Contaminant Levels and their Effects in Birds Breeding in the Hackensack Meadowlands

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New Jersey Meadowlands Commission
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EXECUTIVE SUMMARY

The Meadowlands is a diverse mosaic of habitats that includes tidal, brackish, freshwater and forested wetlands within an urban landscape. The New Jersey Meadowlands Commission, in its Natural Environment System Plan, has set promoting suitable land use practices that are compatible with preserving and enhancing wetlands, other valuable natural resources and open space in the Meadowlands District as one of its primary missions. However, because of persistent sources of contaminants in the District, these valuable habitats are perceived by some as creating an “attractive nuisance” by drawing and exposing wildlife to high levels of toxic chemicals. Birds are likely to be especially susceptible, as they are mobile and can colonize habitats fairly rapidly. Contaminant exposure can negatively affect reproduction, egg hatchability, nestling survivorship and growth of bird species. Contaminants of concern in the District include the metals arsenic, cadmium, chromium, mercury, lead and organic chemicals such as polychlorinated biphenyls (PCBs), dichlorodiphenyl-trichloroethane (DDT) and its derivatives, and several other pesticide compounds.

In 2006 we initiated a two-year project to determine contaminant levels and their effects on breeding birds in wetland habitats of the Meadowlands District. Specifically, our objectives were to (1) determine contaminant levels in feathers, eggs, and blood of several avian species breeding in wetland habitats of the District; (2) investigate patterns and correlations in tissue contaminant levels and breeding success of birds; (3) examine differences in contaminant levels of avian tissues at different sites and habitats in the District and (4) compare these levels with those reported elsewhere.

We collected field data on nestling growth and nest success, as well as contaminants in eggs, nestling feathers and nestling blood from three passerine species, Red-winged Blackbird (*Agelaius phoeniceus*), Marsh Wren (*Cistothorus palustris*), and Tree Swallow (*Tachycineta bicolor*). These species are abundant in wetland habitats across the Meadowlands District. Red-winged Blackbirds, Marsh Wrens, and Tree Swallows were selected because their diet consists of insects and other invertebrates which are at an intermediate trophic level and likely to be affected by biomagnification. In addition, we collected tissue samples from Canada Geese (*Branta canadensis*), and eggs from Mallards ((*Anas platyrhynchos*), two species that forages at a lower trophic level and can be used in comparisons with higher trophic level species. During the 2006 breeding season, 128 Red-winged Blackbird and 374 Marsh Wren nests were located, of which 69 and 46 were active, respectively. Red-winged Blackbird nests were located at Harrier Meadow, Kearny Marsh, and Marsh Resources, while Marsh Wren nests were primarily located at Marsh Resources and Riverbend Marsh, with a few found at Kearny Marsh. During the 2007 breeding season, 172 Red-winged Blackbird and 278 Marsh Wren nests were located, of which 144 and 51 were active, respectively. Red-winged Blackbird nests were located at the same sites as 2006, while Marsh Wren nests were located at Marsh Resources and Kearny Marsh. Also in 2007, we monitored 80 active Tree Swallow nests that were located at Dekorte Park, Mill Creek, Kearny Marsh and Marsh Resources. We monitored nest success, weighed all the nestlings regularly and measured morphometric variables. We collected one egg from each nest when possible and when

nestlings were old enough, we collected feathers and blood samples from each individual young. With assistance from the USDA, we collected eggs and samples of tissue (breast, liver, and feathers) from adult and juvenile Canada Geese. These samples were collected from Mill Creek, Skeetkill, and Harrier Meadow.

Lead (Pb) levels were low in eggs, higher in feathers and very elevated in blood in all passerine species from which samples were collected. Lead levels were especially high in wren blood samples with averages as high as 1.3 ppm at Riverbend and 0.8 ppm at Marsh Resources, values above the threshold level of 0.4 ppm where one would anticipate negative impacts (Eisler 1985). While in 2007 there was a decrease in average Pb levels, with an average of 0.4 ppm in Marsh Wren and 0.2 ppm in Tree Swallow, the maximum Pb values were still high at 3.9 ppm and 2.1 ppm for these two species respectively. Finally Red-winged Blackbirds had similar blood Pb levels during the two years of the study, with an average of 0.45 ppm and a maximum of 2.6 ppm.

We found a negative correlation between blood lead levels and body weight in Marsh Wrens in 2006 and in Tree Swallows in 2007. This is the type of sublethal effect we would anticipate when contaminant concentrations are high, but not high enough to cause nestling mortality. We did not observe any obvious signs of lead poisoning, and most of the chicks with high lead values fledged successfully. However, lower body weights at fledging can result in lower juvenile survival.

Mercury (Hg), while below the levels considered biologically harmful were higher in eggs and feathers of Meadowlands birds than those seen in other studies in passerines and even in some fish eating birds. Even though the egg levels of mercury were below those reported in the literature to have an effect on hatching, we found that unhatched Marsh Wren eggs had higher mercury levels than randomly collected eggs. Therefore, by impacting hatching success mercury contamination may potentially be impacting reproduction in Meadowlands passerines. Blood levels of Hg were low in all three species, in agreement with those measured in nestlings in other studies.

Chromium (Cr) levels were relatively high in eggs and in blood, but lower in feathers when compared to those reported in the literature. Cadmium and arsenic levels were generally low for all tissues and in all species studied compared to those measured in other studies and below the levels that are considered biologically harmful.

We found few effects of site on breeding success and metal levels and these were not consistent among sites, tissues or metals. For example, Red-winged Blackbirds and Marsh Wrens had higher Hg levels in eggs at Marsh Resources in 2007, but no difference was seen among sites in Hg levels in feathers or blood of these two species. Blood Pb levels in nestlings of both these species were higher at Kearny Marsh, while Tree Swallows had higher Hg levels at Mill Creek than at the other sites sampled. Habitat differences in metal levels were more apparent, specifically lower Hg in eggs and lower Pb in blood of Marsh Wrens.in *Phragmites* than in *Spartina.* While *Phragmites* does not provide the best substrate and fledging success is lower in this habitat, metal bioavailability and therefore body contaminant loads may also be lower in this habitat.

This complex interaction of habitat, contaminant level and nesting success should be further explored.

Levels of Pb generally decreased in tissues as the season progressed, while Hg levels generally increased, except for in Marsh Wrens where Hg levels decreased. It is not clear why Hg levels increase while Pb decreases and how these patterns relate to bioavailability of metals or sequestering in feathers and eggs. These patterns of metal concentrations in wildlife tissues may have significant management implications and should be further explored.

Increased lead levels in Canada Goose feathers, liver and eggs with averages of 1.9 ppm, 0.25 ppm and 0.16 ppm respectively, are surprising and may be of concern. Muscle tissue lead was not as high, but we believe that further study is needed to determine whether muscle Pb levels in non-molting birds may be high enough to be of concern to human consumption. It is not clear why Pb levels were elevated, but waterfowl are known to accumulate Pb levels due to ingestion of lead sinkers and shot. More study is needed to understand the source of Pb in Geese in the Meadowlands District.

Finally, all metal levels for Tree Swallow tissues in our study were much lower than those reported for this species at the Meadowlands District in the 1980s. In addition, most metal levels were lower in 2007 than in 2006. Furthermore, we did not see any obvious signs of contaminant poisoning.

Pollution levels are high throughout the NY/NJ Harbor and we do not know how the metal levels measured in passerine bird tissues in Meadowlands relate to those in other sites in the region. We believe that the passerine species that we studied provide a good model for monitoring metal contaminants in this area. This study should be followed up with more monitoring, especially in view of impending clean-up and restoration projects. Tree Swallows, particularly, can be used to look at heavy metal levels and their impacts on reproduction and growth, because they nest in artificial boxes that can be placed in targeted locations and easily monitored.

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GOALS AND OBJECTIVES

The goal of this project was to assess the potential effects of contaminants on birds breeding in the Meadowlands District. Results of this study will help the New Jersey Meadowlands Commission (NJMC) address concerns related to levels of contaminant levels and their effects on wildlife to meet the environmental and land use goals described in the NJMC Master Plan. Specifically, our objectives were to (1) determine contaminant levels in feathers, eggs, and blood of several avian species breeding in wetland habitats of the District; (2) investigate patterns and correlations in tissue contaminant levels and breeding success of birds; (3) examine differences in contaminant levels of avian tissues at different sites and habitats in the District and (4) compare these levels with those reported elsewhere.

BACKGROUND

The Meadowlands and its expansive wetlands have long been recognized as a critical resource for wildlife, especially birds. Given its location amidst a highly urbanized landscape, its importance as an oasis for wildlife cannot be overlooked. The Meadowlands is a diverse mosaic of habitats that includes tidal, brackish, freshwater and forested wetlands. The District is home to many breeding bird species, several of which are listed as "endangered" or "threatened" by the State of New Jersey. The U.S. Fish and Wildlife Service designated the Meadowlands/Hudson River Complex as part of New Jersey's North Atlantic Coast Waterfowl Focus Area. Nonprofit conservation organizations have worked diligently over the last three decades to raise public and government agency awareness of the incredible natural resource value of the Meadowlands. Finally, the NJMC, recognizing the District's value to wildlife, made preservation and restoration of open space a high priority in its Master Plan.

NJMC's goal to promote suitable land use practices that are compatible with preserving and enhancing wetlands, other valuable natural resources and open space in the Meadowlands District is innovative and ambitious. The Commission, in its Natural Environment System Plan, Strategy 1, has articulated a clear set of objectives that have great potential to realize the primary mission. Nearly all of the objectives, however, are dependent on information about the abundance and distribution of wildlife, especially high priority species identified by New Jersey Division of Fish and Wildlife.

Large industrial facilities including paint and pigment manufacturing plants, and petroleum and chemical refineries, have been located along the banks of the Hackensack River since the industrial revolution. Effluent from these facilities has caused severe contamination of sediments in Meadowlands wetlands. Although the majority of the industrial facilities in the study area have been shut down, and the water quality in the Hackensack River and the overall NY/NJ Harbor Estuary has improved since the 1970s, high contaminant levels may persist in sediments at some wetlands in the Meadowlands District (Steinberg et al. 2004).

Contaminants of concern in this area include the metals arsenic, cadmium, chromium, mercury, and lead, organic chemicals such as polychlorinated biphenyls (PCBs), dichlorodiphenyl-trichloroethane (DDT) and its derivatives, and several other pesticide compounds (USFWS 2005, ENSR International 2004). These chemicals bioaccumulate, that is, their concentration increases over time in an individual's tissues, compared to the chemical's concentration in the environment. Furthermore, organic compounds and methylmercury are of special interest because they biomagnify as predators ingest them in increasingly large amounts (Weis 2005, Burger 2002). A contaminant that is not found in high concentrations in the water or the sediments can potentially be found in harmful concentrations in tissues of higher level consumers due to biomagnification, with increasing risk to organisms at the top of the food webs. Contaminant exposure can have negative effects on reproduction, egg hatchability, hatchling survivorship and neurobehavioral development (Burger and Gochfeld 2000a, Bouton et al. 1999, Custer et al. 1999, Ohlendorf et al. 1989, Heinz 1974).

Restored wetlands and landfills in the Meadowlands urban estuary can enhance the quality of the urban landscape and improve habitat for fish and wildlife, thereby increasing the public's opportunities for wildlife viewing and their appreciation for nature. However, because of persistent sources of contaminants in the District, these restored habitats also may create an "attractive nuisance" by drawing fish and other wildlife to areas that still have high levels of toxic chemicals. Birds are especially susceptible, as they are mobile and can colonize new habitats fairly rapidly. It has been hypothesized that birds attracted to newly created habitats in a polluted area may be unable to successfully reproduce because of exposure to high contaminant levels. Thus, these new habitats can have adverse effects on the bird populations using them.

In this study, we investigated contaminant levels in birds breeding in the Meadowlands District. We hypothesized that reproduction and growth could be negatively correlated to contaminant levels. That is, as contaminant levels increase in the birds, reproductive success (e.g., egg hatchability, hatchling survival) and hatchling growth rates would decrease. Furthermore, we hypothesized that contaminant levels may be positively correlated with trophic level resulting in greater contaminant concentrations in birds that are higher on the food chain. We expect this to be especially apparent at sites considered to be of "substantial concern" because of existing high contaminant levels, such as Kearny Marsh and Riverbend Preserve (USFWS 2005).

METHODS

Our overall protocol was to collect eggs, feathers, and blood from passerine species breeding in wetlands of the Meadowlands District, as well as to collect information on reproductive success and growth of these birds to determine whether contaminants may have some impact on their populations. In addition, in 2006 we collected eggs from Mallards (*Anas platyrhynchos*) opportunistically and in 2007 we focused the effort and collected eggs, feathers, muscle and liver tissue from Canada Geese (*Branta canadensis*) throughout the District to explore contaminant levels in resident waterfowl of the Meadowlands. We did not collect any other biological data on Geese or Mallards.

Species selection and study sites

In 2006, we collected data primarily on Red-winged Blackbirds (*Agelaius phoeniceus*) and Marsh Wrens (*Cistothorus palustris*; Table 1); species selected because their diet consists of insects and other invertebrates, and, therefore, they are at a trophic level likely to be affected by biomagnification. We also collected data on these two species in 2007 (Table 1A). These species are abundant in wetland habitats across the Meadowlands District. Red-winged Blackbird nesting activity peaks in late May and early June, with most of the young fledging by early July. Marsh Wren nesting peaks in July, with most of the chicks fledging by mid-August.

Like the other two passerines, Tree Swallows are an insectivorous species. Their contaminant levels and biology have been widely studied in the Northeast, including a study by Kraus (1989) in the Meadowlands. Tree Swallows initiate nesting in early May and fledge by mid-July. In 2006, due to issues of nest box design and access, we collected only a small number of blood and feather samples from Tree Swallows (*Tachycineta bicolor*; Table 1). In 2007 we worked closely with NJMC staff on building and placing swallow nest boxes throughout the Meadowlands District and were thus able to increase our collection effort on this species. Approximately 24 easy to open nest boxes were placed at each site before the start of the breeding season (Table 1A).

Finally, a small number of eggs were collected opportunistically from Mallards, a mostly herbivorous species, in 2006 and eggs, feather, muscle and liver tissue were collected from Canada Geese in 2007. We had originally proposed to collect tissue samples from Yellow-crowned Night-Herons (*Nyctanassa violacea*), but because of logistical constraints and issues relating to access and disturbance, it was decided that we would not pursue this.

We conducted our research at seven sites within the District. These sites included Harrier Meadow, Kearny Freshwater Marsh, Marsh Resources Meadowlands Mitigation Bank (Marsh Resources), Riverbend Wetlands Preserve (Riverbend), DeKorte Park, Mill Creek Marsh and Skeetkill Marsh (see Appendix 2). Of these sites only Riverbend was not visited both years due to logistical constraints. In addition, we attempted to collect data at Sawmill WMA but nests at this site were mostly inaccessible and the site itself was dangerous to walk in and navigate because of the soft mud sediment. This site was, therefore, dropped from monitoring due to researcher safety concerns.

Harrier Meadow is a restored tidal marsh surrounded by tidal mudflats on two sides and urban development and landfill on the remaining two sides. During restoration, three large, tidally influenced open-water areas surrounded by high-marsh and fringe-upland vegetation were created. This site is different than the other restored marsh sites in the Meadowlands because it was constructed on top of rubble and other hard materials.

Kearny Marsh is a freshwater impoundment, dominated by *Phragmites,* and was only accessible by water. We used an electric motor mounted on the back of a canoe to travel around this site. This proved essential as strong wind in the open water areas of this site made it impossible to efficiently survey by paddling.

Marsh Resources Meadowlands Mitigation Bank is a restored tidal marsh. The low marsh areas are dominated by smooth cordgrass (*Spartina alterniflora*), dwarf spike rush (*Eleocharis parvula*) and marsh fleabane (*Pluchea odonatas*). The high marsh areas are dominated by saltmarsh hay (*Spartina patens*), spikegrass (*Distichlis spicata*) and groundseltree (*Baccharis halmifolia*). Access to this site was somewhat limited because the gate was open only during business hours and access by canoe in the tidal channels was limited to the two hours before and after high tide. In 2006, we were only able to visit this site every 2-4 days. In 2007, we were able to access the site almost daily from late-June until mid-August.

Riverbend Wetlands Preserve consists of high saltmarsh vegetation, primarily *Spartina patens*, and areas dominated by common reed (*Phragmites australis*) and open water. Access to Riverbend was provided on the NJMC boat that had enough power to cross the Hackensack River from the launch site. Once we reached this site, the ground was solid enough to climb onto the creek banks from the boat and nest search on foot. We were not able to visit all the nests as often as we had hoped due to boat scheduling limitations. Sometimes we had to wait seven days or more between nest checks.

DeKorte Park consists of *Phragmites* stands interspersed with open water. The site receives water from both Sawmill Creek and Kingsland Creek and water levels are controlled for wildlife habitat and recreational use.

Mill Creek is a restored site that contains low marsh habitats that are flushed daily with the tides, lowland scrub-shrub habitats and open water. During restoration dredge material was excavated, tidal flow re-established, and the surface was graded to provide low marsh and upland habitat. Only Tree Swallow nest boxes were monitored at DeKorte Park and Mill Creek Marsh.

Finally, we collected only Canada Goose tissues at Skeetkill Creek Marsh. This marsh includes about 16 acres within the industrial section of Ridgefield. Before the NJMC acquired the site, it was largely a dense monoculture of phragmites, with very little open water or tidal flow. Enhancement projects at the site included the creation of tidal channels, open water, low marsh habitat and upland islands.

Field survey methods

We monitored nests following protocols used by Martin and Geupel (1993) and Spautz et al. (2003) in San Francisco Bay, and included techniques to minimize disturbance to the birds and habitat. We collected data during egg laying, incubation, hatching and nestling periods by following the success of marked nests. Nests generally were monitored at 2-4 day intervals to determine hatching and fledging dates and overall nest survival. Nest contents were recorded at each visit, and notes were made of missing or predated eggs and nestlings. For numbers of eggs collected, nests monitored, etc. see results section below. During the 2006 field season we noticed some possible differences between nests in different habitat types, therefore we added the collection of nest substrate information in 2007.

All eggs collected from each nest were weighed and measured for length and width. One fresh egg was collected from a subset of nests for contaminants analysis under appropriate USFWS permits. Freshness was determined by floating the egg in water when the age of the nest was unknown. For Marsh Wrens, counting eggs and pulling nestlings out of the dome shaped nests proved challenging and potentially destructive. To minimize disturbance to the nest structure, we only measured the egg we collected for contaminants analysis.

Collected eggs were wrapped in aluminum foil, labeled and placed in a protected container in a cooler. Eggs were refrigerated up to one week until transfer to the Elemental Laboratory at the Environmental and Occupational Health Sciences Institute (EOHSI) in Piscataway, New Jersey.

For nests found with nestlings already present, we determined the nestlings age based on wing chord measurements and degree of eye opening (Holcomb and Twiest 1971; Appendix 1). Nestlings were marked with U.S. Geological Survey bands just before fledging. Marsh Wren nestlings were banded at 9-11 days old, Red-winged Blackbirds at 8-9 days old, and Tree Swallows at 13-16 days old.

We made the following morphometric measurements on nestlings: body mass (nearest 0.1 g), right and left wing chord (mm), culmen length (mm), right and left gape (mm), and right and left nare to bill tip (mm). When possible, nestlings were measured several times during the nestling stage to monitor growth patterns and possible fluctuating asymmetry. Marsh Wren nestlings, however, were measured only once to minimize disturbance to the nest structure as mentioned above. When nestlings were banded, we took morphological measurements, blood and feather samples. Blood samples for Red-winged Blackbirds could be collected at an earlier age (i.e., 6-7 days), but these nestlings were often not developed enough for banding or feather collection until 8-10 days old.

In keeping with humane practice guidelines (Gaunt and Oring 1997), no more than 1% of the body weight of blood was obtained per nestling. Blood samples were collected in 70µl Micro-Hematocrit tubes (Fisher Scientific, Pittsburgh PA) after puncturing the brachial vein using a 26-gauge needle (Becton Dickinson and Company, Franklin Lakes, NJ). Tubes were placed in individually labeled non-additive glass Vacutainer® (Fisher Scientific, Pittsburgh, PA) tubes. The Vacutainer® tubes were placed upright on ice and frozen the same day, until transport to the EOHSI laboratory. Feather samples were pulled from the breast of each nestling and were pooled by nest. Feathers were placed in labeled envelopes and stored in a light-inhibiting box until transport to the EOHSI laboratory. In 2006 a total of 115 blood samples, 72 egg samples and 49 feather samples were collected and in 2007 a total of 300 blood samples, 191 eggs, and 88 feather samples were analyzed (Tables 1 and 1A).

Nest searching was time intensive, especially for Marsh Wrens, because of the large number of nests they build which are not used for breeding purposes (Kroodsma and Verner, 1997). Also, many wren nests were located in difficult marsh terrain, making monitoring an especially arduous and lengthy process. For example, most Marsh Wren nests at Kearny were located in the interior of large areas of thick *Phragmites* that could not be accessed by canoe, and nests at Sawmill Creek were mostly located on *Spartina* stands in soft mud. Furthermore, access to sites where boat transportation was required was limited due to boat availability (Riverbend) and tides (Marsh Resources) and therefore some wren nests fledged prior to sample collection. In addition, Marsh Wren nests tended to be difficult to access and precariously built. For this reason, we were only able to follow a fraction of the total number of nests found.

Metal analysis

Blood samples were frozen, and eggs were refrigerated until they could be transported to the Elemental Laboratory at the Environmental and Occupational Health Sciences Institute (EOHSI) in Piscataway, New Jersey. Feathers were kept in envelopes at room temperature. All samples were analyzed for levels of the heavy metals cadmium, chromium, lead, mercury, and arsenic. Cadmium, lead, and mercury were examined because they are the major contaminants of concern in marine environments (Burger and Gochfeld 2004, Fowler 1990, Spahn and Sherry 1999). Arsenic has been a concern for wildlife in marine and estuarine ecosystems (Neff 1997). Chromium contamination is high within the NY/NJ Harbor region because of chromite processing facilities in Hudson County and chromium waste sites close to Newark Bay (Burke et al. 1991). Our study measured only total chromium, but we believe that using improved analytic methods for quantifying hexavalent chromium would be helpful.

Mercury was analyzed by cold vapor atomic absorption spectrophotometry as total mercury, of which about 85-90% is assumed to be methylmercury (Burger and Gochfeld 2004, Wolfe and Norman 1998). Other metals were analyzed by graphite furnace (flameless) atomic absorption. Whole egg contents were homogenized, dried and digested individually in 70% nitric acid within microwave vessels using a digestion protocol of three stages of 10 min each under 50, 100, and 150 pounds per square inch (10.6 kg/sq cm) at 70X power and subsequently diluted with deionized water. Instrument detection limits are 0.02 ppb for arsenic and cadmium, 0.08 ppb for chromium, 0.15 ppb for lead, and 0.2 ppb for mercury. The “DORM” was used only for mercury and should read 4,600 ppb. All specimens were run in batches that include a standard calibration curve and spiked specimens for QA/QC. Calibration was established using a standard and checked with a reference material. Acceptable recovery for the reference material was between 90 and 110% or the calibration was rejected and we replaced the graphite tube and recalibrated. Spiked blank and matrix specimens were used to monitor assay performance. Approximately 5-10% of samples in each run consisted of replicates, blanks or DORM-2. Metals levels for eggs were analyzed as dry weight, however both dry and wet weight are reported for easier comparisons with other values from published literature. For samples where contaminant levels were below detection limits, we assigned a value of half the detection limit as the contaminant concentration in statistical analyses.

Organic contaminant analysis

Six Mallard eggs were analyzed for chlorinated organic compounds at the Meadowlands Environmental Research Institute (MERI) lab using Gas Chromatography. For extraction, samples were thawed and 5g (wet weight) of egg homogenate were sub-sampled using a stainless steel spatula. Approximately 30g of Na_2SO_4 (previously baked, cleaned with hexane and dried) was added to the sub-sample to absorb water. Sample preparation was performed by mixing of the homogenate with 16g ASE Prep DE (Diatomaceous Earth®, Dionex). A 66mL extraction cell was loaded by inserting a disposable cellulose filter in the cell outlet, followed by 3g of thin layer of activated florisil® (60-100mesh, J.T. Baker). A second disposable cellulose filter was inserted after the spike surrogate and the sample.

After extraction, samples were cleaned up by GPC (US EPA Method 3640A) to minimize the interference from sulfur, lipids, phthalates etc. in biota sample before analysis. The collected fraction containing analytes was concentrated by rotary evaporation and a N_2 stream. Solid-liquid chromatography using florisil was performed as an additional clean-up step. Using this technique, PCBs were eluted from the chromatographic column containing florisil using petroleum ether (F1 fraction). The remaining organochlorine pesticides were eluted using 50:50 petroleum ether and dichloromethane (F2 fraction). The fractions were concentrated to about 0.5mL using rotary evaporation.

