	0.13	1.87	0.41	1.13	1.09	2.22

LCP Pool Crabs ppm dry wt. (n = 15) Date :05/2002

Contaminant	Mean	Standard Error	Median	Standard Deviation	Range	Minimum	Maximum
PCB	1.58	0.36	0.87	1.38	4.10	0.40	4.49
Hg	0.45	0.06	0.37	0.24	0.73	0.18	0.91
Al	956	84	935	326	1048	430	1478
V	2.63	0.19	2.81	0.74	2.32	1.46	3.78
Cr	5.34	0.89	4.01	3.46	14.13	2.93	17.06
Fe	1249	85	1243	330	1254	555	1809
Co	0.49	0.04	0.46	0.14	0.54	0.25	0.79
Ni	1.89	0.45	1.63	1.72	7.70	0.08	7.78
Cu	88.90	6.09	85.58	23.57	86.09	49.63	136
Zn	356	13.20	355	51.11	196	286	482
As	10.78	0.47	10.36	1.82	6.54	7.94	14.48
Se	3.84	0.25	3.65	0.98	3.60	2.36	5.96
Rb	2.65	0.11	2.75	0.43	1.33	1.85	3.19
Sr	1487	85	1417	329	1259	815	2074
Mn	58.59	8.08	49.12	31.31	115.32	27.82	143
Ba	498	23.05	505	89.29	349	288	637
Pb	1.73	0.36	1.17	1.40	4.83	0.78	5.61

Control Muscle ppm dry wt. (PCB n = 33; metals n = 20) Date :05/2000

Contaminant	Mean	Standard Error	Median	Standard Deviation	Range	Minimum	Maximum
PCB	0.70	0.10	0.54	0.59	2.41	0.01	2.42
Hg	0.62	0.18	0.41	0.82	3.81	0.27	4.08
Al	20.08	13.80	7.32	61.70	282	0.10	282
V	0.40	0.01	0.39	0.04	0.18	0.39	0.58
Cr	0.42	0.03	0.41	0.14	0.62	0.11	0.73
Fe	75.98	6.52	67.62	29.16	133	44.38	177
Co	0.05	0.01	0.02	0.06	0.18	0.01	0.18
Ni	0.97	0.26	0.24	1.16	3.90	0.08	3.98
Cu	3.79	0.28	3.44	1.26	3.94	2.15	6.10
Zn	19.02	7.07	11.67	31.60	144	8.77	153
As	0.54	0.07	0.45	0.29	1.03	0.20	1.23
Se	0.50	0.10	0.38	0.46	2.19	0.23	2.42
Rb	2.20	0.09	2.28	0.40	1.46	1.41	2.87
Sr	1.00	0.75	0.24	3.37	15.16	0.13	15.29
Mn	0.94	0.50	0.45	2.22	10.07	0.29	10.35
Ba	0.28	0.23	0.04	1.05	4.72	0.02	4.74
Pb	0.25	0.07	0.18	0.29	1.31	0.04	1.34

LCP Muscle ppm dry wt. (PCB n = 21; metals n = 24) Date :05/2002

Contaminant	Mean	Standard Error	Median	Standard Deviation	Range	Minimum	Maximum
PCB	61.78	26.83	22.12	123	553.07	1.67	554.74
Hg	5.52	0.75	4.67	3.69	15.90	0.47	16.37
Al	84.22	41.88	33.38	205	1025	4.25	1029
V	0.41	0.07	0.31	0.36	1.78	0.22	2.01
Cr	1.21	0.15	0.95	0.75	3.16	0.44	3.59
Fe	346	68.84	225	337	1651	160	1811
Co	0.07	0.01	0.05	0.05	0.17	0.02	0.19
Ni	0.28	0.05	0.23	0.23	1.07	0.08	1.15
Cu	11.65	1.40	9.97	6.86	31.69	5.65	37.34
Zn	46.52	3.74	40.55	18.30	79.67	30.95	111
As	2.44	0.23	2.36	1.11	3.98	0.88	4.86
Se	2.31	0.23	2.07	1.12	5.25	1.42	6.66
Rb	8.68	0.43	9.11	2.12	9.43	3.42	12.84
Sr	2.50	0.74	1.24	3.62	14.45	0.36	14.81
Mn	2.63	0.54	1.88	2.67	12.20	1.05	13.25
Ba	0.33	0.10	0.17	0.47	2.27	0.09	2.36
Pb	0.11	0.02	0.08	0.09	0.43	0.00	0.43