Congener-specific PCBs and organochlorine pesticides were analyzed using a GC/ECD (Agilent 6890 Gas Chromatograph equipped with a ^{63}Ni Electron Capture Detector) (US EPA Method 8081) with a 5% phenyl-methylpolysiloxane capillary column (60m x 0.25mm x 0.25µm). Twelve PCB congeners were identified and quantified based on comparisons (retention times and peak areas) with a known calibration standard (Accustandard, CT) prepared from individual congeners. Organochlorine pesticides (OCPs), including Heptachlor, Aldrin, Endosulfan, Dieldrin, Endrin, and Methoxychlor.were identified and quantified based on comparisons (retention times and peak areas) with a known calibration standard (Accustandard, CT) prepared from individual compounds. The concentrations of PCBs were analyzed by the relative internal standard response factor (RRF) method as outlined by EPA method 8081. Each sample was spiked with internal standards (2,4,6-trichlorobiphenyl, IUPAC no. 30, 2,2´,3,4,4´,5,6,6´-octachlorobiphenyl, IUPAC no. 204).

Appropriate quality assurance and control was included by surrogate recoveries, calculation of QC blank based detection limits, and spike recovery.
The QC blank ranged from 0.1-0.5ng of PCB from 12 congeners. Recovery of surrogates showed constant numbers (95± 10%), so reported data were not corrected by analytical recoveries of surrogate PCB standards, but they were corrected by blank.

Data analysis

Nests were considered successful when nestlings were alive to at least 3 days before their estimated fledge date, unless they were found dead upon final nest inspection. We considered Red-winged Blackbird nests successful when nestlings were last seen alive at 7 days of age (typical fledge at age 10 days) or if there was evidence of post-fledging activity. We considered Marsh Wren nests successful when nestlings were alive at 10 or 11 days of age (typically fledge at age 14-15 days) or if there was evidence of post-fledging activity. Marsh Wren nest failure in *Phragmites* was generally obvious because nests were destroyed by predators, fallen apart, or had nestlings dead inside due to drowning. We considered Tree Swallow nests successful when nestlings were alive at 13 or 14 days of age (typically fledge at age 16-17 days) or if there was evidence of post-fledging activity. One nest at DeKorte was last visited on day 12 in mid-July and we assume that it fledged successfully as there was no predation at this location during the latter part of the breeding season. Post fledging activity included the presence of fledged nestlings in close proximity to the nest, adult defensive behavior, and guano on the nest substrate or below the nest.

Nest survival probability was calculated using the program MARK (Cooch and White 2006) model for nest survival. MARK provides estimates of daily survival rates (DSR) based on the Mayfield method (1975). This analysis corrects for nests that survive to a certain point but eventually fail and for nests found later in the season where early nest history is unknown. When analyzed without these corrections, nest success estimates can be biased. MARK computes Akaike Information Criterion (AIC) for each model, a measure of the goodness of fit of an estimated statistical model. When the difference between two models (ΔAIC) is greater than 2 there is strong evidence to support differences between the models (Cooch and White 2006). Furthermore AIC weights are used to show how much more strongly supported each model is from the next most parsimonious one. Nest survival was modeled with the covariates site, date during the nesting season, nest age, nest stage (egg or nestling) and metal levels.

We calculated the nest survival probabilities at each site based on daily survival rates and the number of days it takes from initiation of incubation to fledging. The duration of incubation and nesting periods was considered to be 19-24 days for Red-winged Blackbirds (Yasukawa and Searcy 1995, Ehrlich et al. 1988) and 25-32 days for Marsh Wrens (Kroodsma and Verner 1997, Ehrlich et al. 1988). We calculated ‘apparent’ nesting success as the percentage of nests that fledged young successfully.

Using SAS (PROC UNIVARIATE) we tested whether the metal levels in tissues were normally distributed. We used SAS (PROC GLM) to model the effects of year, location, and Julian date on the levels of each metal in collected tissues. For this analysis we modeled year, site and the interactive term of year*site as class variables and Julian date as a covariate. When year and date covariates did not contribute significantly to the model, data were collapsed for further statistical analyses.

Similarly, we modeled the effect of nest when we could collect sufficient volume of blood from all of the nestlings at each nest and could run metal assays separately for each blood sample. This way we could explore whether there were any differences in metal levels of blood in different nests within each site. When no nest differences were seen, we combined the data from all blood samples to explore site differences. When nest effects were found, we used the mean and the maximum values of contaminant levels by nest to explore site differences.

We used non-parametric procedures (PROC NPAR, Kruskal Wallis Chi-square test, SAS 2005) to determine species and site differences in heavy metal levels. We used these non-parametric tests because they are more conservative and are best fitted for small datasets. When significant differences were found, we used Duncan's multiple range tests (and log-transformed data when the data were not normally distributed) to explore which species and sites were different (Burger and Gochfeld 2003, 2004). We also used these tests to examine differences in heavy metal loads among the three tissue types (egg, blood, and feather) for each species.

We used similar non-parametric statistics to explore the effects of site and age on the measured morphometric parameters and to compare total numbers of eggs laid, eggs hatched and fledged nestlings of each species among sites. Given that we collected individual blood samples from nestlings at each nest, we tested whether blood contaminant levels and morphometric measures were significantly different among and within nests.

We reviewed metal contaminant levels to determine which contaminants occurred at levels that have negative biological impacts on avian species. We used the measured concentrations of those contaminants in multiple linear regression and correlation (SAS, PROC REG and PROC CORR) to explore relationships of body mass and fluctuating asymmetry (e.g., differences between the right and left side in wing length, culmen and gape) with contaminant levels and age. All data were explored for normal distribution and log-transformed as needed for the regression analysis. When significant relationships were found, the uniqueness index (Hatcher and Stepanski 1994) for each predictor variable was estimated to determine the variable's contribution to the model.

RESULTS

Nests located and number of samples collected

We mapped the location of all nests found during the study, including species from which we didn't collect tissue samples. Location of nests at all sites can be seen in Appendices 3-18.

Red-winged Blackbird

In 2006, we located 98 Red-winged Blackbird nests during our study of which 69 were active. In 2007, we found 172 Red-winged Blackbird nests of which 144 were active. A summary of species-specific nest locations, nest status (e.g., inactive, found with eggs, found with nestlings) and nest fate is presented in Tables 2-2A.

Of the 69 active Red-winged Blackbird nests in 2006, 15 were located at Harrier Meadow, 31 at Kearny Marsh, and 23 at Marsh Resources (Table 2). Forty-five nests found throughout the season remained inactive with no eggs or nestlings found. Inactive nests may have been previously active nests that already fledged young, may have been predated earlier in the season, or abandoned by the female. Yasukawa and Searcy (1995) report that non-breeding nests in this species do not occur. Of the 144 active Red-winged Blackbird nests in 2007, 36 were found at Harrier Meadow, 76 at Kearny Marsh, and 32 at Marsh Resources (Table 2A). Red-winged Blackbird nests were located in either *Phragmites* or groundseltree with the exception of three nests found in cattails (*Typha*, spp) at Kearny Marsh. Two nests were found in *Spartina* at Marsh Resources.

Marsh Wren

In 2006, we found 364 Marsh Wren nests. Of these, 46 were active: 5 nests at Kearny Marsh, 5 nests at Sawmill WMA, 13 nests at Riverbend and 23 nests at Marsh Resources (Table 2). We located 278 Marsh Wren nests in 2007, of which 51 were active: 13 active at Kearny Marsh and 38 at Marsh Resources (Table 2A). The Riverbend site was dropped due to logistical reasons. Even though some nests may have already fledged or been depredated, we found a large number of inactive nests that were probably ‘dummy’ nests. Male Marsh Wrens are known to build numerous nests that are not used by females for egg laying. These may serve as decoys for predators and as an indicator of male vigor or quality of his territory (Kroodsma and Verner 1997). In our study, we found approximately one active nest for every 10 inactive nests found. Consequently, we stopped marking dummy nests found during the study period because it became time consuming. Given this, the ratio of dummy to active nests was probably higher. All Marsh Wren nests were located in either *Phragmites* or *Spartina*.

Tree Swallow

We monitored 7 active Tree Swallow nests in 2006, all at DeKorte Park. In 2007 we monitored 80 active nests. Of these 7 were at Marsh Resources, 20 at DeKorte Park, 33 at Kearny Marsh, and 20 at Mill Creek. At both Kearny Marsh and Mill Creek additional nest boxes were used in the middle of the season because the predation rate on Tree Swallows was high resulting in very few successful nests.

Total number of egg, feather and blood samples is not necessarily equal to the total number of nests found or the total number of successful nests, so refer to each Table for specific sample sizes. For example, some nests could not be sampled, and some samples could not be processed in the lab because of their condition or because there was not sufficient volume.

Nesting success and productivity

Productivity

We found no differences in numbers of eggs hatched or nestlings fledged between nests in which an egg had been collected and ones where no eggs were collected, so we analyzed all productivity data together. Total numbers of eggs laid, eggs hatched and nestlings fledged are presented in Tables 3 and 3A. Fledging success was similar to that reported in other studies for Marsh Wrens (Kroodsma and Verner, 1997), and on the lower part of the range reported for Red-winged Blackbirds (Yasukawa and Searcy

1995).

There were no differences between sites in numbers of eggs laid or hatched for either Red-winged Blackbirds or Marsh Wrens in 2006. However, we found differences between sites in numbers of Red-winged Blackbird nestlings fledged (Kruskal-Wallis Chi-square = 7.81, p=0.02) during the first year of the study. Harrier Meadow and Kearny Marsh were not significantly different from each other, but both had higher fledging success than Marsh Resources. Since we collected eggs from only some of the nests, we used a correction factor and re-ran the analysis to determine if this difference would persist if eggs were collected from all nests. Specifically for nests that fledged successfully without having an egg removed, we subtracted one from the number fledged. The effect of "site" persisted (Chi-square = 6.57 p = 0.037), with Marsh Resources once again having the lowest productivity.

There was an effect of 'site' on hatching success of Red-winged Blackbirds again in 2007 and also an effect of 'nest substrate' on hatching and fledging success in this species (F = 4.19, p = 0.0075, and F = 2.97, p = 0.034 respectively). Habitat effects were driven by very low hatching and fledging success in *Phragmites* vs groundsel habitat at Marsh Resources (Kruskal-Wallis Chi-square = 4.54, p=0.03 and Chi-square = 7.00, p = 0.0081, for number of eggs hatched and nestlings fledged respectively). In 2007, blackbird nests in Marsh Resources were more successful than at other sites. Similarly, we found an effect of nest habitat on fledging success in Marsh Wren at Marsh Resources in 2007 with lower number of nestlings fledged in *Phragmites* than in *Spartina* habitat (F = 5.1, p = 0.03). There were no differences among sites in Tree Swallows.

Daily survival rate analysis

Mayfield nest success modeling revealed that daily survival rates (DSR) in Marsh Wrens are influenced by nest age and nesting stage (Table 4). This is in agreement with our field experience that nests that were close to hatching seemed to survive better, as did nests with hatched nestlings. However, we had many nests that were destroyed in the egg or early nestling stage due to inclement weather, so there may be confounding factors having to do with weather patterns during the specific year of the study, rather than the biology of the species, and these need to be explored further. Another possible cause of nest failure for Red-winged Blackbirds and Marsh Wrens is the nest destruction by Marsh Wrens. Male Marsh Wrens are known for their aggressive breeding behavior. They are known for destroying eggs of other wrens and Red-winged Blackbirds (Kroodsma and Verner 1997). Some of our failed nests could have been a result of this behavior as we found nests that had previously contained eggs empty, but not destroyed on the next visit. This could have been a result of predation by snakes or another bird, but also by the removal of the eggs by aggressive Marsh Wrens.

In 2006 we found no differences between sites and no effect of egg contaminant levels on DSR in either Red-winged Blackbird or Marsh Wren (Table 4). In 2007 we did see some effects (Tables 4A and 4B). In Tree Swallows, the model of DSR including "site" was the most supported model (ΔAIC = 10.68, Table 4A). Specifically, Mill Creek and Kearny Marsh survival rates (DSR = 0.9384 ± 0.0157 and 0.9384 ± 0.0128 respectively) were lower than DeKorte (0.9841 ± 0.0060), and those at Marsh Resources did not differ from any of the others (Table 5A). This is in agreement with our observations of high predation rates at Mill Creek and Kearny Marsh. In Red-winged Blackbird the most supported model was one that included a 'site+habitat' covariate (Table 4A). There were no differences between sites in nest survival in this species and the habitat effect was driven by higher survival rate of nests in Groundsel (0.9650 ± 0.0109) vs. *Phragmites* (0.8585 ± 0.0539) at Marsh Resources the only site where blackbirds were sampled in both habitats (Table 5A). For Marsh Wrens, DSR models that included the "site" or "habitat" covariate or a combination of the two were not supported better than the basic model (Tables 4A and 5A).

Since we did not collect and analyze eggs from all nests, we used the subset of the nests from which we obtained metals data to look at the effects of these contaminants on daily survival rate. Models including heavy metal levels in eggs as a covariate had no support, therefore there is no evidence that metal levels affected nest success (Table 4B). Even in cases where the AIC was lowest for the model that included metal contaminant levels, for example the model including Chromium (Cr) in Red-winged Blackbird and the models including Lead (Pb) and Mercury (Hg) in Marsh Wren, the ΔAICc between the basic model and the model with metals was not greater than 2 in any of our analyses, so there is no support for a real difference between the models (Burnham and Anderson 2002). In this smaller data set, there was again an effect of site on DSR in Tree Swallows with a ΔAIC = 8.09 between the basic model and the model containing the "site" variable. In addition, the model containing the levels of metal contaminants in combination with site was more strongly supported than the basic model (ΔAIC = 2.42), however the model including only "metals" was not strongly supported (Table 4B).

Heavy metal analysis

A summary of maximum, minimum and average levels of metals found during the study are found in Appendices 19-22, Tables 6-8 and Figures 1-3.

Levels of arsenic (As) ranged from not detectable (ND) to 86.8 ppb in eggs (wet weight) across all species, while levels of Cadmium (Cd) ranged from ND to 7.7 ppb (Appendix 19). Levels of As in feathers ranged between ND and 700 ppb, and in blood between ND and 95 ppb, while levels of Cd ranged between ND and 410 ppb and between ND and 214 ppb in feathers and blood respectively (Appendices 20-21). All the levels of Cd and As values were below biological significance (Eisler 1985, 1988; see discussion).

Levels of Chromium (Cr) in eggs of passerines ranged from a maximum of 681 ppb (wet weight) in Red-winged Blackbirds in 2006 down to ND. Levels of Cr in eggs of waterfowl (Canada Geese and Mallards) ranged from a maximum of 187.9 ppb (wet weight) down to a minimum of 6.37 ppb (Appendix 19). Chromium (Cr) in feathers of passerines ranged from a maximum of 4000 ppb in Tree Swallows in 2007 down to 140 ppb in Marsh Wren in 2007. Levels of Cr in feathers of Canada Geese ranged from a maximum of 4700 ppb down to a minimum of 330 ppb (Appendix 20). Chromium (Cr) in blood of passerines ranged from a maximum of 4595 ppb in Red-winged Blackbirds in 2006 down to ND for all species (Appendix 21).

Lead levels (Pb) in eggs ranged from not detectable (ND) to 116 ppb (wet weight) in Marsh Wren, ND to 154.2 ppb (wet weight) in Red-winged Blackbirds and 5.1 to 305.6 ppb (wet weight) in Tree Swallows. Among waterfowl, egg Pb levels were especially high in Canada Goose, ranging between 20.4 and 796.4 ppb (Appendix 19). Lead in feathers ranged from ND to a maximum of 1200 ppb in Marsh Wrens, 4500 ppb in Red-winged Blackbirds, 4276 ppb in Tree Swallows and 6800 ppb in Canada Goose (Appendix 20). Lead in blood ranged from ND to a maximum of 3900 ppb in Marsh Wrens, 2600 ppb in Red-winged Blackbirds, and 3529 ppb in Tree Swallows (Appendix 21).

Levels of egg mercury (Hg) ranged from 24.8 to 417.8 ppb (wet weight) in Marsh Wren, 4.2 to 193.2 ppb (wet weight) in Red-winged Blackbirds and 12.7 to 195.2 ppb (wet weight) in Tree Swallows (Appendix 19). Mercury in feathers ranged from ND to a maximum of 4584 ppb in Marsh Wren, 2331 ppb in Red-winged Blackbirds, 2882 ppb in Tree Swallows and 730 ppb in Canada Goose (Appendix 20). Finally, Hg in blood ranged from ND to a maximum of 347 ppb in Marsh Wren, 107 ppb in Red-winged Blackbirds and 158 ppb in Tree Swallows (Appendix 21).

We present below results on the interactions of location, year, habitat and species on metal levels in each tissue. Metal levels in tissues were in most cases not normally distributed for any of the species (SAS PROC UNIVARIATE Shapiro-Wilks statistic $p<0.001$), so non-parametric statistics were used for most comparisons and log-transformations were used in any parametric statistics. Since Cd and As values were below biological significance in both years these metals were included only in some of the analyses.

Eggs

We used the metal concentrations by wet weight in eggs in all the analyses below. However, for comparison with other studies that may use dry weight instead of wet weight measurements, we present both the wet weight and dry weight metal levels in Tables 6-8.

<u>Differences between years</u>

In Red-winged Blackbirds, there were significant differences between the two years of the study ($p < 0.05$) for Cr and for Pb with both metal concentrations higher in 2006 than 2007 (Table 6B). In Marsh Wrens all metal levels except As were different between years ($p < 0.05$), with Pb and Hg lower and Cr higher in 2007 (Table 6B). However, the effect of 'site' and the interactive term 'site by year' were not significant in the general linear model (PROC GLM) for either of these species for any of the metals. Therefore, we could combine data from the two years of the study in all subsequent comparisons between sites for these two species. Canada Geese and Tree Swallow eggs were only collected in 2007, and Mallard eggs only in 2006, so we do not have any by year comparisons for these three species.

Differences between sites

In 2006 there were no differences in egg metal levels between sites, except for in levels of As (Tables 7A, 7B). Concentrations of this metal with a maximum level of 0.086 ppm in a Marsh Wren egg, were too low in all species to have a biological impact (Eisler 1988).

We found higher levels of Hg (Kruskal-Wallis Chi-Square = 11.49, p = 0.003) in Red-winged Blackbird eggs at Marsh Resources than at Harrier Meadow while Kearny Marsh did not differ from either of the other two sites, in both 2007 (Table 7D) and in the combined egg data from 2006 and 2007. In Marsh Wren eggs from 2007, Cr and Hg levels were also higher at Marsh Resources than at Kearny Marsh (Kruskal-Wallis Chi-Square = 5.57 and 4.59, p = 0.018 and 0.032 respectively, Table 7E). When combining 2006 and 2007 wren data, the only between site difference was seen in Hg levels, which were lower at Kearny Marsh than either Riverbend or Marsh Resources, which were not different from each other (Kruskal-Wallis Chi-Square = 10.68 p = 0.005). Finally, there were no differences between sites in the levels of any of the metal contaminants measured in Canada Goose or Tree Swallow eggs (Kruskal-Wallis Chi-Square p>0.1 in all cases), both species sampled only in 2007 (Tables 7F, 7G).

Differences between habitats

We found that Marsh Wren eggs had lower Hg levels in nests placed in *Phragmites* substrate than those in *Spartina* at the one site where we collected eggs from nests in both habitats, Marsh Resources (Kruskal-Wallis Chi-Square = 5.45, p =0.02, Figure 4). An additional analysis to determine the contribution of habitat, year, and site to the models of metal concentration in eggs, which included data from the other sites, produced similar results. Habitat contributed to the model significantly for Hg (F=10.62, p=0.0023) and for Cr (F =7.85, p = 0.0079), with eggs in *Spartina* habitats having higher concentrations of Hg and lower concentrations of Cr than in *Phragmites* (Figure 4). While 'year' did not have an effect for any of the metals (p>0.05), there was an effect of the 'year*habitat' interactive term in Hg levels (F = 6.72, p = 0.013). Egg concentrations of this metal in *Spartina* was very high in 2006, but the difference between the habitats was not as great in 2007 (Figure 4), probably because Hg overall was lower in 2007.

Differences between species

Marsh Wren eggs in 2006 had significantly higher levels of Hg than the other species while Red-winged Blackbirds had higher egg Cr (Table 6). In 2007, Marsh Wren once again had the highest Hg levels, followed by Tree Swallow, then Red-winged Blackbird with Canada Goose being the lowest (Table 6A). This pattern persisted when combining data from the two field seasons (Kruskal-Wallis Chi-Square = 160.38, p<0.0001).

Levels of Pb sampled in eggs in 2007 and with both years combined, were significantly higher in Canada Goose than the three passerine species and than those of Mallard (Table 6A; Kruskal-Wallis Chi-Square = 81.42, p<0.0001 and Chi-Square = 77.08, p<0.0001).

Finally, the 2007 levels of Cr were highest in Marsh Wrens, and not different among the other three species (Table 6A).

Differences between unhatched and randomly collected eggs

We combined data from both the 2006 and 2007 field season for Marsh Wrens and Red-winged Blackbirds to explore differences between concentrations of heavy metals in unhatched eggs and eggs that were randomly collected during the study. Both non-parametric statistics (Kruskal-Wallis Chi-Square = 5.48 p = 0.019) and GLM models on log-transformed data (F = 4.89 p = 0.031) revealed that levels of Hg were higher in unhatched eggs in Marsh Wrens (Figure 5). Also, in Marsh Wrens, Cr levels differed, with unhatched eggs being lower than the randomly collected eggs (Kruskal-Wallis Chi-Square = 9.37, p = 0.002, F = 10.03 p = 0.0026). Differences between unhatched and randomly collected eggs were not significant for blackbirds. These differences were also not significant for Tree Swallows, for which unhatched eggs were only collected in 2007 (Figure 5).

To further explore the relationship between Hg levels and egg hatchability, we looked at metal levels only in the nests where unhatched eggs were found and compared the un-hatched eggs to the randomly collected ones from the same nest. We included both Marsh Wren and Red-winged Blackbird eggs in this paired sample analysis. We found higher Hg levels in unhatched than in randomly collected eggs (t = 2.51, p = 0.045, n=7; Figure 6). We did not include swallows in this analysis because we had not collected additional eggs from the nests where the unhatched eggs were found.

Temporal effects on egg contaminant levels

The three passerine species in our study are not synchronous, but nest initiation takes place anytime from early May to late June in Red-winged Blackbirds and Tree Swallows and from late May until mid-July in Marsh Wrens. Because of this we were able to examine temporal effects in metal level concentrations. In all three passerine species, there was a significant negative correlation between Pb levels and collection date (Figures 7-9). In Marsh Wrens 'year' and the interactive term 'year*date' also contributed significantly to the explaining the variation in Pb levels (F = 13.89, p<0.0001, r2 = 0.63), while in Red-winged Blackbird there was only a significant effect of 'year*date' (F = 4.0, p = 0.0023, r2 = 0.16), with no effect of 'year'. Tree Swallow eggs were only sampled in 2007 and there was a significant effect of date on Pb levels for that year (F = 2.74 p = 0.038, r2 = 0.17).

Since there were differences among sites in Hg levels, we included the 'site' variable in the analysis of temporal changes in Hg. In both Marsh Wren and Red-winged Blackbird, Hg levels in eggs increased with Julian date (Figure 10). In Marsh Wren, only date contributed significantly to the model explaining Hg levels (F = 5.23, p = 0.0003, r2 = 0.40), while in Red-winged Blackbirds both 'site' and 'date' contributed to the model, but not the interactive 'site*date' (F = 6.73, p<0.0001, r2 = 0.24). There were no other significant correlations between metal levels and date.

Feathers

Since many of the measurements of metal levels across species and years were not normally distributed, we used non-parametric statistics or log-transformed data in all of our analyses. Feathers from Canada Geese were collected only in 2007 so we made no by year comparisons. Feather metal levels are depicted in Figure 2 and Tables 6, 6A, 6B, and 7A-7G.

Differences between years and sites

Feather levels of contaminants revealed more complicated interactions of year and site than eggs.   Marsh Wrens had lower feather As, Pb and Hg in 2007 than 2006 (Table 6B). These differences were also reflected when comparing levels of contaminants at Marsh Resources, the one site from which we have samples for both years (Kruskal-Wallis Chi-Square =5.54, p= 0.018 for Pb and Kruskal-Wallis Chi-Square =14.14, p = 0.0002 for Hg). The Cr levels did not differ between the two years in this species.

In Red-winged Blackbird feathers only Cr levels were different between the two years of the study and higher in 2007 than 2006 (Table 6B). These levels reflected differences for Cr at Harrier Meadow (Kruskal-Wallis Chi-Square = 6.76, p = 0.009) and Kearny Marsh (Kruskal-Wallis Chi-Square = 48.85, p = 0.0001). At both sites, values were higher in 2007 than 2006; Marsh Resources Cr levels were also higher in 2007, but the differences between the two years were not significant.

Feathers were collected from Tree Swallows at just one site in 2006, DeKorte, so we compared contaminant levels in feathers between the two years at this site only. We found that Hg and As levels were lower in 2007 than in 2006 (Kruskal-Wallis Chi-Square = 5.87 and 8.13, p=0.015 and 0.004, respectively).

Differences between sites

Because of the variation between years (Table 6B and section above) there were only a few circumstances in which measurements of contaminants in feathers for the two years of the survey could be combined to make comparisons between sites.

There were few differences within species in comparisons by site when looking at only the 2007 data. Geese had higher feather Cd and Cr levels in Mill Creek (Kruskal-Wallis Chi-Square = 6.9 and 12.27, p= 0.03 and p=0.002, respectively). Tree Swallows had higher cadmium at Kearny Marsh (Kruskal-Wallis Chi-Square =11.6, p=0.008) and lowest at DeKorte. No between site differences were seen in Red-winged Blackbirds and Marsh Wren feathers were only sampled at one site in 2007.

Differences between habitats

We compared feather contaminant levels in Red-winged Blackbird and Marsh Wrens by habitat. We found no differences between habitats in any of the feather metal contaminants in these two species (Kruskal-Wallis Chi-Square p>0.05).

Differences between species

We found a significant effect of 'species' and either 'year' or 'species*year' on concentrations of all metals assayed. Because of this, measurements of contaminants in feathers for the two years of the survey could not be combined to make comparisons. Below we present information by year.

In 2006, Marsh Wren feathers had significantly higher levels of Hg than the other species (Kruskal Wallis Chi-Square = 32.26 and 31.06 respectively, p <0.001), while Red-winged Blackbirds had higher levels of Pb (Kruskal Wallis Chi-Square =7.8, p= 0.02) than Marsh Wrens. Finally, Tree Swallows had higher levels of Cr (Kruskal Wallis Chi-Square = 14.1 , p= 0.0009) and Pb (Kruskal Wallis Chi-Square = 7.8, p = 0.02) in feathers than Marsh Wrens. When looking at differences between species by site, Hg levels at Mash Resources were higher in Marsh Wren than in Red-winged Blackbirds (Kruskal-Wallis Chi-Square = 8.35, p = 0.004), which may be explained by the fact that blackbirds are found in upland areas within this site.

In 2007, overall levels of Pb were highest in feather in Canada Goose and Red-winged Blackbirds, intermediate in Tree Swallows and lowest in Marsh Wrens (Kruskal-Wallis Chi-Square = 23.7, p<0.0001). Red-winged Blackbird had higher Hg and Cr levels in feathers than Marsh Wren, while Canada Geese and Tree Swallows did not differ from the other two species or each other (Kruskal-Wallis Chi-Square = 18.63 and 7.87, p = 0.0003 and 0.048 respectively).

Site specific comparisons of species also revealed some differences in 2007. At Harrier Meadow, Hg was higher in Red-winged Blackbirds than Canada Geese (Kruskal-Wallis Chi-Square = 5.3, p = 0.02) – no other species were surveyed at this site. At Marsh Resources, Red-winged Blackbirds had higher Pb levels than both Tree Swallows and Marsh Wrens, which were not different from each other (Kruskal-Wallis Chi-Square = 14.4 p=0.0007). Finally at Mill Creek Cr and Pb were higher in Canada Geese than in Tree Swallows (Kruskal-Wallis Chi-Square= 7.5 and 8.25, p=0.006 and 0.004) while Hg was higher in Tree Swallows than Geese (Kruskal-Wallis Chi-Square = 4.8, p = 0.03).

Temporal effects on feather contaminant levels

There was a negative correlation of date and feather Pb levels in Red-winged Blackbirds, with 'year' and 'site' not contributing significantly to the model (F = 4.77, p = 0.005; R-square=0.20, Figure 11). The fit of the model was fair and similar to that found when modeling egg Pb level against date in this species. Decrease in feather Pb level as the breeding season progresses were not significant in the other two passerine species.

Blood

Metal distribution in blood was not normally distributed in either year or for any of the species, so non-parametric statistics were used to compare between years and sites and log-transformations were used in any parametric statistics. Blood metal levels are depicted in Figure 3 and Tables 6, 6A, 6B, and 7A-7G.

Differences between years and sites

In Red-winged Blackbirds, levels of Pb were different between the two years of the study and higher in 2006 than 2007 (Table 6B). In comparisons by site, these higher Pb levels in 2006 were reflected in Pb of blood samples collected at Harrier Meadow (Kruskal-Wallis Chi-Square = 10.77, p = 0.001) and there was a 'site' and a 'site*year' effect on levels of this metal (F = 5.49 and 10.96, p = 0.005 and <0.001 respectively).

In Marsh Wren, levels in blood were higher in 2007, while Pb, Cr and Cd levels were lower (Table 6B). We found a 'site*year' effect in Pb and Hg levels in this species (F= 4.48 and 8.33, p=0.036 and 0.004, respectively) which we further explored using non parametric statistics. By site comparisons revealed that Pb blood levels at Marsh Resources were lower in 2007 than 2006 (Kruskal-Wallis Chi-Square= 12.15, p<0.001) and that Hg levels were lower at Kearny Marsh in 2007 than 2006 (Kruskal-Wallis Chi-Square = 9.13, p = 0.002). Chromium levels of Marsh Wren blood were especially high at Riverbend, which was surveyed only in 2006, and these high levels resulted in differences among sites in nonparametrics tests (Kruskal-Wallis Chi-Square = 6.84, p = 0.03) with both years combined. If we leave Riverbend out of the comparisons, inter-annual differences in Cr are no longer significant.

In Tree Swallows, DeKorte was the only site sampled in both years. We found lower levels of Cr and Pb in 2007 than 2006 at this site (Kruskal-Wallis Chi-Square = 12.64 and 14.83, p=0.0004 and 0.0001, respectively).

Since the relationships between metal levels in blood, year, and site were complex, we did not combine data from the two years when exploring species and site differences, rather we present them separately by year below.

Differences between nests

In 2007, we collected blood samples from all of the nestlings at each nest whenever possible, and metal assays were run separately for each blood sample. Before collapsing data to undertake statistical comparisons between sites we explored whether there were any differences in metal levels of blood in different nests within each site. In Red-winged Blackbirds there was a 'nest' effect for Hg across all sites (F = 2.72, p = 0.002) and this effect seems to be driven specifically by samples collected at Marsh Resources (F= 9.05, p < 0.0001).

In Tree Swallows there was a 'nest' effect for Cd, Cr and Pb (F = 2.57, 2.11, and 1.73 ; p = 0.0003, 0.004, and 0.025 respectively). This nest effect was reflected in differences of Cr levels at Kearny Marsh and Mill Creek (F = 2.28 and 3.86; p = 0.03 and 0.025 respectively) and for Pb at Marsh Resources and Mill Creek (F = 8.11 and 7.93; p = 0.0027 and p = 0.0015 respectively). For Cd there were by nest differences at Kearny Marsh, Marsh Resources, and Mill Creek (F = 2.53, 3.82 and 14.15; p = 0.02, 0.04 and <0.0001. There was no 'nest' effect on blood metal levels of Marsh Wren at any of the sites surveyed and for any of the metals analyzed.

These results show that there are within site differences among Red-winged Blackbird and Tree Swallow nests: contaminant levels in siblings (nestlings within the same nest) differ from those in other nests. This was especially true at Mill Creek where we found inter-nest differences in both Cr and Pb levels. Parents feeding nestlings may be exposed to varying levels of contaminant depending on their foraging habitat or prey selection. While blood levels of metals typically reflect recent diet, by nest variation in Hg levels of Marsh Resources blackbirds may result in longer term 'by nest' differences and differential impacts on these birds, as the result of bioaccumulation of this metal.

Site differences

In 2006, we found that Marsh Wrens had higher Hg levels in blood samples at Kearny Marsh than those at other sites (Table 7B). In 2007, wren nestlings had higher blood Pb levels at Kearny Marsh than those at Marsh Resources and higher Cr levels at Marsh Resources than Kearny (Table 7E).

In 2006, there were no differences among sites in contaminant levels in Red-winged Blackbird blood samples. In 2007, Red-winged Blackbirds had higher Pb levels at Kearny than at Harrier Meadow and Marsh Resources (Kruskal-Wallis Chi-Square = 18.55, $p < 0.0001$). We found no differences among sites in blackbird Hg or Cr levels.

Tree Swallows were sampled only at one site in 2006, so there are no by site comparisons for the first year of the study. Since in Tree Swallows there was no 'nest' effect for Hg levels, we did not collapse the blood levels of this metal into one entry for each nest, rather we used the full set of data for the analysis. Tree Swallows at Mill Creek had higher blood levels of Hg than at all the other sites (Table 7F). No other by site differences were seen in this species.

Differences by habitat

We collected blood samples in Marsh Wrens from nests in two types of habitat substrates and, therefore, we were able to run comparisons by habitat. To increase our sample size, we included data from both years of the study in some of our analyses. During the first year of the study we did not record nest substrate for each nest, but we were able to use the nest site descriptions from the field log to obtain the habitat information. There were no differences in Hg, Cr and Pb levels by habitat overall. When comparing metal levels only from Marsh Resources, however, the one site where nests were found in both *Phragmites* and *Spartina* habitats, we found significantly higher levels of Pb in blood from nests built in *Spartina* (Kruskal-Wallis Chi-Square = 6.76, $p = 0.009$, Figure 12). In 2006, Pb levels were higher than 2007 and all Marsh Resources samples were collected in *Spartina*, therefore, the difference may be simply the result of the 'year' effect. This difference between habitats disappears when comparing data from only the 2007 field season, when we had samples from both habitats.

Red-winged Blackbirds were sampled at three habitats, *Phragmites*, Groundsel and *Spartina*. However, each site was represented by only one type of habitat except for Marsh Resources that had all three. At Marsh Resources, successful nests from which we collected samples were mostly in Groundsel habitat, with only one nest in *Spartina* from which we collected blood samples from 3 chicks. This does not allow for a 'by habitat' statistical analysis. However, the three *Spartina* samples fell right into the middle of the levels of the other samples and were neither high nor low outliers.

<u>Species differences</u>

In 2006, Tree Swallows had higher levels of blood Cr than the other species (Kruskal-Wallis Chi-Square =10.2, p= 0.006), and higher levels of blood Pb than Red-winged Blackbirds (Table 6).

As shown in Table 6A, in 2007, levels of both Pb and Cd were higher in Red-winged Blackbird and Marsh Wren than in Tree Swallows (Table 6A). Arsenic levels were higher in Marsh Wren (Table 6A) than in Red-winged Blackbird and Tree Swallow levels were lower than both. Chromium was similar among all three species (Table 6A) as was Hg (Table 6A). Blood was not sampled from Canada Geese.

<u>Temporal effects on blood contaminant levels</u>

We found a positive relationship between date and Hg levels in blood and date in Tree Swallows ($F = 5.24$, $p < 0.0001$, R-square = 0.19) and a negative relationship in Marsh Wrens ($F = 7.31$, $p= 0.0001$, R-square = 0.15, Figure 13). This indicates that blood Hg levels increase as the breeding season progresses in swallows, while it decreases in wrens. There was no temporal pattern in Red-winged Blackbirds. Year, site and the interactive site*date variables did not contribute to any of the models for the three species, and the results presented are based on both years of the study.

In Red-winged Blackbirds, Cr blood levels were negatively correlated with 'date'. There was a significant effect of year and the interactive term 'date*year' on this metal ($F = 5.48$, $p <0.0001$). When looking at the levels for 2006 and 2007 separately, in 2006 there was a significant negative correlation of Cr with 'date' ($F = 14.7$, $p = 0.0002$, R-square = 0.22) but there was no effect of 'date' in 2007. A similar effect was seen in this species with the interactive term 'date * year' having a significant effect on blood Pb levels ($F = 16.64$, $p <0.0001$). There was also a significant effect of 'date' on Pl blood levels in 2006 ($F = 11.78$, $p = 0.001$) vs. no effect in 2007 (Figure 14). This implies that Cr and Pb levels in blood of nestlings decreased during the breeding season in 2006 but not in 2007.

Goose tissues

In Canada Geese, we sampled muscle and liver tissue in addition to feathers and eggs (Appendix 22). We also collected information on age for all collected samples. We compared levels of all metals analyzed and found no significant differences between adults and juvenile geese (Kruskal-Wallis Chi-Square $p >0.1$) in either muscle or liver tissue, so we combined the data in all further analyses. Site comparisons revealed differences between sites in levels of Cr, Hg, and Pb in muscle and Cd in liver (Table 7G). Muscle Cr and Pb levels were highest at Mill Creek and not different between the other two sites, while muscle Hg levels were also highest at Mill Creek and lowest at Harrier Meadow, with Skeetkill not being different from either one (Table 7G). Finally, Cd liver levels were highest at Skeetkill and lowest at Harrier Meadow, with Mill Creek not being different from either one (Table 7G).

Differences and correlations between tissues

In both years, levels of all metal contaminants were significantly different among tissues of Marsh Wrens and Red-winged Blackbirds (Tables 8, 8A). In Tree Swallows, there were significant differences among tissues for all metal levels in 2007 and for Hg and As levels, but not for Cd, Cr, or Pb in 2006 (Tables 8, 8A).

In 2006, for all species together, there were significant differences in As, Pb and Hg levels among the different tissues, with concentrations being higher in feathers, followed by eggs and then by blood levels. Chromium levels were significantly higher in feathers than in eggs, but blood levels were not significantly different for the other two tissues. Feathers and blood had significantly higher levels of Cd than eggs, but were not different from each other.

In 2007, feathers had higher levels of Cr, Pb, and Hg than the other tissues, except for in Marsh Wrens where blood had the highest Pb concentration, but not significantly higher than feathers. In most cases blood had higher or similar levels of contaminants as eggs, except for Hg in Marsh Wrens that was higher in eggs.

Since we collected feathers and blood from the same nestlings in the three passerine species, were looked to see if the metal levels in these tissues are correlated. We found that Hg levels of feathers and blood were positively correlated in Marsh Wrens and Tree Swallows, ($F = 6.33$, $p = 0.04$, R-square = 0.47, and $F = 8.74$, $p = 0.006$, R-square = 0.23), but not in Red-winged Blackbirds.

In Canada Geese, Hg, Pb, Cr and As were higher in feathers that all the other tissues (Table 8A). Since the levels of metals in feathers were much greater than those seen in eggs, muscle and tissue, we undertook comparisons of those other 3 tissues separately. We found that Cd, and Hg levels were highest in liver and lowest in eggs, with muscle having an intermediate value (Kruskal-Wallis Chi-Square = 61.07, $p < 0.0001$ and Chi-Square = 31.94, $p < 0.0001$ respectively). Cr was also highest in liver, but not different between eggs and muscle (Kruskal-Wallis Chi-Square = 20.67 $p < 0.0001$). Finally Pb was high in both liver and eggs, and lower in muscle (Kruskal-Wallis Chi-Square = 49.81 $p < 0.0001$).

Metal levels in blood and nestling morphometry

Arsenic and cadmium were not included in the analysis as their concentrations were too low to anticipate an adverse effect on the nestlings of the three passerine species studied (see discussion below).

Comparisons across all nests

We found no significant differences between nests in any morphometric measurements of Marsh Wren nestlings (Kruskal Wallis Chi-square, $p > 0.05$), therefore we dealt with metal levels and morphometrics for each nestling for this species as independent rather than averaging values by nest. In the other two species sampled there were some differences within sites by nest, and in those cases we used average values by nest rather than use each observation as independent.

While we attempted to measure all nestlings at approximately the same age, in fact, measurements were made over a span of 2-4 days of age. In 2006. we sampled Marsh Wrens at ages 9-12 days in 2006 and Red-winged Blackbirds at ages 6-10 days. For Marsh Wrens, the model containing age and Pb levels was significantly correlated to the model predicting nestling weight with age accounting for approximately 38% of the variance, while lead levels explained approximately 8% of the variance in weight. In Red-winged Blackbirds, age and Cr contributed to the model, with Cr only explaining about 1% of the variability in weight. Both relationships of weight with metal levels were negative.

During 2007, we were successful at sampling blood from nestlings within a narrower age span than in 2006 (10-11 days in Marsh Wrens and 8 -9 days old in Red-winged Blackbirds) and analysis of body measurements by age showed no significant effect (Kruskal Wallis X^2, p>0.05), so we combined all ages in our analysis. We found no effect of age or metal levels on any of the morphometric measurements in Marsh Wrens and Red-winged Blackbirds nestlings (all variables log transformed, p>0.1 for all Pearson correlation coefficients). It may be that eliminating the contribution of age eliminated some of the variability in the model that resulted in including an effect of metals in 2006. However, overall metal levels were lower in 2007 as well and therefore possibly below the level where adverse effects would be visible.

Sample sizes of Tree Swallows were large enough only in 2007 to explore relationships between body measurements and metal levels. Tree Swallows were sampled at ages 12-16 days, and as in the other two passerine species, there was no significant effect of age on the morphometric parameters of their nestling. There was also no effect of site, and no effect of either site or nest on any of the asymmetry measures. However, we found an effect of nest on weight (Kruskal-Wallis Chi-Square = 79.17 p<0.0001). Furthermore, there was an effect of 'nest' on levels of blood Pb and Cr and of 'site'on Hg levels in this species (see previous section). We, therefore, included a 'site' and a 'nest' variable in an analysis of covariance to model the effects of metal levels on body measurements. We found a negative relationship between Pb levels and body weight in swallows using this model (overall model F = 2.27, p = 0.001, r2=0.44; effect of Pb variable F = 7.21, p = 0.0086).

<u>Within nest comparisons</u>

To further explore possible effects of metal contaminants on size and eliminate other potential factors that might affect the results of the previous analysis, we made paired comparisons of the largest and smallest nestling in each nest.

In Tree Swallows, we found that the heaviest young per nest was significantly heavier (paired t-test T = 7.31, p<0.0001) and had a lower level of Pb than the lightest one (paired t-test T = 3.36, p = 0.0021, Figure 15). Specifically, the average Pb levels in the heaviest nestling were 154.9 ppb, and in the lighter ones 261.1 ppb. In addition, in these paired comparisons we found that Hg levels (paired t-test $T = 2.85$, $p = 0.0079$) were also higher at 23.36 ppb in the lighter nestlings than the heavier nestlings at 12.27 ppb. We found no differences in metal levels in comparisons of the other body measurements.

We found no difference in metal levels between the smallest and largest nestlings in Marsh Wrens or Red-winged Blackbirds.

Organic contaminant analysis

Concentrations in ppb of all organics analyzed can be seen in Table 9. We only analyzed a small set of samples for organics and we will only be able to run statistical comparisons when we can run these analyses from other species and tissues. We do not have the data for total PCBs yet. Results for subset of PCB congeners considered toxic (Van den Berg et al. 1998) reveal generally low concentrations of these congeners expressed as wet weight, with the highest being PCB 118 (31.3±11.2 ppb) and PCB 156 (13.6±5.7 ppb), followed by PCB 105 (12.5±11.7 ppb) and PCB 77 (10.1±6.5 ppb).

DISCUSSION

We studied a diverse group of sites, both restored and un-restored, and ones with various levels of concern regarding their contaminant levels based on a report produced by the US Fish and Wildlife Service (USFWS 2005, NJMC biologists pers. comm.). In addition, each site was dominated by different types of vegetation, *Phragmites*, or *Spartina* in wetlands and groundsel in uplands.

Our study revealed few differences between sites in metal levels or in nesting success. The only site effects we found in nest daily survival rate were for Tree Swallows, which had higher DSR at DeKorte and lower at Mill Creek and Kearny Marsh. Mill Creek swallows had higher Hg levels in blood than the other sites, however, DeKorte had higher feather Hg levels, and there were no differences in levels of the other four metals (that occurred at biologically significant levels) or tissues between sites for this species. Therefore, it does not appear that metal levels have an effect on the measured nesting success, which is also in agreement with the AIC analysis when including metal contaminants into the model. In fact, the reason for the lower nesting success in tree Swallows appears to have been higher predation on nests at Mill Creek and Kearny based on our field observations.

While we did not find an effect of site on nest survival rate in Red-winged Blackbirds or Marsh Wrens, we did find effects of site and nest substrate on hatching and fledging success. Red-winged Blackbirds had very low fledging success at Marsh Resources in 2006. We believe that this was the result of beetle defoliation of the groundsel that took place in Spring/Summer 2006, making the nests vulnerable to predation. In fact, the vegetation had recovered in 2007 and fledging success was higher at Marsh Resources than at the other sites. Except for Marsh Resources in 2006, fledging success at all sites and for Red-winged Blackbirds studied was close to or greater than 1 young fledged per active nest monitored (Tables 3 and 3A). Fledging success for Marsh Wren and Tree

Swallows was close to or greater than 1.5 young fledged. We would need information on post-fledging survival as well as adult survival to model the study site population and determine its overall contribution of to the general population. However, based on information on demographics from the literature (Kroodsma and Verner 1997; Yasukawa and Searcy 1995; Robertson et al. 1992), it appears that the birds studied are reproducing at a sufficient level to maintain their populations at most of our study sites.

Marsh Wrens had lower success raising their young in nests placed in *Phragmites*, because these nests tended to be more flimsy and likely to fall down during storms. There were also some differences among sites in contaminants levels for Marsh Wrens and Red-winged Blackbirds. Specifically, in 2006 of the five metals assayed we found higher Hg levels in blood of Marsh Wrens at Kearny Marsh. In 2007, we found higher blood Pb levels at Kearny Marsh and higher egg Hg levels at Marsh Resources in both Marsh Wrens and Red-winged Blackbirds. These differences in metal levels between sites were not associated with decreased nesting success at these sites. However, the high levels of Hg observed at Marsh Resources during 2007 are surprising. We would have expected higher contamination levels at Kearny Marsh since it is located adjacent to the contaminated Keegan Landfill. The Keegan Landfill was contained after the end of the study and is currently active. Follow-up data collection would be useful to determine if there are changes in metal levels of bird tissue.

We believe that habitat factors may play an important role in how metals influence reproductive success. For example, based on field observations of Marsh Wren nest location and structure, we had anticipated that nest success would have been higher in *Spartina* vs *Phragmites* habitats. *Phragmites* does not provide the best substrate and many nests in this habitat collapsed during the breeding season, as reflected in lower fledging success in *Phragmites* habitat vs groundsel for Red-winged Blackbirds and *Spartina* for Marsh Wren. However, we did not find any differences between habitats in nest daily survival rates. We found higher Hg levels in eggs from nests in *Spartina*, and all un-hatched eggs from Marsh Resources, the site where nests were found in both habitats, were recorded in *Spartina*. In addition our data suggest that Pb levels in nestling blood were also higher in *Spartina* habitats. Further research is critical to determine whether higher Hg levels in the eggs, critical for egg viability, together with increased Pb levels during nestling growth, may lend a disadvantage to nests in *Spartina* and counterbalance effects of less appropriate nest substrate vegetation in the *Phragmites* habitat.

Even though there was not a habitat effect on nesting success, a larger number of Marsh Wren nestlings fledged successfully in *Spartina* than in *Phragmites* habitat. Similarly, there was also a higher number of Red-winged Blackbird eggs hatched and nestlings fledged in groundsel than *Phragmites* and nest survival was also better in this habitat (Table 5A), however, we found no differences between habitats in metal levels. This complex interaction of habitat, contaminant level and nesting success should be further explored.

Heavy metal levels

Arsenic

Arsenic is associated with pesticides and industry, especially smelting (Eisler 1988). It is a relatively common element, and is present in air, water, soil, and all living tissues. Chronic exposure to arsenic, however, can cause liver, kidney, and heart damage, hearing loss, and impaired resistance to viral infections(Eisler 1988). It is considered one of the most toxic elements to fish. EPA standard for arsenic has been set to 0.010 ppm in drinking water and NJ Soil Cleanup Criteria is 20 ppm.

In bird tissues, 2-10 ppm is considered elevated, and above 10 ppm is indicative of arsenic poisoning (Eisler 1988). Maximum arsenic levels in any egg was 0.086 ppm in a Marsh Wren egg in 2006, well below the level at which we might anticipate any harmful effects. Levels of arsenic in blood were similarly low, with high values reaching 0.09 ppm. Average values in feathers were a bit higher, with those of blackbirds and geese reaching maximum values of over 0.5 ppm. However, these arsenic levels are still on the lower range of those reported by others (Golden et al. 2003, 0.96 ppm was the average reported in Burger 1993), and also below the level where it may have biological impacts (Eisler 1988).