Control Livers ppm dry wt. (PCB n = 17; metal n =20) Date :05/2000

Contaminant	Mean	Standard Error	Median	Standard Deviation	Range	Minimum	Maximum
PCB	7.77	1.03	7.06	4.25	14.11	2.17	16.29
Hg	1.22	0.12	1.21	0.52	1.68	0.54	2.23
Al	1.47	0.75	0.10	3.37	10.04	0.10	10.13
V	0.67	0.07	0.59	0.31	1.24	0.31	1.55
Cr	0.41	0.02	0.38	0.07	0.22	0.33	0.54
Fe	601	82.27	506	368	1302	92.22	1395
Co	0.07	0.02	0.05	0.07	0.27	0.03	0.31
Ni	0.09	0.02	0.08	0.07	0.36	0.02	0.38
Cu	4.89	0.15	5.00	0.69	2.66	3.70	6.35
Zn	45.60	2.30	47.39	10.28	46.31	13.25	59.56
As	0.63	0.05	0.59	0.24	0.81	0.34	1.15
Se	1.47	0.13	1.39	0.59	3.02	0.46	3.49
Rb	2.31	0.11	2.28	0.50	1.87	1.39	3.26
Sr	0.52	0.07	0.43	0.30	1.24	0.23	1.47
Mn	4.04	0.24	4.07	1.08	5.03	0.50	5.52
Ba	0.05	0.00	0.04	0.02	0.08	0.02	0.10
Pb	0.17	0.03	0.12	0.12	0.39	0.06	0.46

LCP Livers ppm dry wt. (PCB n = 17; metals n = 20) Date :05/2002

Contaminant	Mean	Standard Error	Median	Standard Deviation	Range	Minimum	Maximum
PCB	381	168	126	772	3482	8	3490
Hg	22.03	3.46	19.83	16.23	74.61	3.27	77.88
Al	17.85	3.05	13.29	14.33	51.14	2.12	53.26
V	3.46	0.51	2.63	2.40	9.07	1.14	10.21
Cr	1.62	0.32	0.99	1.52	6.36	0.24	6.60
Fe	1404	400	898	1878	9066	382	9448
Co	0.18	0.01	0.18	0.06	0.21	0.07	0.28
Ni	0.25	0.03	0.23	0.13	0.54	0.07	0.61
Cu	16.63	1.10	15.02	5.16	18.15	10.24	28.39
Zn	142	7.60	138	35.65	172	81.54	254
As	3.03	0.36	2.78	1.67	6.20	0.88	7.07
Se	10.01	1.28	7.94	6.00	28.38	4.25	32.63
Rb	8.20	0.41	8.01	1.90	8.35	3.48	11.83
Sr	2.63	0.64	1.65	2.98	13.17	0.54	13.71
Mn	12.07	0.60	12.06	2.80	9.92	7.12	17.04
Ba	0.26	0.06	0.16	0.30	1.22	0.05	1.27
Pb	0.23	0.03	0.19	0.15	0.58	0.00	0.58

Control Chicks ppm dry wt. (n = 18) Date :05/2000

Contaminant	Mean	Standard Error	Median	Standard Deviation	Range	Minimum	Maximum
PCB	31.88	6.31	25.76	26.76	105	9.29	114
Hg	1.98	0.32	1.51	1.37	4.63	0.77	5.40
Al	17.68	5.82	10.96	24.70	109	7.05	116
V	0.26	0.02	0.26	0.10	0.46	0.04	0.50
Cr	3.10	0.18	3.08	0.76	2.49	2.09	4.58
Fe	9.24	2.51	6.30	10.64	48.07	1.88	49.95
Co	11.41	1.16	11.75	4.92	16.10	3.81	19.91
Ni	120	7.58	113	32.17	120	84.66	204
Cu	115	7.38	108	31.31	116	81.97	198
Zn	2.39	0.08	2.30	0.34	1.24	1.93	3.17
As	4.32	0.12	4.25	0.52	2.00	3.67	5.67
Se	0.06	0.02	0.03	0.11	0.38	0.01	0.39
Rb	0.04	0.02	0.01	0.08	0.27	0.00	0.27
Sr	0.97	0.15	0.75	0.66	2.87	0.39	3.26
Mn	0.08	0.01	0.08	0.05	0.19	0.00	0.19
Ba	2.00	0.33	1.51	1.38	4.67	0.77	5.44
Pb	1.99	0.32	1.51	1.37	4.63	0.77	5.40

LCP Chicks ppm; dry wt. (n = 57) Date :05/2000

Contaminant	Mean	Standard Error	Median	Standard Deviation	Range	Minimum	Maximum
PCB	147	19.18	81.77	145	646	13.94	660
Hg	4.32	0.25	4.22	1.85	8.66	1.22	9.88
Al	15.54	1.48	11.95	11.15	56.87	4.41	61.28
V	0.28	0.01	0.28	0.08	0.45	0.04	0.49
Cr	3.66	0.13	3.49	1.02	4.79	2.25	7.04
Fe	9.24	1.17	6.70	8.80	44.85	1.45	46.29
Co	12.65	2.87	7.58	21.70	166	3.96	169
Ni	117	4.49	109	33.90	222	80.22	302
Cu	115	4.90	106	36.98	232	76.54	309
Zn	2.33	0.05	2.38	0.37	2.15	1.42	3.57
As	4.23	0.10	4.32	0.77	3.29	2.75	6.04
Se	0.09	0.02	0.02	0.15	0.74	0.01	0.74
Rb	0.05	0.01	0.01	0.10	0.53	0.00	0.54
Sr	0.91	0.09	0.77	0.66	3.83	0.29	4.11
Mn	0.11	0.01	0.08	0.10	0.53	0.00	0.53
Ba	4.34	0.24	4.20	1.79	8.43	1.39	9.82
Pb	4.33	0.24	4.22	1.80	8.49	1.40	9.88