Cadmium

Cadmium levels in our study at an average across all species of 60.81 ppb for feathers, 11.73 ppb for blood, and 0.45 ppb (wet weight) for eggs were generally low compared to other levels reported in the literature for feathers (50 to 41000 ppb, Burger 1993; Burger and Gochfeld 2000b), eggs (2–200 ppb, Burger et al. 2004; Burger and Gochfeld 2004), and blood (9–90 ppb, Burger and Gochfeld 1997). Cadmium levels in liver of Canada Geese were higher, over 200 ppb at Mill Creek and over 300 ppb at Skeetkill Marsh (Tables 6-8). These levels are lower than those reported elsewhere in Canada Geese and should not be harmful (Blus et al. 1995) Additionally, cadmium levels in Meadowlands birds were lower than the level viewed as evidence of probable cadmium contamination in vertebrates, which is 2.0 ppm in whole body fresh weight (Eisler1985).

Chromium

At high environmental concentrations, chromium is a mutagen, teratogen, and carcinogen, however chromium chemistry and the way this chemical is processed through the food chain is not fully understood (Eisler 1988). Chromium contamination is high within the NY/NJ Harbor region because of chromite processing facilities in Hudson County and chromium waste sites close to Newark Bay (Burke et al. 1991). While hexavalent chromium has the greatest biological impact (NIOSH 2002), in our study we measured total chromium, but we believe that using improved analytic methods to quantify the hexavalent component would be helpful.

Chromium levels in eggs in this study were relatively high (Appendix 19, Figure 1) and similar to those reported in herring gull eggs in the NY/NJ Harbor Bight (0.3-2.2 ppm, Gochfeld 1997) and higher than those reported for Scrub Jays in Florida (Burger et al. 2004), and terns in New Jersey (Burger and Gochfeld 2003, 2004). Chromium levels were especially high in Red-winged Blackbird eggs, with maxima > 3.5 ppm (dry weight) in 2006, which is nearing the 4.0 ppm level where they may be considered contaminated (Eisler 1986). These values are higher than those reported in eggs of other passerines, but within the same range as other avian species (reviewed by Burger et al. 2004). However, Cr levels of blackbird eggs in 2007 were significantly lower with a maximum value of 0.75 ppm (dry weight). While Marsh Wrens had higher average levels of Cr in eggs in 2007 than in 2006, their Cr maximum value was lower in 2007 at 1.6 ppm vs 2.4 ppm (dry weight) in 2006. Wrens had higher levels of Cr in eggs than blackbirds in 2007 and blackbirds had higher levels in 2006. Tree Swallow eggs, only sampled in 2007, had similar levels of Cr to those seen in the other two passerine species. Finally, the levels of Cr in waterfowl were lower, with a maximum value of 0.5 ppm (dw). However, overall there was not any strong trend in differences between species in the level of this metal contaminant for the two years of the study.

Chromium concentrations in blood were also relatively high in our study (Appendix 21, Figure 3). Although Cr levels in avian blood are not well documented in the literature, the values we found during the 2006 field season in swallows at 1.03 ppm were almost three times higher than those reported in gulls by Burger and Gochfeld (1997) that ranged between 0.19 and 0.35 ppm. Similarly, blood Cr levels of Marsh Wrens were twice as high at Riverbend in 2006 (average 0.7 ppm) than those recorded by Burger and Gochfeld. Chromium levels overall were lower in the samples collected in 2007, and this difference was statistically significant in Tree Swallows, for which the average Cr levels fell to within the range reported by Burger and Gochfeld (1997). The Cr concentrations in marsh wren blood samples from Riverbend were higher than those from Marsh Resources and Kearny Marsh when looking at data from both years of the study.

The maximum recorded levels of chromium, above 4 ppm, were found in feathers collected in Canada Geese and Tree Swallows in 2007 (Appendix 20, Figure 2). Canada Goose feathers had significantly higher Cr levels at Mill Creek compared to other sites (average 2.74 ppm). These levels were in the lower range of those reported in birds, (average 8.8 ppm, high values 17.9 ppm as reviewed by Burger 1993). They were also lower than those for Cattle Egrets (*Bubulcus ibis*) in the Northeast (average 8.2 and 7.2 ppm, Burger et al. 1992) seabirds in the Pacific (average 1.3 to 11.6 ppm, Burger and Gochfeld 2000b), and lower than those reported for Black-crowned Night-Herons (*Nycticorax nycticorax*) in Chesapeake and Delaware Bays (Golden et al. 2003).

In Tree Swallows feather chromium levels were higher in 2007 than in 2006, and ranged between 0.14 to 4 ppm vs 0.3 and 1.5 ppm, (average for the two years = 1.1 ppm). Even the highest measured values in our study are much lower than the average 25.5 ppm reported for Tree Swallows by Kraus (1989). The average levels of Cr in feathers collected across the two field season were also higher in 2007 than 2006 in Red-winged Blackbirds, but similar for the two years of the study in Marsh Wrens.

While Cr levels in feathers in at least one species (Red-winged Blackbird) were higher in 2007, the levels in eggs and blood were lower during this second year of the study. This decrease may be of importance, since these two tissues (eggs and blood) were the ones that had comparatively high levels of this metal. In Marsh Wrens in 2006 we had found a significant negative correlation between Cr levels in feathers and nestling weight, but we found no such correlations in 2007 for any of the species and tissues sampled. Because little is known about the effects of chromium in birds, its effect on weight gain at various tissue levels is unclear, and we do not know if, perhaps, the levels measured in 2006 actually reached an effect threshold level while those found in 2007 did not. Even though our results do not suggest a strong impact of Cr in the species studied, because its measured levels were relatively high we recommend continuing to monitor Meadowlands biota for this metal contaminant. Finally, high levels of Cr in Canada Geese, especially at Mill Creek, compared to the passerine species are surprising and warrant further study.

Mercury

Sediment levels of mercury contamination in Upper Newark Bay and in the Hackensack River are above the median level at which adverse biological effects are expected (Steinberg et al. 2004). Mercury can affect bird behavior, physiology and reproductive success (Wolfe et al. 1998, Burger and Gochfeld 2003, Gochfeld 1997). Mercury accumulates especially well in bird feathers because it has high affinity for the sulfhydryl groups in keratin. Concentrations of Hg in feathers above 5 ppm are linked to reduced reproduction (Eisler 1987a). Female birds also can sequester mercury in eggs (Gochfeld 1997) and levels between 0.5-1.5 ppm (wet weight) can affect hatchability, while egg levels of 0.5-1 ppm can have adverse behavioral effects on nestlings (Wolfe et al. 1998).

None of the eggs in our study had mercury levels higher than 0.5 ppm, the value above which one would anticipate deleterious effects, and the highest value (0.4 ppm wet weight) was seen in an egg from a nest that successfully hatched, and fledged 4 nestlings. Overall, Marsh Wren eggs had higher levels of Hg than the other species, with, over 70% of the samples at Marsh Resources and over 50% of the samples at Riverbend having mercury levels over 0.2 ppm in 2006 (Appendix 19, Table 7B). These values were higher than values reported in eggs of Tree Swallows, Salt Marsh Sparrows and other passerines elsewhere (Burger et al. 2004, Evers et al. 2005, Lane and Evers 2006). In 2007, the Hg levels found in eggs were lower, with only 10% of the samples, all from Marsh Resources, having levels greater than 0.2 ppm. In comparing different collection sites, we found that Marsh Resources had the highest levels of Hg for both Marsh Wren and Red-winged Blackbird. This was surprising, as we had anticipated that Kearny Marsh, which is considered heavily polluted due to leachate from the Keegan landfill (USFWS 2005) would have the highest Hg levels. Differences between habitats in Hg levels may partially explain the higher egg Hg levels at Marsh Resources. This site is dominated by *Spartina* where we found higher egg Hg levels in wrens than in *Phragmites*, the dominant habitat at Kearny Marsh. The differences between habitats is in agreement with research that shows *Phragmites* as being more effective at sequestering metals (Burke et al. 2000).

We found that unhatched Marsh Wren eggs in 2006 had higher levels of mercury than randomly collected eggs. In 2007, we further refined that analysis by comparing levels of Hg within nests to remove the influence of factors relating to parental genetics and physiology or nest location – that is any factors that may cause differences between nests.

In paired-tests of randomly collected vs. unhatched eggs from the same nest, the difference in Hg persists, with viable eggs having lower Hg levels (Figures 5-6). While below the reported level 0.5 ppm for negative effects on hatching based on the literature (Eisler 1987a), in this case we observed impacts on hatching occurring at lower Hg levels. More research is needed to determine how specific effect levels differ in passerines from those in waterfowl that are typically used to determine the negative effect thresholds of contaminants (Heinz 1974, 1979).

Feather mercury levels in nestlings represent local environmental loads obtained mainly through their diet, in addition to loads obtained from egg constituents, and typically reflect concentrations in the body during the molting periods. Feather mercury levels in all species we sampled were relatively high (Appendix 20, Figure 2, Tables 6-8). Mercury levels in Marsh Wren feathers, especially, with values from over 3 ppm up to 4.5 ppm in 2006, approximate the 5 ppm level where negative effects may be anticipated. These high concentrations likely reflect the higher trophic level this species occupies as an insectivore. Tree Swallows, another insectivore, also had relatively high levels of feather mercury, averaging over 2 ppm, while Red-winged Blackbirds had the lowest values, possibly reflecting a more varied diet than the other two species. In 2007, the levels of Hg we found in Marsh Wrens and Tree Swallows were lower than those in 2006. Since levels of Hg in feathers of Red-winged Blackbirds were similar in the two years, this metal was found in significantly higher concentrations in this species than in wrens, opposite of what we had found in 2006.

Feather mercury levels we report here are higher than those reported for passerines and terrestrial bird species elsewhere. For example, Solonen and Lodenius (1984) report levels from 1 to 2.5 ppm in Finland passerines (reviewed by Burger 1993). Burger et al. (1993) found lower levels of mercury in passerine feathers in Papua New Guinea and for Mourning Doves (*Zenaida macroura*) in South Carolina (Burger et al. 1997). Rimmer et al. (2005), studying passerines in montane forests, report mean mercury levels from 0.4 ppm in Blackpoll Warbler (*Dendroica striata*) to 1.1 ppm in Yellow-rumped Warbler (*Dendroica coronata*). As mentioned above, Hg levels in our study were lower in 2007 than 2006. However, while Marsh Wrens sampled in 2007 all had levels of feather Hg below 1 ppm, about 25% of the Tree Swallows and 20% of the Red-winged Blackbirds had levels above 1 ppm. In fact, feather Hg levels in all three of our passerine study species are higher than those reported for Cattle Egret from the northeast U.S. (Burger et al. 1992). Interestingly, they are more similar to those reported for Black-crowned Night-Herons in Chesapeake and Delaware Bays (Golden et al. 2003) and seabirds in the Pacific Ocean, species that occupy higher trophic levels in the food chain. Tree Swallow Hg levels in feathers were especially high at DeKorte in 2006, at an average above 2 ppm, but in 2007 they were lower at an average of 0.86 ppm at the same site. In Canada Geese, feather Hg was lower than in the passerine species with an average of 0.25 ppm.

While Marsh Wrens had significantly higher levels of mercury in feathers than Red-winged Blackbirds and Tree Swallows in 2006 (Table 6), they had lower feather levels in 2007 (Table 6A). Their blood levels were not significantly different from the other two species (Tables 6 and 6A). Blood levels of mercury for all passerines and both years were mostly below 0.06 ppm, a level consistent with the lowest levels reported for breeding passerines in New England (Lane and Evers 2005).

Mean mercury levels in blood of all three passerine species were the same order of magnitude but lower than those reported for breeding montane birds (Rimmer et al. 2005) and similar, but again generally lower than those reported for juvenile birds in New England (Evers et al. 2005). Maximum values, however, exceeded 0.1 ppm in some cases (Appendix 4). One blood sample from a Marsh Wren nestling at Kearny Marsh in 2006 had a higher mercury load at 0.35 ppm, approximating blood levels reported for marsh sparrows in New England (Lane and Evers 2005). These other studies reported mostly on mercury levels in adults, which usually exceed those of juvenile birds (Burger and Gochfeld 1997, Burger 1993, Evers et al. 2005). However, even when comparing our results with other passerine juveniles (Evers et al. 2005), blood mercury values we obtained were generally lower.

There were few differences among sites in blood Hg levels. Specifically, in Tree Swallows from Mill Creek, levels were higher than from other sites (Table 7F). Given that blood levels of Hg are generally low, we do not believe that this difference in this metal contaminant levels has any biological significance. We collected feathers and blood from the same nestlings and we saw relatively high levels of feather Hg compared to low levels of blood mercury. We therefore believe that low levels in nestling blood probably results from mercury sequestering in the rapidly growing feathers during the nestling development period (Condon and Cristol 2008).

Lead

Birds take up lead into their tissues through diet and inadvertent soil consumption. In people, Pb is of particular concern for infants and young children because it can affect their developing brain and nervous system (Eisler 1985). Similarly, the presence of lead in blood can have serious health consequences for birds, including reduced weight gain for nestlings, reduced organ growth, and a reduced ability to sustain necessary metabolic function (Eisler 1985, Burger 1995, Burger and Gochfeld 2000a). Lead levels of 4 ppm in feathers are associated with negative effects including delayed parental and sibling recognition, impaired thermoregulation, locomotion, depth perception, and feeding behavior, thereby resulting in lowered nestling survival (Burger and Gochfeld 2000a, Burger 1995). Adverse physiological effects in birds may occur at blood lead levels as low as 0.4 ppm (Eisler 1988). Lead contamination in the NY/NJ Harbor is relatively high and originates from various sources such as leaded gasoline, lead paint chips and residues, pesticides, and incinerator and other industrial emissions (Steinberg at al. 2004). Consequently, tissue lead levels in this region also tend to be elevated (Burger pers. comm.)

Eggs in the three passerine species we studied had comparatively low levels of lead, with means between 0.03 and 0.06 ppm (wet weight). While these levels are similar to those reported in some other passerines (e.g., 0.006-0.06 ppm in Scrub Jays, *Aphelocoma coerulescens*, in South Carolina, Burger et al. 2004), they are relatively low compared with levels measured in seabirds in this region that are typically greater than 1 ppm (Gochfeld 1997, Burger and Gochfeld 2004). We found no differences in lead levels among the three passerine species or among sites, and in Marsh Wrens levels of Pb in eggs were lower in 2007 than in 2006. However, levels of Pb were significantly higher in Canada Geese than the passerine species. These levels are higher than those reported by Burger et al. (2008) in Alaskan eiders and similar to levels of Pb reported in seabirds which feed at higher trophic levels (Sydeman et al. 1998), and therefore may be a cause for concern.

Average levels of Pb in feathers of Red-winged Blackbirds, Marsh Wrens, and Tree Swallows were lower than the averages reported elsewhere for passerines (Eens et al. 1999, Burger 1993, Nam et al. 2003), and below the 4 ppm threshold for anticipated adverse effects (Burger and Gochfeld 2000a), except for two Red-winged Blackbirds from Kearny Marsh (in 2007) and two Tree Swallows, one from Kearny Marsh (in 2007) and one from DeKorte (in 2006, Appendix 20, Figure 2, Tables 6-7). Although lead levels in these four feather samples were above the 4 ppm adverse effect level, these nests all fledged successfully. In addition, 20% of the lead concentrations observed in passerines and 42% of the values observed in goose in our study are above the median value of 1.6 ppm reported by Burger (1993) and Burger et al. (1997) in an extensive review of metal levels in birds. In addition 4 out of 26 Canada Geese had lead levels above 4 ppm.

Red-winged Blackbirds had higher levels of Pb in feathers than the other two passerine species in both years of the survey, although in this species we also found a decrease in average Pb levels from 2006 to 2007. Canada Goose Pb levels were not different from Red-winged Blackbird, and were higher than the other two passerine species. Feather Pb levels were especially high in Canada Geese from Mill Creek, averaging 3.14 ppm. These are much higher than levels reported in feathers of Night-Herons (Golden et al. 2003) and seaducks (Burger et al. 2008) and possibly a cause for concern.

Tree Swallows Pb levels in feathers over the two years of the survey (mean = 0.68 ppm, range 0.0007 to 4.3 ppm) were lower than those reported by Kraus (1989) in the Meadowlands (1989, mean = 4.3 ppm,), who even reported some samples with concentrations as high as 16.2 ppm. We would anticipate decreasing Pb levels in feathers since 1988 (i.e., the year of Kraus's study) because of the steady decrease of lead after the ban on leaded gasoline and the generally improved environmental conditions in the Meadowlands District. It is encouraging to see that there has been a lowering of Pb levels since the 80s, but given that these levels are still elevated, especially in geese, this metal should be further monitored.

Blood Pb levels were elevated in all species (Appendix 21, Figure 3, Tables 6-7) compared to those reported in the literature and consistent with the higher range typically reported in avian blood (Burger and Gochfeld 1997). Marsh Wrens at Marsh Resources in 2006 had average blood Pb levels of 0.7 ppm with a high of 3.3 ppm and at Riverbend average blood Pb levels of 1.2 ppm and a high of 2.4 ppm. All these values are higher than the 0.4 ppm effect threshold level (Eisler 1985). Tree Swallows had average Pb levels of 0.9 ppm, with a high value of 3.5 ppm in 2006. While in 2007 there was an overall decreasing trend in average Pb levels, with an average of 0.4 ppm in Marsh Wren and 0.2 ppm in Tree Swallow, the maximum Pb values were still high at 3.9 ppm and 2.1 ppm for these two species respectively. In 2006, we found a negative correlation between wren nestling weight and Pb levels and in 2007 we saw a relationship between blood Pb levels and weight in swallows, which are described in a later section of this report. Finally Red-winged Blackbirds had slightly lower values of Pb in blood in 2006 than the other two species, but higher values in 2007. Blood Pb levels were similar for the two years in this species with an average of 0.45 ppm and a maximum of 2.6 ppm.

We found no difference in Pb levels between sites from Tree Swallow; however in both Marsh Wren and Red-winged Blackbird, levels of Pb were higher in samples collected at Kearny Marsh. In addition, we found that blood samples collected from nestlings at Marsh Resources in nests located in *Spartina* had higher Pb levels than those in *Phragmites*. This may have been due to between year differences in blood Pb levels, however, the trend is there and warrants further study. This type of difference between habitats would be in agreement with research that shows that *Spartina* releases more metals from its leaves while *Phragmites* is more effective at sequestering heavy metals (Windham et al. 2003, Burke et al. 2000). Since *Phragmites* is the dominant habitat at Kearny Marsh, and therefore one would anticipate more effective at removing metal contaminants, the higher levels of Pb at this site compared to sites dominated by other habitats may imply that the Pb contaminant concentrations of vegetation and the birds' prey base at this site are especially high.

We would anticipate adverse effects at the blood Pb levels found in this study. Some nestlings were still actively molting when the blood samples were collected, so they may still have been mobilizing some of the metal to deposit in feather tissues at the time of collection. Although we did not observe any obvious signs of lead poisoning, and most of the nestlings with high lead values fledged successfully, we did find a negative correlation between blood lead levels and body weight in Marsh Wrens in 2006 and Tree Swallows in 2007. These high Pb levels in Meadowlands birds are a concern and warrant further research.

Heavy metals and trophic level effects

All three passerine species in our study are intermediate level consumers whose diet consists of insects and other invertebrates, although Red-winged Blackbirds have a more varied diet (Kroodsma and Verner 1997, Yasukawa and Searcy 1995, Robertson et al. 1992) so it was not surprising that differences in the levels of heavy metals were not consistent in any one direction for the tissues analyzed (Figures 1-3, Tables 6-6A). For example, Marsh Wren eggs had higher levels of Hg than the other two species in both years of the study, but lower levels in feathers than the other two species in 2007. In addition, they had higher levels of blood Pb, but had lower feather Pb levels than blackbirds and swallows. Tree Swallows had higher levels of blood Cr than the other two species in 2006, but not different levels in 2007 and not different levels of feather Cr. As some metal contaminants are known to biomagnify (Weis 2005, Burger 2002), higher levels in consumer tissues may result from foraging at different trophic levels. However, the differences we found were not large in magnitude, nor were they consistent and in the same direction for all metals. Thus, we believe that these three species likely feed at similar trophic levels but have slightly different diets, thereby obtaining different contaminant loads through their food.

Mercury levels in eggs and feathers of Canada Geese were lower than the other species in this study, as would be expected since they are herbivorous and forage at a lower trophic level than the insectivorous passerines (Mowbray et al. 2002). Similarly, Hg levels in liver, with an average value of 0.04 ppm and maximum 0.13 ppm, and in muscle, with an average value of 0.01 ppm and maximum of 0.06 ppm, are low compared to those in the literature (e.g. in seaducks, Henny et al. 1995;) The environmental quality standard for human consumption set for Hg by the USFDA is 1.0 ppm (FDA 2001), while the European environmental standard which is more stringent is 0.3 ppm, both higher than the levels seen in Goose tissues we sampled. Therefore, these would be safe for human consumption in terms of the Hg levels.

The muscle levels of Pb of Canada Geese, at an average of 0.023 ppm and a maximum value of 0.19 ppm were relatively low compared to those reported in the literature (e.g. Fedynich et al. 2007, Henny et al. 1995). However, liver levels of Pb, at an average of 0.25 ppm and maximum 0.95 ppm were high, with 20 samples (over 75% of the samples) greater than 0.1 ppm, and 4 samples (15%) being greater than 0.5 ppm, the FDA action level of 0.5 µg/mL for lead in food products, and almost all had Pb levels over 0.1 ppm, the 0.1 µg/mL FDA action level for candy intended for use by infants and children (ATDSR 2005, FDA 2006). All of our samples were below the 5 ppm in the liver that would result in lead toxicosis (Friend 1987). The levels of Pb in goose feathers at an average of 1.9 ppm (Table 6A) were also elevated and higher than the levels found in the other species in our study. That is surprising considering that geese forage at a lower trophic level that the insectivorous passerines. Studies in marine environments have shown some trophic level effects in concentrations of this metal in bird eggs although the relationships are not always clear (Burger 2002, Burger ad Gochfled 2000b). Most marine organisms primarily accumulate lead from the water as lead is not transferred efficiently through the marine food chain (Szefer 1991), however lead may be transferred more efficiently from marine animals to mammalian consumers (Regoli and Orlando 1994). In Greenland, mussels had higher lead levels than fish, seagulls, and ringed seals from the same ecosystem (Dietz et al. 2000). These studies indicate that lead is not biomagnified through the marine food chain and often highest concentrations of lead are found at the lowest trophic levels. This may also be true of terrestrial food webs. It is also of interest that there was no difference between the three sites where these birds were sampled in the Pb levels in feathers or eggs, implying that this is not a local observation but that it describes the levels of this contaminant in geese overall.

Goose eggs at an average of 161 ppb (Table 6A) had higher levels of Pb than those of the passerines and again similar levels throughout the study area. Three of the eggs had Pb levels over 0.5 ppm, While it is unlikely that humans would consume these eggs, the high Pb levels may impact avian and especially mammalian predators that tend to be more sensitive to elevated Pb levels (Eisler 1988).

Furthermore, average levels of egg Pb, typically much lower than those in liver (Sydeman and Jarman 1998), were approximately 64% of the liver values. This implies that the birds likely sequester large amounts of this contaminant in the egg as has been seen in Pb dosing studies (e.g. Jeng et al. 1997). Similarly, the high levels of Pb in feathers compared to other tissue imply that birds are successful at sequestering that metal in the feathers. The birds were collected at the end of the breeding season and were involved in active molt, therefore were active at mobilizing and sequestering their contaminant loads. It would be interesting to assay muscle and liver tissue in non-molting birds, to determine whether their contaminant levels will be higher. We believe further study is needed on contaminant levels in waterfowl tissues to determine whether these high levels are a concern for human consumption.

The reasons behind the elevated Pb levels in geese are not clear and need to be further explored. Waterfowl are known to be subject and susceptible to poisoning from ingested lead shot (Mowbray et al. 2002, Pokras and Kneeland 2008). Lead shot stopped being used in the 1970s for hunting, (Mowbray et al. 2002), however, lead shot continues to be used in skeet shooting. In addition, lead sinkers used in fishing are known to result in increased Pb levels in waterfowl tissue (Pokras and Kneeland 2008, Pokras and Chafel 1992).

Differences and correlations between tissues

Cadmium and arsenic levels were generally low for all tissues and in all species studied compared to those measured in other studies (e.g. Burger 1993, Burger and Gochfled 2000b) and to the levels that are considered biologically harmful (Eisler 1985, 1988). In 2006, Hg levels were relatively high in eggs and feathers, but low for blood tissue in all species. Lead levels were low in eggs, but higher in feathers and in blood. Chromium levels were high in eggs and in blood, but relatively low in feathers. All metal levels for Tree Swallows in our study were much lower than those reported for swallows in the Meadowlands District by Kraus (1989). In Canada Geese, Cd and Hg levels were highest in liver and lowest in eggs, with muscle having an intermediate value. Chromium was also highest in liver, but not different between eggs and muscle. Lead was high in both liver and eggs, and lower in muscle.

Correlations between feather and blood concentrations of metals were weak. However, in cases where they were significant, the correlations were similar or stronger than those reported by Burger (1993). We suggest that we did not see a close correlation between blood and feathers because the blood samples were collected in nestlings that were at various stages of molt and thus at various stages of eliminating metals in the feathers (Condon and Cristol 2008).

Temporal effects on metal contaminant levels

We found a negative correlation between date and Pb levels in eggs of the three passerine species in our study. We also found a negative correlation of date and feather Pb in Red-winged Blackbirds, and date and blood Pb and Cr of blackbirds in a least one year of the study. Finally, we found a negative correlation of Pb levels and blood Hg levels of Marsh Wrens. Date explained a fair amount of the variation in the data (15-25%). Conversely, we found that Hg levels in blood and eggs of blackbirds, eggs of wrens and blood of swallows increased during the field season. Samples were taken from nestlings at approximately the same age throughout the season, so this cannot be explained as an age effect, that is, decreasing or increasing levels of metals in nestlings because of physiological changes as they grow.

There are some possible explanations for seasonal changes in contaminant levels. Eggs or nestlings sampled later in the season may have been produced by parents that had made earlier nesting attempts allowing them to sequester a significant amount of contaminants in a previous clutch. Bioavailability of Pb may decrease later in the season either because it is being incorporated into the tissues of the growing marsh plants or simply due to the chemical nature of the metals themselves. Similarly, perhaps bioavailability of Hg in water and sediments increases during the season or diet shifts result in intake of prey items that have higher Hg concentrations.

However, it is not clear why Hg levels would decrease in blood of Marsh Wren nestlings, increase in Tree Swallows and exhibit no change in Red-winged Blackbirds, or why Hg levels would increase in wren eggs but decrease in the blood with progressing season. The overall higher levels of Hg in wren eggs (Tables 6, 6A) suggest that nestlings of this species start their lives with an increased contaminant load, which decreases as the nestlings grow. Why they would be more effective at accomplishing this later in the season or why we do not see this pattern in the other two species is not clear. Possibly Hg levels in the diet of the other two species are higher and while they do sequester sufficient amounts of this metal to the feathers so it continues to concentrate in the blood. Since Marsh Wrens initiate nesting later in the season, another possibility is that the different patterns reflect an increasing then decreasing trend in bioavailable Hg levels. Further research is needed to understand the connection between bioavailability, prey contaminant levels, and levels of contaminants in bird tissues.

Effect of metals on egg viability and nestling growth

Mercury levels in Marsh Wrens in 2006 were higher in un-hatched vs. randomly collected eggs. Because the measured levels of mercury in eggs during that first field season were lower than the levels of reproductive impacts reported in the literature (Wolfe et al. 1998), we further explored that effect with samples collected during the 2007 field season, including additional samples from Red-winged Blackbirds and Tree Swallows. We once again found that unhatched eggs had higher Hg levels (Figures 5-6). Even within a nest, unhatched eggs had higher Hg levels than the ones randomly collected. Out of 433 nests found and monitored, unhatched eggs were found in only 15 (approximately 3%), therefore, we believe that the impact on the passerine populations is currently minimal. However, these birds may have lower sensitivity thresholds to this metal when it accumulates in their eggs than that of species typically used in egg hatching success studies (Heinz 1974, 1979, Wolfe et al. 1998). This relationship should be further explored and Hg levels should be carefully monitored during restoration of heavily contaminated sites in the District (e.g. Berry’s Creek), because increased levels of this metal during the restoration process may impact passerine bird hatching success in the NJ Meadowlands and the populations of these species.

Increased contaminant levels in nestling feathers for all species compare to the eggs, and in some cases blood, suggest that after eggs hatch, offspring receive additional contaminant loads through food delivered by parents (Table 8, 8A). Increased contaminant levels can affect physiology and behavior associated with foraging, and both of these may impact body weight and growth (Burger and Gochfeld 2003, Burger and Gochfeld 2000, Wolfe et al. 1998, Gochfeld 1997, Burger 1995, Eisler 1988, Eisler 1987a,b, Eisler 1986, Eisler 1985). We found an effect of Pb on body weight during our study, but no effects on any other morphometric parameters that we measured. Although mercury levels in tissues were also generally high and may have contributed to observed differences in nesting success (see above), we found no effect of this contaminant on growth.

In Marsh Wrens, in 2006, lead levels in blood were negatively correlated with body weight. We did not find this relationship in 2007 in this species, possibly because Pb levels were generally lower in wren blood samples during the second year of our study. However, in 2007 we found a similar negative relationship between blood Pb levels and nestling weight in Tree Swallows. In this case, the model explaining weight was complex and included site and specific nest as well as Pb levels, but had a good fit, explaining 40% of weight. To explore the relationship further we looked at differences between nestlings from the same nest. Doing this removes effects of specific nest location, parental quality, and possibly genetic differences. The effect of Pb persisted in that the smaller nestling had higher Pb levels than the larger nestling. Our results are an indication that Pb may have an effect on growth in this species. Reduced weight gain is one of the known effects of elevated lead levels (Burger 1995), thus elevated lead levels found in our study likely resulted in the reduced weights we observed in wren nestlings. These negative impacts on growth in young birds, are the type of the sublethal effects one would anticipate when contaminant concentrations are high, but not high enough to cause nest failure.

Organic contaminants

Levels of DDT and derivatives in Mallard eggs were generally low compared to those reported in other duck species in the 1970s (e.g. Longcore and Mulhern 1973), in Canada Geese from Hamilton Harbor in 1989 (Weseloh et al. 1995), and in more recent studies of Osprey (*Pandion haliaetus*) in the Delaware River (Clark et al. 1998) and below the levels that may cause egg shell thinning (Wiemeyer et al. 1988). We do not think that DDT and derivatives are a concern for waterfowl species in the Meadowlands. Heptachlor, Endosulfan, Endrin and Methoxychlor levels were similarily low or not detected. Dieldrin levels were higher, but still below the levels considered harmful (Peakall 1996).

Declining populations of Caspian Terns (*Sterna caspia*) has been associated with elevated PCB levels in the blood (Eisler and Belisle 1996), and high levels of PCBs in White-tailed Sea Eagles (*Haliaeetus albicilla*) in the Baltics have resulted in lowered reproductive success (Falandysz et al. 1994). PCB 126, 81, and 77 (the non-ortho PCBs) are among the most toxic of all PCB congeners based on their toxic equivalence factor (Eisler and Belisle 1996, Van der Berg et al. 1998, Custer et al. 1997). Of these, PCB 126 and 81 were below detection limits or very low in all of the Mallard eggs sampled during our study. PCB 77 was found in high levels (10.1±6.5 ppb) compared to those seen in other studies, for example in Peregrine Falcon (*Falco peregrinus*) eggs in

California (0.9 ppb; Jarman et al. 1993) and Red-breasted Merganser (*Mergus serrator*) eggs in Michigan (3-5 ppb; Williams et al. 1995). However, even concentrations of PCB 77 as high as 100-5,000 ppb in eggs have been reported to not affect hatchability and not produce any abnormalities in Mallard chicks (Eisler and Belisle 1996) and the high toxicity is reflected mainly in studies of domestic chickens (Brunstrom and Darnerud 1983, Brunstrom and Lund 1988).

PCB 118 was found in the highest concentrations among the PCB congeners analyzed in our study, at an average 31.3 ppb. These are lower than the averages measured in Great Blue Heron (*Ardea herodias*) eggs on the Upper Mississippi (80.78 ppb, Custer et al. 1997), Red-breasted Merganser eggs in the Great Lakes (415 ppb, Williams et al. 1995), and pipping eggs of Black-crowned Night Herons (63.8 ppb, Rattner et al. 2000), as would be expected for species that are at a higher trophic level.

While the limited analysis of organic contaminants in this study does not raise any major concerns about the effects they may have on breeding bird populations, further study is needed to improve our understanding of risks. We have only analyzed eggs from Mallards, species that forage at a lower trophic level and are not as susceptible to the effects of biomagnification as are the three insectivorous passerine species in our study. Furthermore, the recommended approach for determining the overall toxicity of organic contaminants on wildlife is to calculate toxic equivalency concentrations of polychlorinated dibenzo-p-dioxins (PCDDs) and dibenzofurans (PCDFs) in tissues along with those of PCBs (Van der Berg et al. 1998).

CONCLUSION AND FUTURE RESEARCH NEEDS

Our study revealed few differences between sites in metal levels or in nesting success, and even in cases where we did find differences among sites these were not consistent across tissues and species. For example, eggs of Red-winged Blackbirds and Marsh Wrens had higher Hg levels at Marsh Resources, but no difference was seen among sites in Hg levels in feathers or blood of these two species. Furthermore, blood Pb levels of these two species were higher at Kearny Marsh.

Habitat may play a more important role in reproductive success and metal levels than site. *Phragmites* does not provide the best substrate and many nests in this habitat collapsed during the breeding season, as reflected in lower fledging success in *Phragmites* habitat vs. groundsel for Red-winged Blackbirds and *Spartina* for Marsh Wren. On the other hand, metal contaminant levels may be lower in this type of habitat, as metal bioavailability is lower (Windham et al. 2003). We found a few cases of lower metal levels in bird tissues from nests in *Phragmites* vs. *Spartina,* specifically lower Hg in eggs and lower Pb in blood of Marsh Wrens. This complex interaction of habitat, contaminant level and nesting success should be further explored.

In Tree Swallows, we found lower nesting success at Mill Creek and Kearny Marsh than at the other sites. Even though blood Hg levels were higher at Mill Creek in this species, we think that other factors (e.g. higher predation) is the cause of the decreased breeding success. This is a question that should be pursued further in terms of nest box placement, considering that the NJMC has an extensive nest box program.

Mercury, lead and chromium levels in our study were high relative to those found in other studies and in some cases reached levels where one may anticipate adverse effects. Specifically, average lead levels in blood were higher than the 0.4 ppm effect threshold level (Eisler 1985) for all three passerine species in our study. On the positive side, all metal levels measured in Tree Swallows were lower than those measured in the 80s (Kraus et al. 1988), suggesting that conditions in the Meadowlands have improved in the past twenty years.

We found some impacts of elevated contaminant levels on reproductive success during our study. First, our results suggest an effect of Hg on hatching success; unhatched eggs had higher Hg levels than randomly collected eggs in our study, a pattern that held true even when looking at eggs within the same nest. Second, we found a negative correlation between Pb level and growth in nestlings. In within nest comparisons, the lightest nestlings had higher levels of Pb in their blood than the heaviest nestlings. Survival of juvenile passerines is positively correlated with fledging mass (Tinbergen and Boerlijst 1990), so lower weight at fledging results in lower survival. Since the combination of impacts on hatching success and nestling growth have the potential to affect fitness and reproductive success in the Meadowlands, contaminants and various measures of breeding success should continue to be monitored in the District.

Our results suggest that passerines may provide a good species group to study at contaminant levels. We believe continued monitoring is essential, given the ongoing restoration activities in the Meadowlands District. While many suggest that upper level consumers, such as raptors, are the best models for looking at contaminants in biota, our work with intermediate level consumers reveals that we can use these species to track contaminant levels and their effects. Tree Swallows may be an especially effective model species, since they can easily be attracted to nest boxes that can be monitored through the season. We recommend targeted placement and monitoring of nest boxes in association with suspected or potential issues with metal contaminants in the District. We also recommend continued monitoring of contaminant levels in birds to track changes and respond effectively to any potential increases. Furthermore this species is a good model to look at reproductive success of birds across the Meadowlands District to determine whether specific sites can support source populations or are reproductive sinks.

There were some interesting temporal patterns in metal contaminant levels, which should be explored further. Levels of Pb generally decreased in tissues as the season progressed, while Hg levels generally increased. It is not clear whether the decrease in Pb is the result of eliminating metals in early clutches or the result of lower bioavailability of contaminants as the season progresses and possibly more metals from sediments and water are taken up by growing vegetation. Also it is not clear why Hg levels increase while Pb decreases. Understanding what drives these patterns of metal concentrations in wildlife tissues has significant management implications. For example, restoration activities may be timed to avoid a huge influx of contaminants into biota during the reproductive period. We recommend incorporating a temporal aspect in any biomonitoring of heavy metals in the Meadowlands District.

Increased lead and mercury levels in birds of the Meadowlands District that eventually may be consumed by people can have a human health impact if contaminant levels are elevated. We found very high levels of Pb in Canada Goose feathers and eggs. We also found high levels of Pb in the livers of these birds. Our samples were all collected from molting or recently molted birds, which thereby would have sequestered their contaminant loads into feathers. We believe further study is needed to determine whether muscle Pb levels in non-molting birds are high enough to be of concern to human consumption. In addition, more study is needed to understand why levels of Pb are high in geese in the Meadowlands District.

Finally, while we had proposed to assay tissues for organic contaminants, we were only able to analyze a small set of egg samples from Mallards. The difficulty of assaying eggs and the small amount of sample available for most of our tissues, as well as the specificity of some of the organics analyses (for example dioxins, PBDEs) make this analysis feasible only at some laboratories. However, we believe that it is important to continue to pursue this, given the high levels of metals in some of our samples, including the Goose tissues, and the possibility of synergistic effect.

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Table 1. Listing of samples collected for contaminant analysis during the 2006 breeding season in the Meadowlands District. Table is arranged in alphabetical order by species.

Site	Species	Number of nests where eggs were collected	Number of eggs collected	Number of egg samples analyzed	Number of nests where blood was collected	Number of blood samples analyzed *	Number of feather samples analyzed
Kearny Marsh	Marsh Wren	4	4	4	1	4	1
Marsh Resources	Marsh Wren	15	19	16	11	28	11
Riverbend	Marsh Wren	8	10	10	3	6	3
Sawmill	Marsh Wren	1	1	1	0	0	0
Harrier Meadow	Red-winged Blackbird	8	11	11	12	17	9
Kearny Marsh	Red-winged Blackbird	14	15	14	21	35	15
Marsh Resources	Red-winged Blackbird	11	12	10	7	11	5
DeKorte bird boxes	Tree Swallow	0	0	0	5	14	5
Harrier Meadow	Mallard	2	2	2			
Marsh Resources	Mallard	4	4	4			
TOTAL		**67**	**78**	**72**	**60**	**115**	**49**

* Blood was collected from each nestling at each nest whenever possible, so total number of blood samples is not equal to the number of nests sampled

Table 1A. Listing of samples collected for contaminant analysis during the 2007 breeding season in the Meadowlands District. Table is arranged in alphabetical order by species.

Site	Species	Number of nests where eggs were collected	Number of eggs collected	Number of egg samples analyzed	Number of nests where blood was collected	Number of blood samples analyzed	Number of feather samples analyzed
Kearny Marsh	Marsh Wren	9	10	8	6	20	0
Marsh Resources	Marsh Wren	16	16	16	19	71	9
Harrier Meadow	Red-winged Blackbird	24	25	24	15	14	5
Kearny Marsh	Red-winged Blackbird	37	38	34	44	28	16
Marsh Resources	Red-winged Blackbird	19	20	18	15	35	10
DeKorte	Tree Swallow	16	17	17	13	41	12
Kearny Marsh	Tree Swallow	19	20	18	11	54	10
Marsh Resources	Tree Swallow	6	6	6	4	17	4
Mill Creek	Tree Swallow	16	16	16	5	19	6
Harrier Meadow	Canada Goose						13
Kearny Marsh	Canada Goose		2	2			0
Mill Creek	Canada Goose		29	29			5
Skeetkill Marsh	Canada Goose		3	3			8
TOTAL		**162**	**202**	**191**		**299**	**98**

Table 2. Listing of nests found during the 2006 breeding season in the Meadowlands District. Table is arranged in alphabetical order by species and site.

						Red-winged Blackbird				Tree Swallow	
	Kearny Marsh	**Marsh Resources**	**Riverbend**	**Sawmill**	**Total**	**Harrier Meadow**	**Kearny Marsh**	**Marsh Resources**	**Total**	**DeKorte**	**Total**
Total # of nests found	21	279	41	23	**364**	21	49	28	**98**	15	**15**
# of active nests found	5	23	13	5	**46**	15	31	23	**69**	7	**7**
# of nests that were found with eggs and were monitored	2	17	10	0	**29**	11	21	20	**52**	4	**4**
# of nests that were found with nestlings and were monitored	1	5	2	0	**8**	4	10	3	**17**	3	**3**
# of active nests found with eggs or nestlings and monitored	**3**	**22**	**12**	**0**	**37**	**15**	**31**	**23**	**69**	**7**	**7**
# of nests found at the egg stage that hatched succesfully	2	12	6	0	**20**	9	16	10	**35**	4	**4**
# of nests found at the egg stage that fledged succesfully	1	8	3	0	**12**	9	15	9	**33**	3	**3**
# of nests found at the nestling stage that fledged successfully	1	5	2	0	**8**	3	10		**13**	3	**3**
Total # of nests that fledged succesfully	2	13	5	Unknown	**20**	12	25	11	**48**	6	**6**
Apparent Nesting success: nests fledged/active nests	**0.40**	**0.57**	**0.38**	Unknown	**0.43**	**0.80**	**0.81**	**0.48**	**0.70**	**0.86**	**0.86**

Table 2A. Listing of nests found during the 2007 breeding season in the Meadowlands District. Table is arranged in alphabetical order by species and site.

	Marsh Wren			Red-winged Blackbird				Tree Swallow				
	Kearny Marsh	**Marsh Resources**	**Total**	**Harrier Meadow**	**Kearny Marsh**	**Marsh Resources**	**Total**	**DeKorte**	**Kearny Marsh**	**Marsh Resources**	**Mill Creek**	**Total**
Total # of nests found	49	229	**278**	45	92	35	**172**	20	33	7	20	**80**
# of active nests found	13	38	**51**	36	76	32	**144**	20	33	7	20	**80**
# of nests that were found with eggs and were monitored	13	28	**41**	33	68	28	**129**	20	23	7	19	**69**
# of nests that were found with nestlings and were monitored	0	9	**9**	3	8	4	**15**	0	10	0	1	**11**
# of active nests found with eggs or nestlings and monitored	**13**	**37**	**50**	**36**	**76**	**32**	**144**	**20**	**33**	**7**	**20**	**80**
# of nests found at the egg stage that hatched succesfully	9	18	**27**	16	16	18	**50**	17	10	5	5	**37**
# of nests found at the egg stage that fledged succesfully	6	12	**18**	14	40	12	**66**	13	2	4	3	**22**
# of nests found at the nestling stage that fledged successfully	0	9	**9**	2	6	4	**12**		9		1	**10**
Total # of nests that fledged young (found at egg or nestling stage)	6	21	**27**	16	46	16	**78**	13	11	4	4	**32**
Apparent Nesting success: nests fledged/active nests	**0.46**	**0.55**	**0.53**	**0.44**	**0.61**	**0.50**	**0.54**	**0.65**	**0.33**	**0.57**	**0.20**	**0.40**

Table 3. Total number of eggs laid, eggs hatched and fledged nestlings of Red-winged Blackbirds and Marsh Wrens and Tree Swallows for all sites in 2006. Number fledged is presented as the average number of nestlings fledged per nest for nests that fledged sucessfully and as the average number fledged across all nests that were monitored during the survey. Tree Swallow data from 2006 are not included because all nests were found with nestlings already in them.

	Site	Number of eggs laid (found in egg stage)	Number nestlings (found already hatched)	Maximum Number of nestlings observed	Number of nests monitored	Number of nests fledged	Number of chicks fledged	Total number fledged per successful nest	Total number fledged across all nests
Red-winged Blackbird									
All nests	Harrier	37	10	28	15	12	22	1.83	1.47
	Kearny	59	30	63	31	25	42	1.68	1.35
	Marsh Resources	61	5	34	23	11	15	1.36	0.65
Marsh Wren									
All nests	Kearny	9	3	7	3	2	7	3.50	2.33
	Marsh Resources	87	13	50	22	13	38	2.92	1.73
	Riverbend	52	4	27	12	5	12	2.40	1.00

Table 3A. Total number of eggs laid, eggs hatched and fledged nestlings of Red-winged Blackbirds and Marsh Wrens and Tree Swallows for all sites in 2007. Number fledged is presented as the average number of nestlings fledged per nest for nests that fledged sucessfully and as the average number fledged across all nests that were monitored during the survey.

	Site	Number eggs laid (found in egg stage)	Eggs Collected	Number nestlings (found already hatched)	Maximum Number of nestlings observed	Number of nests monitored	Number of nests fledged	Number of nestlings fledged	Total number fledged per successful nest	Total number fledged across all nests
Red-winged Blackbird										
All nests	Harrier	101	25	8	46	36	16	33	2.06	0.92
	Kearny	218	38	17	155	76	46	90	1.96	1.18
	Marsh Resources	89	20	9	53	32	16	35	2.19	1.09
Marsh Wren										
All nests	Kearny	54	10	0	33	13	6	18	3.00	1.38
	Marsh Resources	122	16	33	100	37	21	72	3.43	1.95
Tree Swallow										
All nests	DeKorte	96	16	0	61	20	13	43	3.31	2.15
	Kearny	118	20	46	89	33	11	55	5.00	1.67
	Marsh Resources	36	6	0	20	7	4	17	4.25	2.43
	Mill Creek	81	16	4	26	20	4	19	4.75	0.95

Table 4. Effects of nest age and stage and site on Daily Survival Rates (DSR) of Red-winged Blackbirds and Marsh Wrens in the Meadowlands District in 2006. For Red-winged Blackbirds, sites included were Kearny Marsh, Harrier Meadow, and Marsh Resources. For Marsh Wrens, sites were Kearny Marsh, Marsh Resources, and Riverbend Marsh. {Basic}is the DSR model without incorporating any covariates. Scaled values of Akaike's Information Criterion (ΔAICc) and Akaike weights are also presented.

Red-winged Blackbird	AICc	ΔAICc	AICc Weights	Model Likelihood
basic + site	150.056	0.000	0.217	1.000
Nest Daily Survival Rate basic model (DS	151.232	1.176	0.120	0.556
basic + age	151.517	1.462	0.104	0.482
basic + date	152.069	2.013	0.079	0.365
basic + stage	160.909	10.853	0.001	0.004

Marsh Wren	AICc	ΔAICc	AICc Weights	Model Likelihood
basic + stage	66.462	0.000	0.586	1.000
basic + age	67.995	1.533	0.272	0.465
Nest Daily Survival Rate basic model (DS	70.000	3.538	0.100	0.171
basic + site	73.932	7.471	0.014	0.024
basic + date	148.254	81.792	0.000	0.000

* Metals were included when running the model, but are not shown here because the AIC weights and Model Likelihood were approximately zero.

Table 4A. Model results for Daily Survival Rates (DSR) of Red-winged Blackbirds, Marsh Wrens, and Tree Swallows in the Meadowlands District obtained using nest success data for all nests studied in 2007. Covariates inlude site and habitat where appropriate. {Basic}is the DSR model without incorporating any covariates. Scaled values of Akaike's Information Criterion (ΔAICc) and Akaike weights are also presented.

Red-winged Blackbird	AICc	ΔAICc	AICc Weights	Model Likelihood
{basic}+habitat}+site}	389.96	0.00	0.77	1.00
{basic}	393.67	3.71	0.12	0.16
{basic}+site}	394.62	4.66	0.08	0.10
{basic}+habitat}	396.53	6.57	0.03	0.04
Marsh Wren				
{basic}	119.00	0.00	0.92	1.00
{basic}+site}	125.43	6.43	0.04	0.04
{basic}+habitat}	125.46	6.45	0.04	0.04
{basic}+habitat}+site}	131.88	12.88	0.00	0.00
Tree Swallow				
{basic}+site}	233.95	0.00	1.00	1.00
{basic}	244.63	10.68	0.00	0.00

Table 4B. Model results for Daily Survival Rates (DSR) of Red-winged Blackbirds, Marsh Wrens, and Tree Swallows in the Meadowlands District obtained using nest success data for nests from which eggs were collected and analyzed in 2007. Covariates include site, habitat and metal levels. {Basic}is the DSR model without incorporating any covariates. Scaled values of Akaike's Information Criterion (ΔAICc) and Akaike weights are also presented.

Red-winged Blackbird	AICc	ΔAICc	AICc Weights	Model Likelihood
{basic}+cr}	193.00	0.00	0.47	1.00
{basic}	194.74	1.74	0.20	0.42
{basic}+Pb}	195.05	2.04	0.17	0.36
{basic}+hg}	195.38	2.37	0.14	0.31
{basic}+habitat}	196.35	1.68	0.18	0.43
{basic}+site}	198.34	3.67	0.07	0.16
{basic+site+habitat}	198.41	5.41	0.03	0.07
{basic}+metals}	199.12	6.12	0.02	0.05
Marsh Wren				
{basic}+pb}	67.24	0.00	0.38	1.00
{basic}+hg}	68.49	1.25	0.20	0.54
{basic}	68.71	1.47	0.18	0.48
{basic}+cr}	70.53	3.29	0.07	0.19
{basic}+site}	70.66	3.42	0.07	0.18
{basic}+habitat}	70.73	3.50	0.07	0.17
{basic}+metals}	73.00	5.76	0.02	0.06
Tree Swallow				
{basic}+site}	156.07	0.00	0.90	1.00
{basic}+metals}+site}	161.73	5.66	0.05	0.06
{basic}	164.16	8.09	0.02	0.02
{basic+PB}	164.45	8.38	0.01	0.02
{basic+cr}	165.25	9.18	0.01	0.01
{basic+hg}	166.11	10.04	0.01	0.01
{basic}+metals}	167.72	11.65	0.00	0.00

Table 5. Daily Survival Rates (DSR) and nesting success at Meadowlands breeding sites in 2006. Nesting success estimates are presented based on the number of days it takes from intitiation of incubation to fledging. Incubation periods for these species and nesting duration from the literature are included.

Red-winged Blackbird	Kearny Marsh	Marsh Resources	Harrier Meadow
Daily Survival Rate	0.98	0.96	0.98
Nest Success (range)	0.64 - 0.70	0.34 - 0.43	0.69 - 0.75
Apparent nest success	0.81	0.48	0.69
Incubation period (from day 1st egg layed)	10 --12 days		
Nestling duration	9 -- 12 days		

Marsh Wren	Kearny Marsh	Marsh Resources	Riverbend
Daily Survival Rate	0.98	0.97	0.97
Nest Success (range)	0.61 - 0.54	0.51 - 0.42	0.51 - 0.42
Apparent nest success	0.40	0.57	0.38
Incubation period (from day 1st egg layed)	12 -- 16 days		
Nestling duration	13 -- 16 days		

Tree Swallow	DeKorte
Daily Survival Rate	
Nest Success (range)	
Apparent nest success	0.86
Incubation period (from day 1st egg layed)	16 -- 23 days
Nestling duration	16 -- 17 days

Table 5A. Daily Survival Rates (DSR) estimates of Red-winged Blackbirds, Marsh Wrens, and Tree Swallows in the Meadowlands District in 2007 obtained using nest success data and program MARK. Values in Bold were significantly higher than values in Bold Italic.

			95% Confidence Interval	
Red-winged Blackbird	**DSR estimate**	**Standard Error**	**Lower**	**Upper**
Harrier Meadow	0.9522	0.0105	0.9270	0.9690
Marsh Resources	0.9514	0.0119	0.9221	0.9701
Kearny Marsh	0.9684	0.0056	0.9554	0.9777
Groundsel	0.9574	0.0076	0.9397	0.9701
Phragmites	0.9638	0.0058	0.9505	0.9737
Marsh Resources/*Phragmites*	***0.8585***	0.0539	0.7176	0.9354
Marsh Resources/Groundsel	**0.9650**	0.0109	0.9362	0.9811
Marsh Wren				
Marsh Resources	0.9660	0.0081	0.9458	0.9788
Kearny Marsh	0.9684	0.0118	0.9351	0.9849
Spartina	0.9663	0.0118	0.9339	0.9831
Phragmites	0.9669	0.0082	0.9466	0.9797
Tree Swallow				
DeKorte	**0.9841**	0.0060	0.9671	0.9924
Mill Creek	***0.9384***	0.0157	0.8995	0.9628
Marsh Resources	0.9801	0.0114	0.9400	0.9936
Kearny Marsh	***0.9384***	0.0128	0.9080	0.9592

Table 6. Level of metals (Mean and Standard Error) in different tissues for 4 species of birds in the Meadowlands District 2006. Metal levels are in parts per billion and are presented as both dry and wet weight for eggs, dry weight for feathers and wet weight for blood. Statistical analyses for egg metal levels were run on the dry weight values,, but wet weights are also shown. Kruskal Wallis values reflect comparisons among species. Means marked with different letters (A or B) were significantly different from each other; means with more than one letter (AB) were not significant from means marked with either A or B. NS= Nonsignificant.

	Red-winged blackbird		**Marsh Wren**		**Tree Swallow**		**Mallard**		KRUSKAL WALLIS X^2 (P)
	Mean	Std Error	Mean	Std Error	Mean	Std Error	Mean	Std Error	
Blood	n=63		n= 38		n=14		N/A		
Arsenic (As)	4.64	1.98	3.73	2.61	0.95	0.85			NS
Cadmium (Cd)	13.55 (AB)	3.35	26.89 (A)	6.74	3.58 (B)	1.09			12.06 (0.0024)
Chromium (Cr)	517.81 (B)	103.55	504.77 (B)	78.62	1032.43 (A)	212.21			10.2 (0.0061)
Lead (Pb)	418.61 (B)	52.36	795.64 (A)	142.25	944.15 (A)	226.43			9.43 (0.009)
Mercury (Hg)	23.18	3.43	35.32	9.7	19.43	5.44			NS
Feathers	n=29		n=15		n=5		N/A		
Arsenic (As)	142.18 (A)	30.12	7.01 (B)	4.27	70.24 (AB)	39.25			5.34 (0.0158)
Cadmium (Cd)	18.59 (B)	6.61	30.93 (A)	7.06	11.4 (B)	4.28			8.62 (0.0134)
Chromium (Cr)	606.83 (B)	53.21	1043.27 (A)	109.28	658.8 (B)	219.13			14.1 (0.0009)
Lead (Pb)	1077.62 (AB)	141.85	431.87 (B)	73.63	1364.6 (A)	776.18			7.8 (0.0202)
Mercury (Hg)	825.97 (_C)	114.95	3231.47 (A)	236.55	2043.8 (B)	355.16			31.06 (0.001)
Eggs (Wet Weight)	n=35		n=31		N/A		n=6		
Arsenic (As)	5.98	1.61	10.07	3.61			16.23	6.01	8.76 (0.01)
Cadmium (Cd)	0.26	0.08	0.37	0.17			0.29	0.14	NS
Chromium (Cr)	120.33	27.57	59.08	16.85			42.6	20.52	13.29 (0.001)
Lead (Pb)	38.47	5.33	34.71	5.28			62.14	12.66	NS
Mercury (Hg)	48.21 (B)	6.42	197.07 (A)	19.22			75.14 (B)	12.76	33.65 (<.0001)
Eggs (Dry Weight)	n=35		n=31		N/A		n=6		
Arsenic (As)	34.14	9.15	50.67	18.19			51.37	19.02	
Cadmium (Cd)	1.47	0.048	1.87	0.84			0.92	0.45	
Chromium (Cr)	707.09	159.53	297.33	84.83			134.83	64.95	
Lead (Pb)	219.6	29.8	174.68	26.55			196.67	40.08	
Mercury (Hg)	275.2	35.82	991.87	96.72			237.83	40.38	

Table 6A. Level of metals (Mean and Standard Error) in different tissues for 4 species of birds in the Meadowlands District 2007. Metal levels are in parts per billion and are presented as both dry and wet weight for eggs, dry weight for feathers and wet weight for blood. Statistical analyses for egg metal levels were run on the dry weight values,, but wet weights are also shown. Kruskal Wallis values reflect comparisons among species. Means marked with different letters (A, B, C, D) were significantly different from each other; means with more than one letter (AB) were not significant from means marked with either A or B. NS= Nonsignificant.

	Red-winged blackbird		**Marsh Wren**		**Tree Swallow**		**Canada Goose**		KRUSKAL WALLIS X^2 (P)
	Mean	Std Error	Mean	Std Error	Mean	Std Error	Mean	Std Error	
Blood	n=77		n= 91		n=131		N/A		
Arsenic (As)	2.03 (B)	0.59	19.57 (A)	2.65	1.12 (B)	0.39			89.56 (<.0001)
Cadmium (Cd)	13.58 (A)	2.45	14.11 (A)	2.04	3.53 (B)	0.7			47.35 (<.0001)
Chromium (Cr)	259.63	17.39	275.25	20.18	288.38	19.96			NS
Lead (Pb)	363.92 (A)	59.53	348.02 (A)	51.3	202.27 (B)	27.35			17.87 (<.0001)
Mercury (Hg)	15.28	1.95	16.85	2.19	15.58	1.77			NS
Feathers	n=31		n=9		n=32		n=26		
Arsenic (As)	102.49 (A)	32.64	0.1 (B)	0	0.1 (B)	0	67.46 (AB)	31.95	3.7 (0.014)
Cadmium (Cd)	63.4 (B)	17.04	83.89 (A)	16.2	91.72 (A)	21.32	85.58 (A)	10.22	12.62 (0.005)
Chromium (Cr)	1276.48 (A)	88.05	970 (B)	288.95	1181.41 (AB)	178.81	1358.08 (AB)	240.85	7.87 (0.048)
Lead (Pb)	1450.11 (A)	236.64	172.28 (_C)	134.13	571.32 (B)	176.44	1908.85 (A)	385.73	23.7 (<.0001)
Mercury (Hg)	620.94 (A)	79.98	298.57 (B)	75.19	658.94 (AB)	84.36	258.02 (AB)	41.83	18.63 (0.0003)
Eggs (Wet Weight)	n=76		n=24		n=57		n=34		
Arsenic (As)	5.83	1.34	1.12	0.57	6.78	1.62	5.47	2.55	NS
Cadmium (Cd)	0.79	0.17	0.31	0.14	0.39	0.17	0.22	0.08	27.44 (<.0001)
Chromium (Cr)	50.92 (AB)	3.2	74.32 (A)	16.15	47.68 (BC)	6.64	37.29 (_C)	6.29	19.71 (0.0002)
Lead (Pb)	27.73 (B)	2.04	10.9 (_C)	3.34	19.99 (B)	1.71	161.1 (A)	36.71	77.08 (<.0001)
Mercury (Hg)	39.49 (_C)	3.32	121.05 (A)	10.78	76.66 (B)	5.27	4.29 (D)	0.3	122.12 (<.0001)
Eggs (Dry Weight)	n=76		n=24		n=57		n=34		
Arsenic (As)	32.84	7.55	5.45	2.75	33.27	7.93	17.17	8.01	
Cadmium (Cd)	4.45	0.96	1.5	0.67	1.93	0.82	0.7	0.24	
Chromium (Cr)	286.86	18.01	360.63	78.36	234	32.59	117.06	19.74	
Lead (Pb)	156.21	11.48	52.87	16.18	98.11	8.37	505.71	115.24	
Mercury (Hg)	222.49	18.73	587.34	52.33	376.24	25.85	13.48	0.95	

Table 6B. Level of metals (Mean and Standard Error) in different tissues for Red-winged Blackbirds and Marsh Wrens of the Meadowlands District collected in 2006 and 2007. Metal levels are in parts per billion and are presented as both dry and wet weight for eggs, dry weight for feathers and wet weight for blood. Statistical analyses for egg metal levels were run on the wet weight values,, but dry weights are also shown for comparisons with peer reviewed literature. Kruskal Wallis values reflect comparisons between years, NS= Nonsignificant.

	Red-winged blackbird					**Marsh Wren**				
	2006		2007			2006		2007		
	Mean	Std Error	Mean	Std Error	KRUSKAL WALLIS X2 (P)	Mean	Std Error	Mean	Std Error	KRUSKAL WALLIS X2 (P)
Blood	n=63		n=77			n= 38		n= 91		
Arsenic (As)	4.64	1.98	2.03	0.59	5.7 (0.017)	3.73	2.61	19.57	2.65	28.61 (<.0001)
Cadmium (Cd)	13.55	3.35	13.58	2.45	NS	26.89	6.74	14.11	2.04	4.68 (0.03)
Chromium (Cr)	517.81	103.55	259.63	17.39	NS	504.77	78.62	275.25	20.18	3.4 (0.048)
Lead (Pb)	418.61	52.36	363.92	59.53	3.88 (0.049)	795.64	142.25	348.02	51.3	8.79 (0.003)
Mercury (Hg)	23.18	3.43	15.28	1.95	NS	35.32	9.7	16.85	2.19	NS
Feathers	n=29		n=31			n=15		n=9		
Arsenic (As)	142.18	30.12	102.487	32.64	NS	7.01	4.27	0.1	0	NS
Cadmium (Cd)	18.59	6.61	63.4	17.042	NS	30.93	7.06	83.89	16.2	10.19 (0.0014)
Chromium (Cr)	606.83	53.21	1276.484	88.054	27.96 (<.0001)	1043.27	109.28	970	288.95	NS
Lead (Pb)	1077.62	141.85	1450.111	236.644	NS	431.87	73.63	172.28	134.13	6.51 (0.012)
Mercury (Hg)	825.97	114.95	620.935	79.977	NS	3231.47	236.55	298.57	75.19	16.2 (<.0001)
Eggs (Wet Weight)	n=35		n=76			n=30		n=24		
Arsenic (As)	5.98	1.61	10.07	3.61	NS	5.83	1.34	1.12	0.57	NS
Cadmium (Cd)	0.26	0.08	0.37	0.17	NS	0.79	0.17	0.31	0.14	6.45 (0.02)
Chromium (Cr)	120.33	27.57	59.08	16.85	6.98 (0.0082)	50.92	3.2	74.32	16.15	4.29 (0.04)
Lead (Pb)	38.47	5.33	34.71	5.28	6.31 (0.013)	27.73	2.04	10.9	3.34	12.54 (0.0004)
Mercury (Hg)	48.21	6.42	197.07	19.22	NS	39.49	3.32	121.05	10.78	6.82 (<0.009)

Table 7A. Metal levels (Mean ± SE) in birds in the Meadowlands Disctrict in 2006 as a function of location of tissue collection. Metal levels are in parts per billion and are presented as both dry and wet weight for eggs, dry weight for feathers and wet weight for blood. Means marked with different letters (A, B, C, D) were significantly different from each other; means with more than one letter (AB) were not significant from means marked with either A or B. NS= Nonsignificant.

Site name	Kearny Marsh		Marsh Resources		Harrier Meadow		KRUSKAL WALLIS X^2 (P)
	Mean	Std Error	Mean	Std Error	Mean	Std Error	
Red-Winged Blackbirds							
Eggs (Dry Weight)	n=14		n=10		n=11		
Arsenic (As)	21.5 (B)	11.64	75.12 (A)	22.77	12.97 (B)	6.27	9.16 (0.0102)
Cadmium (Cd)	0.93	0.61	1.32	0.08	2.3	1.11	NS
Chromium (Cr)	762.85	279.81	326.6	29.78	987.09	355.62	NS
Lead (Pb)	253.21	57.99	214.4	30.69	181.55	54.6	NS
Mercury (Hg)	310.86	70.39	301.7	65.36	205.73	38.49	NS
Eggs (Wet Weight)	n=14		n=10		n=11		
Arsenic (As)	3.87	2.09	13.53	4.1	2.3	11.29	
Cadmium (Cd)	0.16	0.11	0.24	0.14	0.41	0.94	
Chromium (Cr)	127.63	47.69	58.85	5.37	177.85	15.2	
Lead (Pb)	45.62	10.45	38.63	5.53	32.712	22.72	
Mercury (Hg)	56.01	12.68	54.36	11.77	37.06	19.78	
Blood	n=35		n=11		n=17		
Arsenic (As)	2.44	2.34	5.63	3.71	8.55	5.03	NS
Cadmium (Cd)	15.74	5.76	10.55	4.71	11	2.31	NS
Chromium (Cr)	451.92	124.09	470.82	120.88	683.88	279.89	NS
Lead (Pb)	390.26	54.48	309.39	103.8	547.65	142.84	NS
Mercury (Hg)	24.8	4.79	18.1	7.76	22.86	6.53	NS
Feathers	n=15		n=5		n=9		
Arsenic (As)	109.72	38.2	198.82	74.46	164.82	62.68	NS
Cadmium (Cd)	7.67 (B)	2.28	12.6 (B)	5.12	40.11 (A,B)	19.61	NS
Chromium (Cr)	551.07	74.15	841	172.77	569.67	54.55	NS
Lead (Pb)	1014.2	198.15	1138.2	370.58	1149.67	269.27	NS
Mercury (Hg)	915.13	180.18	1127.2	296.87	510	97.02	NS

Table 7B. Metal levels (Mean ± SE) in birds in the Meadowlands Disctrict as a function of tissue location. Metal levels are in parts per billion and are presented as both dry and wet weight for eggs, dry weight for feathers and wet weight for blood. Means marked with different letters (A, B, C, D) were significantly different from each other; means with more than one letter (AB) were not significant from means marked with either A or B. NS= Nonsignificant.

Site name	Kearny Marsh		Marsh Resources		Riverbend		KRUSKAL WALLIS X^2 (P)
	Mean	Std Error	Mean	Std Error	Mean	Std Error	
Marsh Wrens							
Eggs (Dry Weight)	n=4		n=16		n=10		
Arsenic (As)	130.53 (A)	56.84	10.82 (B)	5.87	64.96 (A)	44.36	8.09 (0.0442)
Cadmium (Cd)	0.76	0.48	0.51	0.22	4.28	2.47	NS
Chromium (Cr)	251	76.5	177.89	60.57	463.71	236.65	NS
Lead (Pb)	249	114.33	123.57	21.69	238.91	54.37	NS
Mercury (Hg)	440.5	99.56	1185.31	124.08	946.8	178.21	NS
Eggs (Wet Weight)	n=4		n=16		n=10		
Arsenic (As)	25.93	11.29	2.15	1.17	12.91	8.84	
Cadmium (Cd)	0.15	0.09	0.1	0.04	0.85	0.49	
Chromium (Cr)	49.87	15.2	35.34	12.03	92.13	47.01	
Lead (Pb)	49.47	22.72	24.55	4.31	47.47	10.80	
Mercury (Hg)	87.52	19.78	235.5	24.65	188.12	35.41	
Blood	n=4		n=28		n=7		
Arsenic (As)	0.1	0	1.95	1.85	14.42	14.32	NS
Cadmium (Cd)	18.33	12.39	19.22	4.32	67	33.64	NS
Chromium (Cr)	280	133.18	488.97	91.73	728.34	231.46	NS
Lead (Pb)	256.77	170.54	780.08	159.61	1227.51	467.5	NS
Mercury (Hg)	139.25 (A)	69.83	21.4 (B)	5.27	31 (B)	11.49	12.4 (0.002)
Feathers	n=1		n=11		n=3		
Arsenic (As)	0.1		7.54	5.61	7.4	7.3	NS
Cadmium (Cd)	16		25.09	4.66	57.33	29.99	NS
Chromium (Cr)	1083		1003.27	123.37	1176.67	356.99	NS
Lead (Pb)	290		439.92	95.03	449.67	143.42	NS
Mercury (Hg)	3370		3013.55	282.86	3984.33	343.58	NS

Table 7C. Metal levels (Mean ± SE) in birds in the Meadowlands Disctrict as a function of tissue location. Metal levels are in parts per billion and are presented as both dry and wet weight for eggs, dry weight for feathers and wet weight for blood. Means marked with different letters (A, B, C, D) were significantly different from each other; means with more than one letter (AB) were not significant from means marked with either A or B. NS= Nonsignificant.

Site name	DeKorte						KRUSKAL WALLIS X^2 (P)
Tree Swallows							
Blood	n=14		N/A		N/A		
Arsenic (As)	0.95	0.85					
Cadmium (Cd)	3.58	1.09					
Chromium (Cr)	1032.43	212.21					
Lead (Pb)	944.15	226.43					
Mercury (Hg)	19.43	5.44					
Feathers	n=5		N/A		N/A		
Arsenic (As)	70.24	39.25					
Cadmium (Cd)	11.4	4.28					
Chromium (Cr)	658.8	219.13					
Lead (Pb)	1364.6	776.18					
Mercury (Hg)	2043.8	355.16					
			Marsh Resources		Harrier Meadow		
Mallard							
Eggs (Dry Weight)	N/A		n=4		n=2		
Arsenic (As)			77	15.72	0.1	0	NS
Cadmium (Cd)			0.63	0.19	1.51	1.5	NS
Chromium (Cr)			55	6.23	294.5	157.5	NS
Lead (Pb)			230.5	47.23	129	62	NS
Mercury (Hg)			293.5	25.45	126.5	44.5	NS
Eggs (Wet Weight)	N/A		n=4		n=2		
Arsenic (As)			24.33	4.97	0.031	0	
Cadmium (Cd)			0.19	0.06	0.475	0.47	
Chromium (Cr)			17.37	1.97	93.05	49.76	
Lead (Pb)			72.83	14.92	40.76	19.59	
Mercury (Hg)			92.73	8.04	39.97	14.06	

Table 7D. Metal levels (Mean ± SE) in tissues collected in 2007 from Red-winged Blackbirds of the Meadowlands Disctrict by location of tissue collection. Metal levels are in parts per billion and are presented as both dry and wet weight for eggs, dry weight for feathers and wet weight for blood. Statistical analyses for egg metal levels were run on the dry weight values,, but wet weights are also shown. Kruskal Wallis values reflect comparisons among species. Means marked with different letters (A, B, C, D) were significantly different from each other; means with more than one letter (AB) were not significant from means marked with either A or B. NS= Nonsignificant.

Red-Winged Blackbirds	**Kearny Marsh**		**Marsh Resources**		**Harrier Meadow**		KRUSKAL WALLIS X^2 (P)
	Mean	Std Error	Mean	Std Error	Mean	Std Error	NS
Blood	n=28		n=35		n=14		
Arsenic (As)	3.04	1.4	1.05	0.32	2.46	1.35	NS
Cadmium (Cd)	21.14	5.33	7.35	1.75	14.07	6.26	NS
Chromium (Cr)	252.64	23.94	276.94	29.48	230.36	39.05	NS
Lead (Pb)	704.17 (A)	138.13	189.25 (A)	27.84	120.1 (B)	36.86	18.55 (<.0001)
Mercury (Hg)	18.03	4.05	11.44	2	19.35	4.78	NS
Feathers	n=16		n=10		n=5		
Arsenic (As)	123.81	44.02	44.08	32.24	151.06	137.65	NS
Cadmium (Cd)	57.8	22.49	28.15	14.07	151.8	62.8	NS
Chromium (Cr)	1368.75	89.4	1226.1	219.89	1082	171.79	NS
Lead (Pb)	1419.59	395.23	1607	225.02	1234.02	690.64	NS
Mercury (Hg)	577.19	113.47	675	145.26	652.8	211.46	NS
Eggs (Dry Weight)	n=34		n=18		n=24		
Arsenic (As)	22.77	9.9	24.3	8.18	53.49	18.02	
Cadmium (Cd)	3.5	1.3	7.25	2.77	3.71	1.22	
Chromium (Cr)	265.62	31.86	326.67	26.58	287.08	28.57	
Lead (Pb)	134.74	12.15	157.39	23.58	185.75	26.21	
Mercury (Hg)	228.22	29.74	316.14	43.87	144.14	14.23	
Eggs (Wet Weight)	n=34		n=18		n=24		
Arsenic (As)	4.04	1.76	4.31	1.45	9.49	3.2	NS
Cadmium (Cd)	0.62	0.23	1.29	0.49	0.66	0.22	NS
Chromium (Cr)	47.15	5.66	57.98	4.72	50.96	5.07	NS
Lead (Pb)	23.92	2.16	27.94	4.19	32.97	4.65	NS
Mercury (Hg)	40.51 (AB)	5.28	56.11 (A)	7.79	25.58 (B)	2.53	12.86 (0.016)

Table 7E. Metal levels (Mean ± SE) in tissues collected in 2007 from Marsh Wrens of the Meadowlands Disctrict by location of tissue collection. Metal levels are in parts per billion and are presented as both dry and wet weight for eggs, dry weight for feathers and wet weight for blood. Statistical analyses for egg metal levels were run on the dry weight values,, but wet weights are also shown. Kruskal Wallis values reflect comparisons among species. Means marked with different letters (A, B, C, D) were significantly different from each other; means with more than one letter (AB) were not significant from means marked with either A or B. NS= Nonsignificant.

	Kearny Marsh		**Marsh Resources**		
Marsh Wren	Mean	Std Error	Mean	Std Error	KRUSKAL WALLIS X^2 (P)
Blood	n=20		n=71		
Arsenic (As)	28.39	6.62	17.08	2.8	NS
Cadmium (Cd)	17.51	5.47	13.15	2.13	NS
Chromium (Cr)	218.65	43.75	291.19	22.55	4.84 (0.028)
Lead (Pb)	587.6 (A)	189.05	280.53 (B)	36.15	4.53 (0.033)
Mercury (Hg)	14.09	3.73	17.63	2.61	NS
Feathers	N/A		n=9		
Arsenic (As)			0.1	0	
Cadmium (Cd)			83.89	16.2	
Chromium (Cr)			970	288.95	
Lead (Pb)			172.28	134.13	
Mercury (Hg)			298.57	75.19	
Eggs (Wet Weight)	n=8		n=16		
Arsenic (As)	0.92	0.64	1.23	0.8	NS
Cadmium (Cd)	0.16	0.16	0.38	0.19	NS
Chromium (Cr)	34.78 (B)	3.68	94.1 (A)	22.77	5.57 (0.018)
Lead (Pb)	9.36	4.96	11.67	4.44	NS
Mercury (Hg)	92.13 (B)	10.89	135.51 (A)	14.07	4.59 (0.032)
Eggs (Dry Weight)	n=8		n=16		
Arsenic (As)	4.45	3.1	5.95	3.89	
Cadmium (Cd)	0.78	0.77	1.86	0.93	
Chromium (Cr)	168.75	17.87	456.56	110.49	
Lead (Pb)	45.41	24.06	56.6	21.55	
Mercury (Hg)	447.04	52.85	657.49	68.28	

Table 7F. Metal levels (Mean ± SE) in tissues collected in 2007 from Tree Swallows of the Meadowlands Disctrict by location of tissue collection. Metal levels are in parts per billion and are presented as both dry and wet weight for eggs, dry weight for feathers and wet weight for blood. Statistical analyses for egg metal levels were run on the dry weight values,, but wet weights are also shown. Kruskal Wallis values reflect comparisons among species. Means marked with different letters (A, B, C, D) were significantly different from each other; means with more than one letter (AB) were not significant from means marked with either A or B. NS= Nonsignificant.

	DeKorte		Kearny Marsh		Marsh Resources		Mill Creek		
Tree Swallow	Mean	Std Error	Mean	Std Error	Mean	Std Error	Mean	Std Error	KRUSKAL WALLIS X^2 (P)
Blood	n=41		n=54		n=17		n=19		
Arsenic (As)	1.82	1	0.61	0.39	1.66	1.21	0.56	0.42	NS
Cadmium (Cd)	3.29	1.22	4.1	1.07	5.26	2.97	0.86	0.4	NS
Chromium (Cr)	308.63	35.47	251.83	27.92	269.12	66.67	365.79	55.93	NS
Lead (Pb)	289.53	76.65	128.82	22.99	141.08	36.44	277.43	36.52	NS
Mercury (Hg)	17.92 (B)	2.97	7.94 (B)	0.76	17.58 (B)	5.07	30.44 (A)	8.12	20.04 (0.0002)
Feathers	n=12		n=10		n=4		n=6		
Arsenic (As)	0.1	0	0.1	0	0.1	0	0.1	0	NS
Cadmium (Cd)	44.34 (B)	12.47	206.8 (A)	50.83	41.25 (B)	8.81	28.33 (B)	10.56	11.6 (0.008)
Chromium (Cr)	1521.25	350.43	1057	146.36	1517.5	834.73	485	102.75	NS
Lead (Pb)	445.22	166.56	1130.02	470.95	308.27	232.4	46.73	46.65	NS
Mercury (Hg)	853.75	163.37	405.71	86.9	549.53	270.12	764.33	160.29	NS
Eggs (Wet Weight)	n=17		n=18		n=6		n=16		
Arsenic (As)	4.66	1.47	7.01	2.87	0.02	0	11.31	4.35	NS
Cadmium (Cd)	0.77	0.51	0.17	0.1	0	0	0.4	0.21	NS
Chromium (Cr)	62.54	17.7	32.54	4.76	57.05	17.15	45.4	11.42	NS
Lead (Pb)	14.29	2.6	21.27	2.94	25.47	6.33	22.55	3.38	NS
Mercury (Hg)	89.19	12.42	62.99	7.43	54.01	13.47	87.22	7.48	NS
Eggs (Dry Weight)	n=17		n=18		n=6		n=16		
Arsenic (As)	22.87	7.22	34.39	14.11	0.1	0	55.51	21.36	
Cadmium (Cd)	3.77	2.53	0.81	0.5	0.01	0	1.95	1.02	
Chromium (Cr)	306.94	86.87	159.72	23.35	280	84.18	222.81	56.07	
Lead (Pb)	70.12	12.76	104.39	14.42	125	31.07	110.69	16.59	
Mercury (Hg)	437.73	60.94	309.15	36.46	265.08	66.12	428.08	36.69	

Table 7G. Metal levels (Mean ± SE) in tissues collected in 2007 from Canada Geese of the Meadowlands Disctrict by location of tissue collection. Metal levels are in parts per billion and are presented as both dry and wet weight for eggs, dry weight for feathers and wet weight for blood. Statistical analyses for egg metal levels were run on the dry weight values,, but wet weights are also shown. Kruskal Wallis values reflect comparisons among species. Means marked with different letters (A, B, C, D) were significantly different from each other; means with more than one letter (AB) were not significant from means marked with either A or B. NS= Nonsignificant.

Canada Goose	**Harrier Meadow**		**Mill Creek**		**Skeetkill Marsh**		KRUSKAL WALLIS
	Mean	Std Error	Mean	Std Error	Mean	Std Error	X^2 (P)
Feathers	n=13		n=5		n=8		
Arsenic (As)	6.39	4.26	198.06	122.47	85.08	63.32	NS
Cadmium (Cd)	69.31 (B)	9.52	153.2 (A)	29.4	69.75 (B)	12.07	6.96 (0.03)
Chromium (Cr)	800.77 (B)	184.12	2740 (A)	544.61	1400 (B)	479.67	12.28 (0.002)
Lead (Pb)	1646.16	555.9	3140	904.21	1566.26	637.18	NS
Mercury (Hg)	200.34	63.45	276.2	72.68	340.38	73.73	NS
Liver	n=13		n=5		n=8		
Arsenic (As)	6.238	4.448	3.04	2.122	0.1	0	NS
Cadmium (Cd)	121.7 (B)	38.514	221.4 (AB)	58.6	311 (A)	41.742	8.51 (0.01)
Chromium (Cr)	200.923	72.725	150	38.471	109.875	50.261	NS
Lead (Pb)	207.5	58.092	376	145.691	237.5	66.029	NS
Mercury (Hg)	36.815	10.422	52	14.67	40.7	11.388	NS
Muscle	n=13		n=5		n=8		
Arsenic (As)	1.108	0.775	0.1	0	0.1	0	NS
Cadmium (Cd)	4.172	0.784	6.4	1.313	7.733	2.521	NS
Chromium (Cr)	48.462 (B)	14.037	203.2 (A)	64.08	28.1 (B)	7.875	6.91 (0.031)
Lead (Pb)	3.312 (B)	2.092	60.415 (A)	35.1	3.306 (B)	2.115	8.27 (0.016)
Mercury (Hg)	8.162 (B)	2.905	23.2 (A)	9.774	12.713 (AB)	2.843	7.39 (0.025)

	Kearny Marsh		**Mill Creek**		**Skeetkill Marsh**		KRUSKAL WALLIS
	Mean	Std Error	Mean	Std Error	Mean	Std Error	X^2 (P)
Eggs (Dry Weight)	n=2		n=29		n=3		
Arsenic (As)	0.1	0	14.26	7.62	56.73	56.63	
Cadmium (Cd)	0.07	0.06	0.76	0.28	0.56	0.28	
Chromium (Cr)	87	23	122.38	22.97	85.67	17.29	
Lead (Pb)	192	128	558.62	132.63	203.33	74.24	
Mercury (Hg)	5.96	0.8	14.33	1.01	10.28	2.03	
Eggs (Wet Weight)	n=2		n=29		n=3		
Arsenic (As)	0.03	0	4.54	2.43	18.07	18.04	NS
Cadmium (Cd)	0.02	0.02	0.24	0.09	0.18	0.09	NS
Chromium (Cr)	27.72	7.33	38.99	7.32	27.29	5.51	NS
Lead (Pb)	61.17	40.78	177.96	42.25	64.78	23.65	NS
Mercury (Hg)	1.9	0.25	4.56	0.32	3.27	0.65	NS

Table 8. Tissue differences (Mean ± SE) within species for samples collected in 2006. Metal levels are in parts per billion and are presented as wet weight for eggs, dry weight for feathers and wet weight for blood. Means marked with different letters (A, B, C, D) were significantly different from each other; means with more than one letter (AB) were not significant from means marked with either A or B. NS= Nonsignificant.

	Blood		Feathers		Eggs (wet weight)		KRUSKAL WALLIS X^2 (P)
Species							
Red-Winged blackbird	n=63		n=29		n=31		
Arsenic (As)	4.64 (B)		142.18 (A)	30.12	6.86 (B)	1.82	26.51 (< .0001)
Cadmium (Cd)	13.55	3.35	18.59	6.61	0.24	0.08	49. 54 (< .0001)
Chromium (Cr)	517.81	103.55	606.83	53.21	129.9	31.44	39.18 (< .0001)
Lead (Pb)	418.61 (B)	52.36	1077.62 (A)	141.85 (A)	42.7 (BC)	5.73	62.92 (< .0001)
Mercury (Hg)	23.18 (B)	3.43	825.97 (A)	114.95 (A)	50.8 (B)	7.24	78.12 (< .0001)
Marsh Wren	n= 38		n=15		n=27		
Arsenic (As)	3.73 (B)	2.61	7.01 (A)	4.27	11.56 (B)	4.08	12.30 (0.0064)
Cadmium (Cd)	26.89 (AB)	6.74	30.93 (A)	7.06	0.4 (B)	0.19	49.25 (< .0001)
Chromium (Cr)	504.77 (B)	78.62	1043.27 (A)	109.28	67.4 (C)	18.86	47.34 (< .0001)
Lead (Pb)	795.64 (A)	142.25	431.87 (AB)	73.63	35.9 (B)	5.89	34.02 (< .0001)
Mercury (Hg)	35.32 (B)	9.7	3231.47 (A)	236.55	182.6 (B)	20.46	62.57 (< .0001)
Tree Swallow	n=14		n=5		N/A		
Arsenic (As)	0.95	0.85	70.24	39.25			6.74 (0.0094)
Cadmium (Cd)	3.58	1.09	11.4	4.28			3.53 (0.0601)
Chromium (Cr)	1032.43	212.21	658.8	219.13			0.86 (0.3545)
Lead (Pb)	944.15	226.43	1364.6	776.18			0.0086 (0.9262)
Mercury (Hg)	19.43	5.44	2043.8	355.16			

Table 8A. Tissue differences (Mean ± SE) within species for samples collected in 2007. Metal levels are in parts per billion and are presented as wet weight for eggs, dry weight for feathers and wet weight for blood. Means marked with different letters (A, B, C, D) were significantly different from each other; means with more than one letter (AB) were not significant from means marked with either A or B. NS= Nonsignificant.

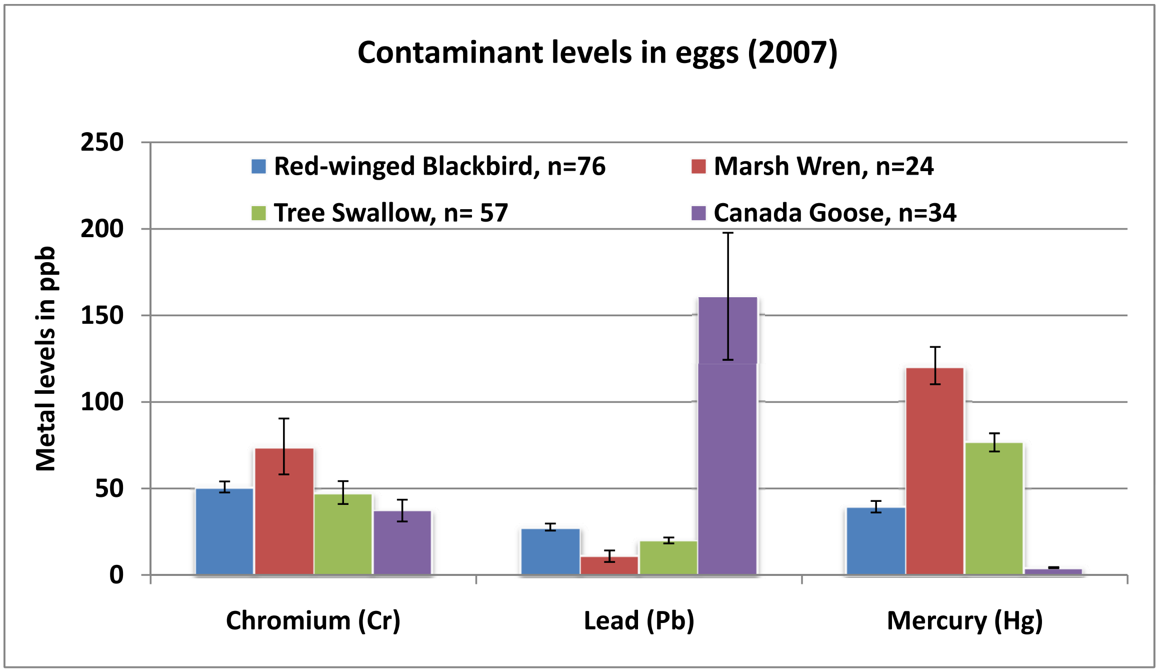
	Blood		**Feathers**		**Eggs (wet weight)**		KRUSKAL WALLIS X^2 (P)
	Mean	*Std Error*	Mean	*Std Error*	Mean	*Std Error*	
Red-Winged blackbird	n=77		n=31		n=76		
Arsenic (As)	2.03 (B)	*0.59*	102.487 (A)	*32.64*	5.753 (B)	*1.325*	7.77 (0.02)
Cadmium (Cd)	13.58 (A)	*2.45*	63.4 (A)	*17.042*	0.78 (B)	*0.168*	78.82(< .0001)
Chromium (Cr)	259.63 (B)	*17.39*	1276.484 (A)	*88.054*	50.256 (_C)	*3.224*	148.32 (< .0001)
Lead (Pb)	363.92 (A)	*59.53*	1450.111 (A)	*236.644*	27.368 (B)	*2.044*	64.88 (< .0001)
Mercury (Hg)	15.28 (_C)	*1.95*	620.935 (A)	*79.977*	38.979 (B)	*3.321*	104.53 (< .0001)
Marsh Wren	n= 91		n=9		n=24		
Arsenic (As)	19.569 (A)	*2.652*	0.1 (B)	*0*	1.123 (B)	*0.568*	45.27 (< .0001)
Cadmium (Cd)	14.11 (B)	*2.045*	83.889 (A)	*16.198*	0.309 (_C)	*0.138*	60.80 (< .0001)
Chromium (Cr)	275.245 (B)	*20.184*	970 (A)	*288.954*	74.325 (_C)	*16.15*	44.62 (< .0001)
Lead (Pb)	348.02 (A)	*51.295*	172.281 (A, B)	*134.132*	10.897 (B)	*3.335*	42.29 (< .0001)
Mercury (Hg)	16.852 (C)	*2.189*	298.567 (A)	*75.188*	121.051 (B)	*10.784*	59.09 (< .0001)
Tree Swallow	n=131		n=32		n=57		
Arsenic (As)	1.121(B)	*0.389*	0.1 (B)	*0*	6.78 (A)	*1.616*	6.78 (0.033)
Cadmium (Cd)	3.528 (B)	*0.701*	91.72 (A)	*21.322*	0.394 (B)	*0.168*	118.4 (< .0001)
Chromium (Cr)	288.382 (B)	*19.956*	1181.406 (A)	*178.812*	47.678 (C)	*6.641*	129.03 (< .0001)
Lead (Pb)	202.265 (B)	*27.35*	571.322 (A)	*176.436*	19.989 (C)	*1.706*	11.78 (0.028)
Mercury (Hg)	15.577 (B)	*1.768*	658.944 (A)	*84.362*	76.661 (B)	*5.268*	131.59 (< .0001)

	Muscle (wet weight)		**Feathers**		**Eggs (wet weight)**		**Liver (wet weight)**		
	Mean	*Std Error*	Mean	*Std Error*	Mean	*Std Error*	Mean	*Std Error*	
Canada Goose	n=26		n=26		n=34		n=26		
Arsenic (As)	0.604(B)	*0.393*	67.462 (A)	*31.95*	5.47(B)	*2.55*	3.735 (B)	*2.276*	42.74 (< .0001)
Cadmium (Cd)	5.696 (_C)	*0.922*	85.577 (B)	*10.22*	0.223 (_C)	*0.077*	199.119 (A)	*29.825*	88.85 (< .0001)
Chromium (Cr)	71.954 (B)	*18.606*	1358.077 (A)	*240.849*	37.292 (B)	*6.287*	163.115 (B)	*39.966*	70.25(< .0001)
Lead (Pb)	14.291 (B)	*7.72*	1908.852 (A)	*385.728*	161.104 (B)	*36.714*	249.135 (B)	*44.708*	66.91 (< .0001)
Mercury (Hg)	12.454 (B)	*2.63*	258.015 (A)	*41.829*	4.294 (B)	*0.303*	40.931 (B)	*6.719*	70.98 (< .0001)

Table 9. Organic contaminants in part per billion (ppb - raw data) from Mallard eggs (Wet Weight) collected in the Meadowlands Disctrict in 2006.

PCB Congener No.	***06 HM MALL L1E***	***06 HM MALL L2E***	***06 HM MALL B11E***	***06 HM MALL B18E***	***06 HM MALL B27E***	***06 HM MALL B56E***	***QC Blank***
81	ND	4.362	0.790	ND	ND	ND	
77	11.955	2.389	4.496	7.486	14.994	19.504	0.099
123	ND	ND	ND	ND	ND	ND	ND
118	13.711	31.304	35.039	27.642	48.289	32.017	ND
114	6.315	3.935	1.674	1.451	2.449	5.261	ND
105	29.142	0.000	6.285	5.654	9.121	24.821	0.117
126	ND	ND	ND	ND	ND	ND	ND
167	11.246	16.966	2.600	2.232	3.760	8.721	ND
156	20.925	17.062	7.912	6.278	12.707	16.994	ND
157	7.283	3.602	1.230	1.392	2.697	5.780	ND
169	1.782	1.542	1.133	1.051	1.340	1.504	0.446
189	2.713	1.327	0.190	0.478	0.835	1.993	ND

Organo Chlorine Pesticides	***06 HM MALL L1E***	***06 HM MALL L2E***	***06 HM MALL B11E***	***06 HM MALL B18E***	***06 HM MALL B27E***	***06 HM MALL B56E***	***QC Blank***
a-BHC	1.519	2.167	1.469	0.744	1.447	1.952	ND
b-BHC	1.084	4.180	1.585	0.604	0.887	3.766	ND
g-BHC	3.152	4.563	4.794	4.092	4.048	4.112	2.633
d-BHC	ND	ND	ND	ND	ND	ND	ND
Heptachlor	ND	ND	ND	ND	ND	ND	ND
Aldrin	1.258	2.579	1.323	1.017	1.779	5.124	ND
Heptachlor Epox	10.864	15.521	8.085	7.617	10.986	13.985	0.076
Endosulfan I	ND	ND	ND	ND	ND	ND	ND
Dieldrin	16.256	17.695	26.181	28.318	44.117	15.944	ND
DDE	34.665	35.263	12.606	6.470	37.048	31.774	0.138
Endrin	ND	ND	ND	ND	ND	ND	ND
Endosulfan II	4.195	4.126	ND	ND	4.071	0.000	ND
DDD	11.050	10.866	6.859	8.610	16.398	14.001	ND
Endrin Aldehyde	ND	ND	ND	ND	ND	ND	ND
Endosulfan Sulf	2.889	4.569	1.566	1.198	2.168	4.117	4.619
DDT	4.907	5.165	6.632	7.862	7.063	4.394	ND
Endrin Ketone	ND	ND	ND	ND	ND	ND	ND
Methoxychlor	ND	ND	ND	ND	ND	ND	ND



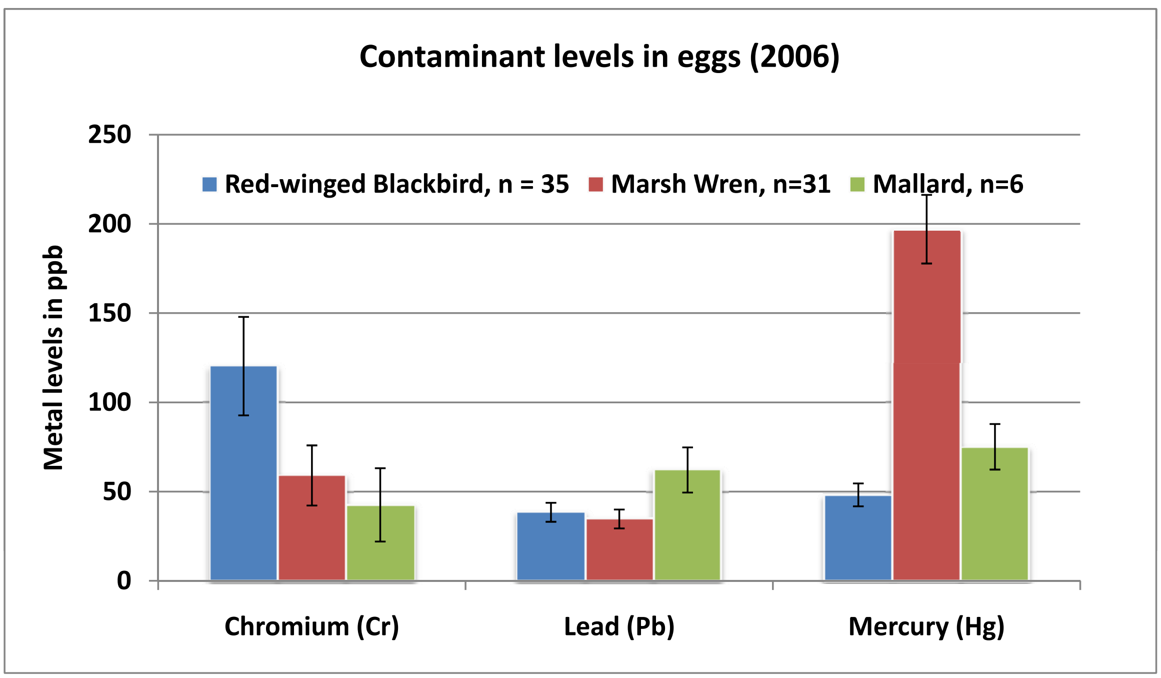
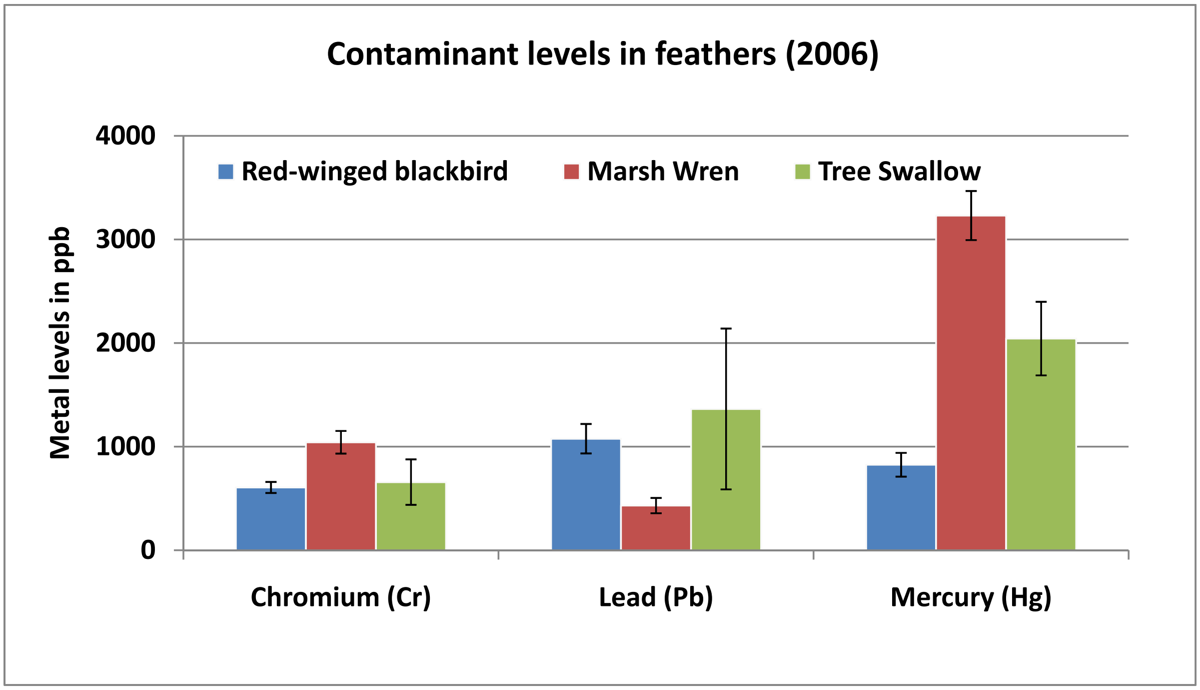


Figure 1. Contaminant levels in parts per billion (ppb) in eggs of Red-winged Blackbirds, Marsh Wrens, Tree Swallows and Canada Geese collected during the 2006 and 2007 field season in the NJ Meadowlands



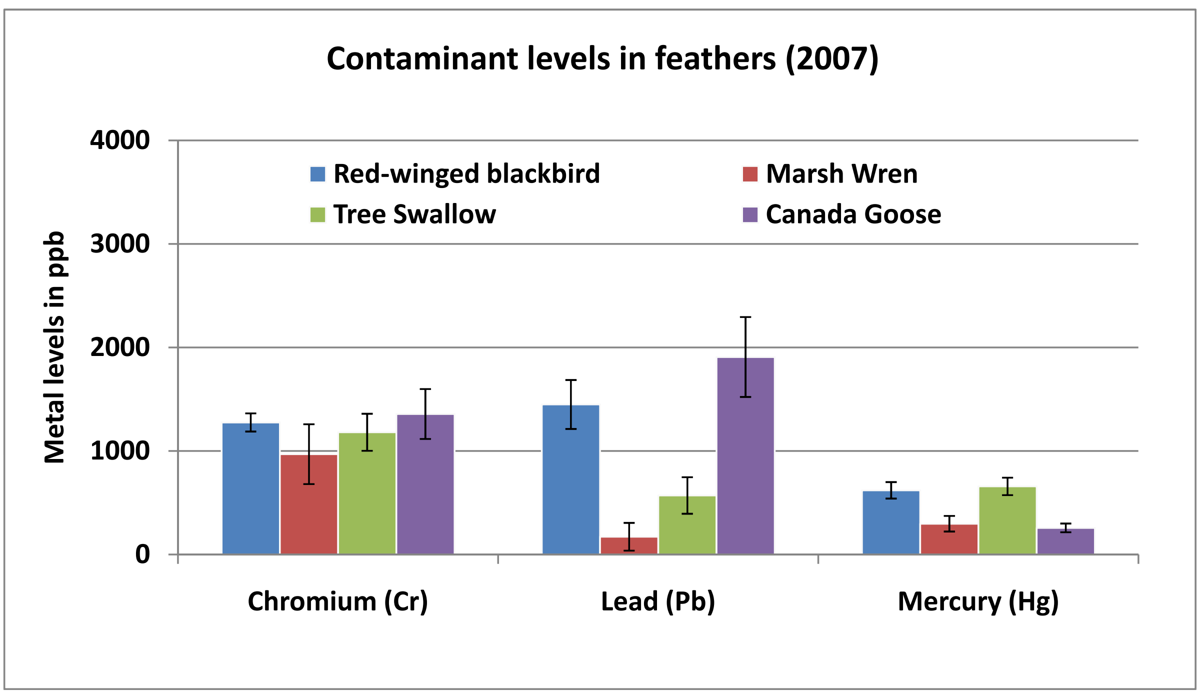
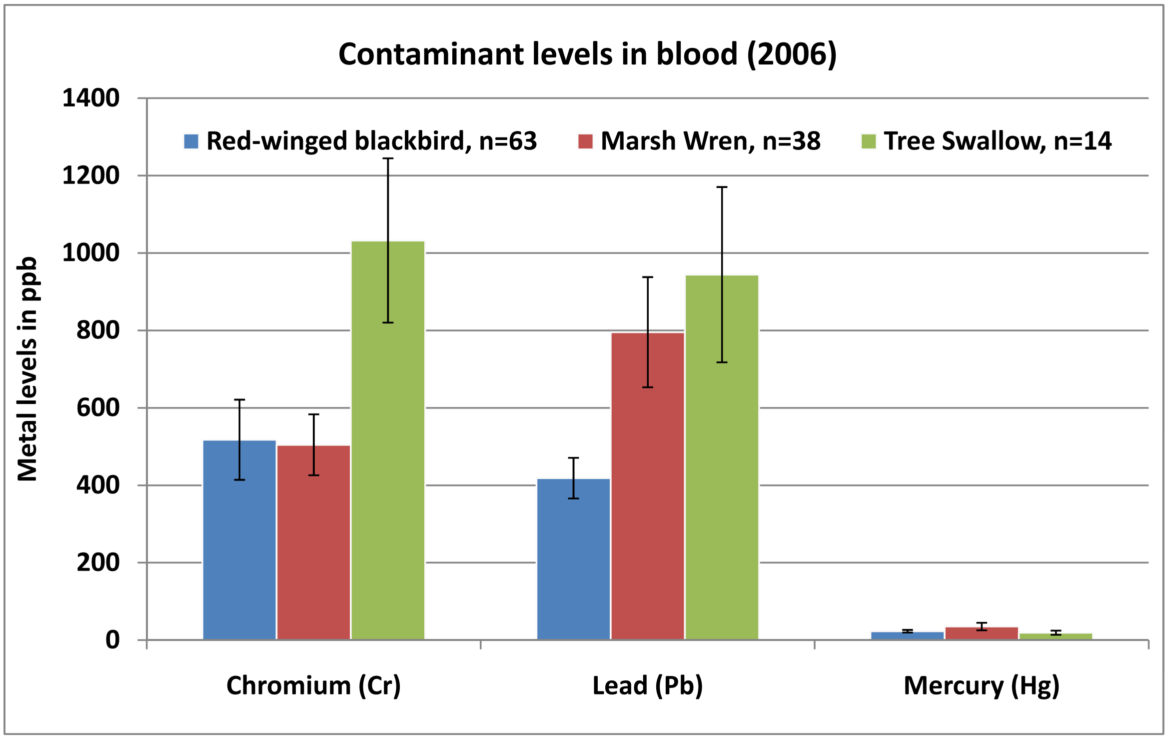


Figure 2. Contaminant levels in parts per billion (ppb) in feathers of Red-winged Blackbirds, Marsh Wrens, Tree Swallows and Canada Geese collected during the 2006 and 2007 field season in the NJ Meadowlands



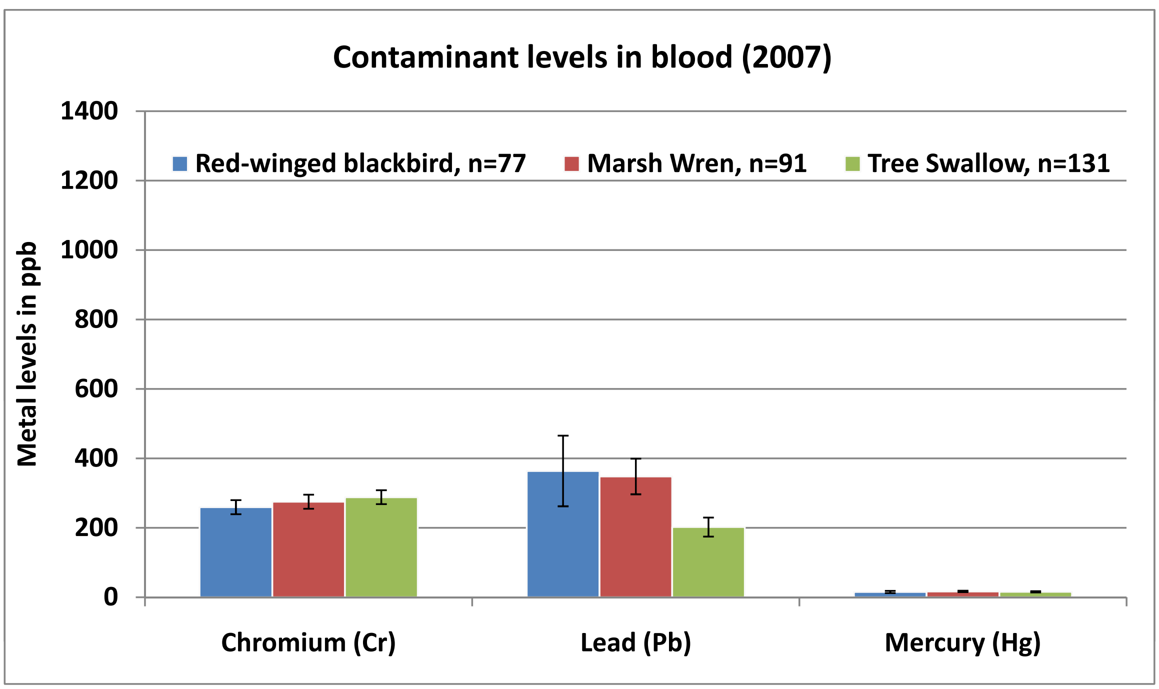


Figure 3. Contaminant levels in parts per billion (ppb) in blood of Red-winged Blackbirds, Marsh Wrens, and Tree Swallows collected during the 2006 and 2007 field season in the NJ Meadowlands

Figure 4. Mercury (Hg) and Chromium (Cr) levels in eggs of Marsh Wrens collected at Marsh Resources in 2006 and 2007 (Mean ± SE) Concentrations of Hg and Cr were different in the two habitats

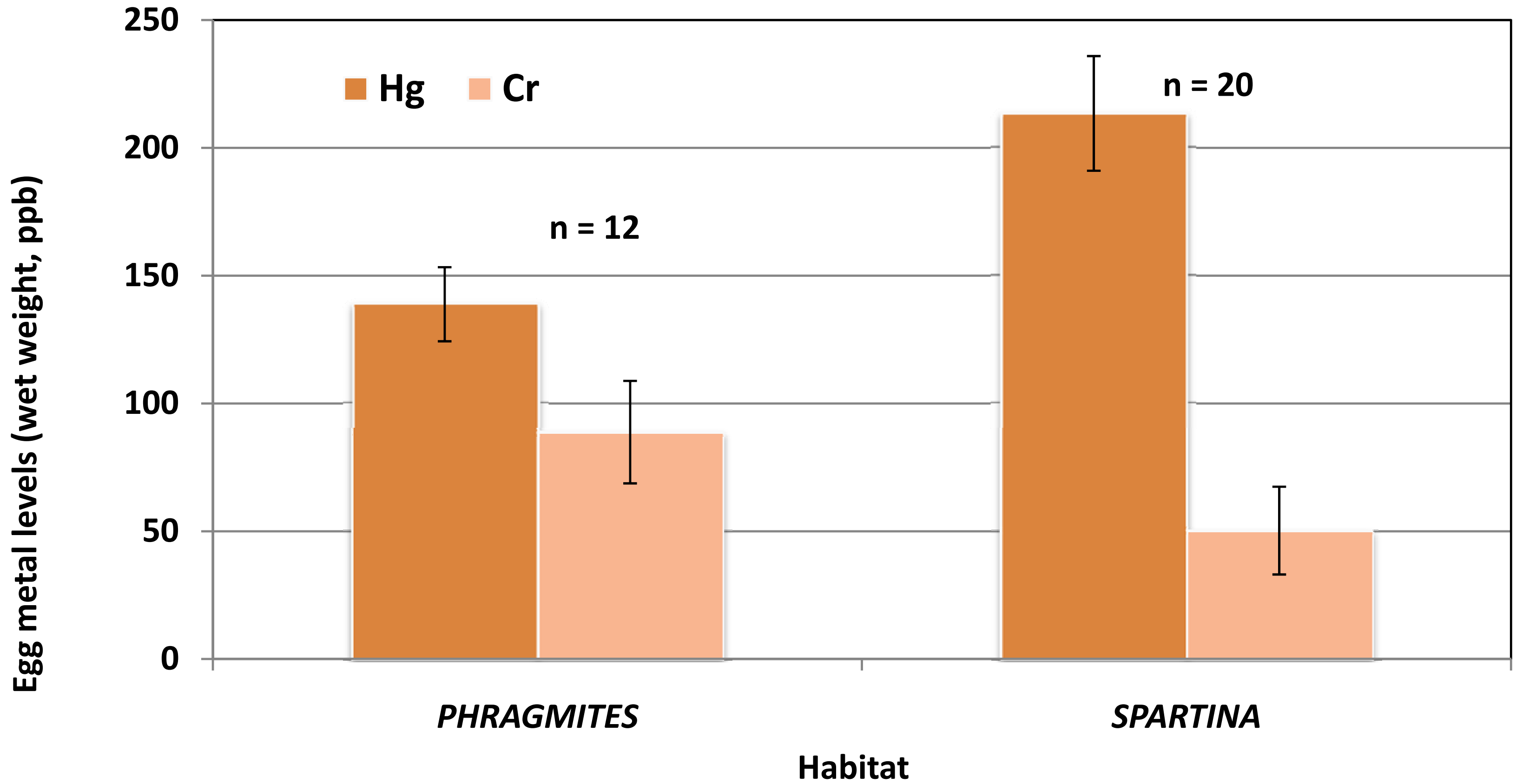


Figure 5. Mercury (Hg) levels in unhatched and randomly collected eggs of Marsh Wrens (MAWR), Red-winged Blackbirds (RWBL), and Tree Swallows (TRES)

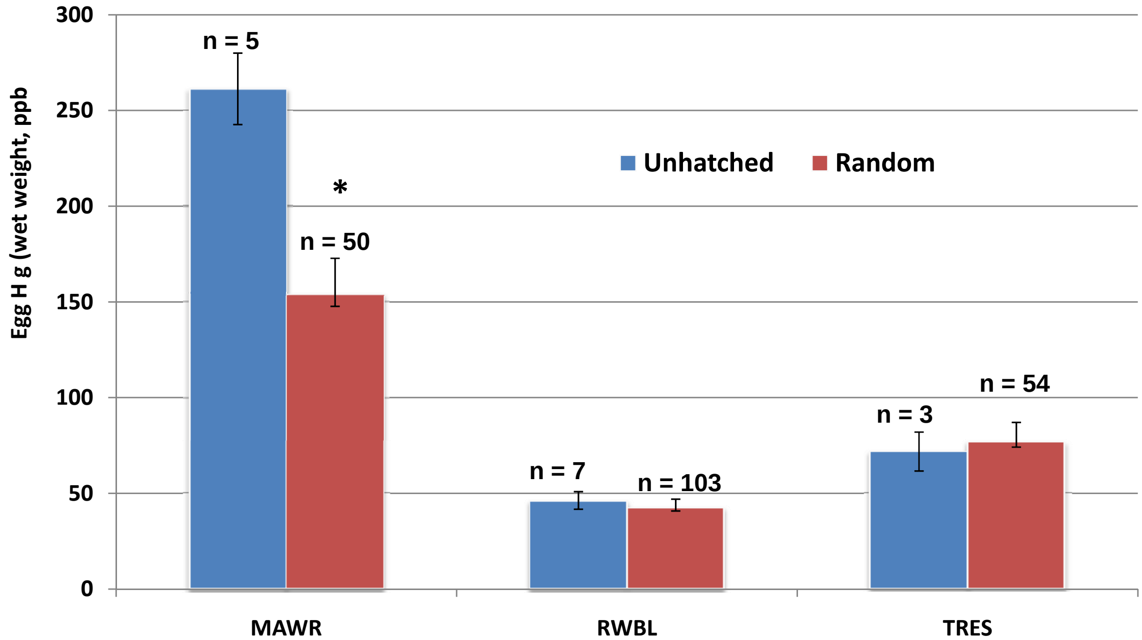
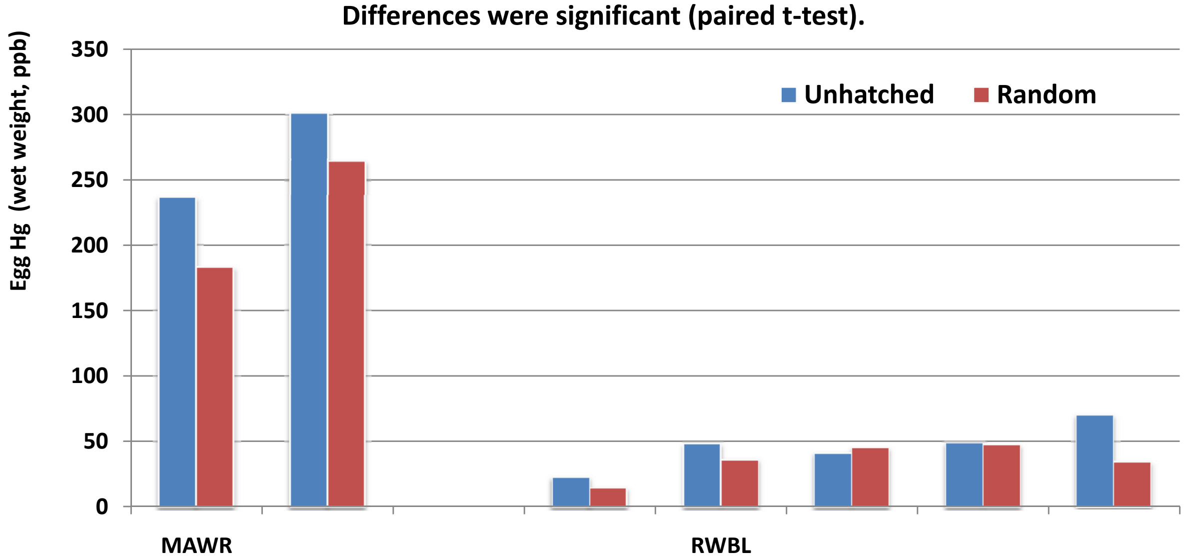


Figure 6. Mercury (Hg) levels in paired unhatched and random eggs collected from the same nest of Marsh Wrens (MAWR), and Red-winged Blackbirds (RWBL). Differences were significant (paired t-test).



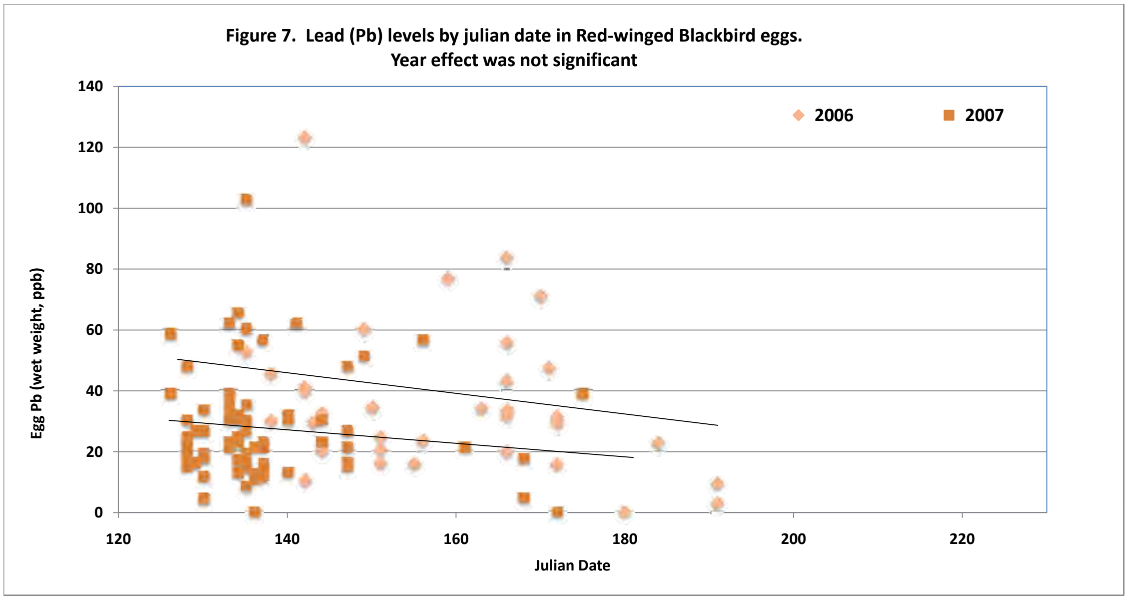


Figure 7. Lead (Pb) levels by julian date in Red-winged Blackbird eggs.
Year effect was not significant
2006
2007
Egg Pb (wet weight, ppb)
Julian Date
140
120
100
80
60
40
20
0
120
140
160
180
200
220

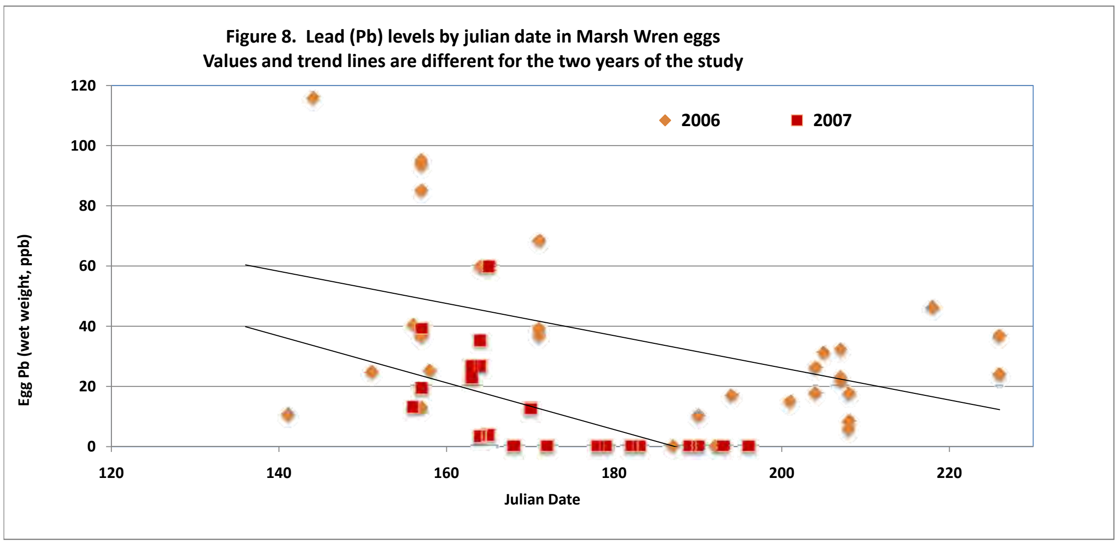


Figure 8. Lead (Pb) levels by julian date in Marsh Wren eggs
Values and trend lines are different for the two years of the study
2006
2007
Egg Pb (wet weight, ppb)
Julian Date
120
100
80
60
40
20
0
120
140
160
180
200
220

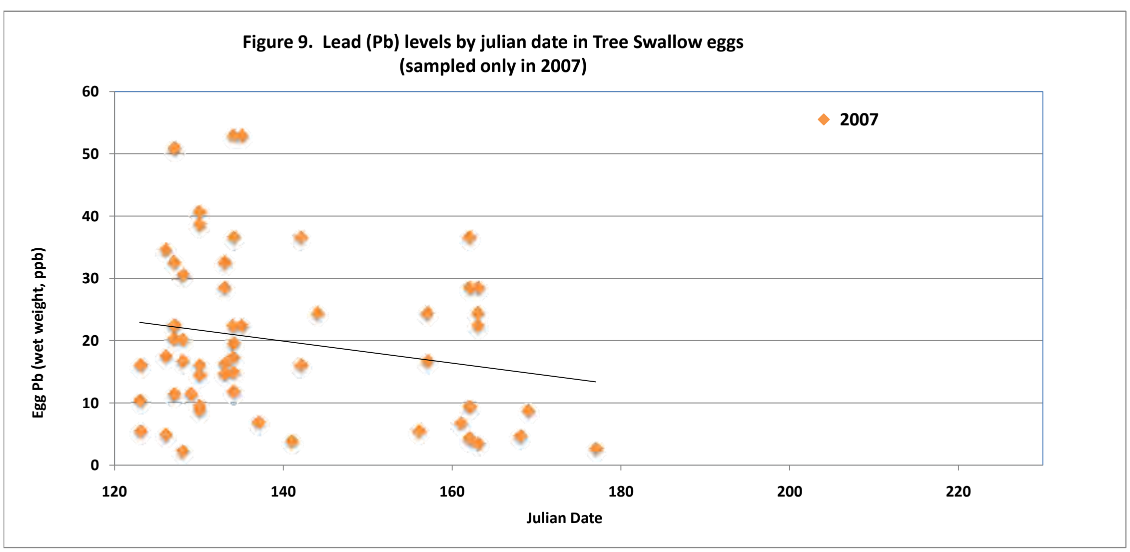


Figure 9. Lead (Pb) levels by julian date in Tree Swallow eggs
(sampled only in 2007)
2007
Egg Pb (wet weight, ppb)
Julian Date
60
50
40
30
20
10
0
120
140
160
180
200
220

Figure 10. Mercury (Hg) levels by date in Marsh Wren (MAWR) and Red-winged Blackbird (RWBL) eggs. Since there was no year effect data from the two years of the study were combined.

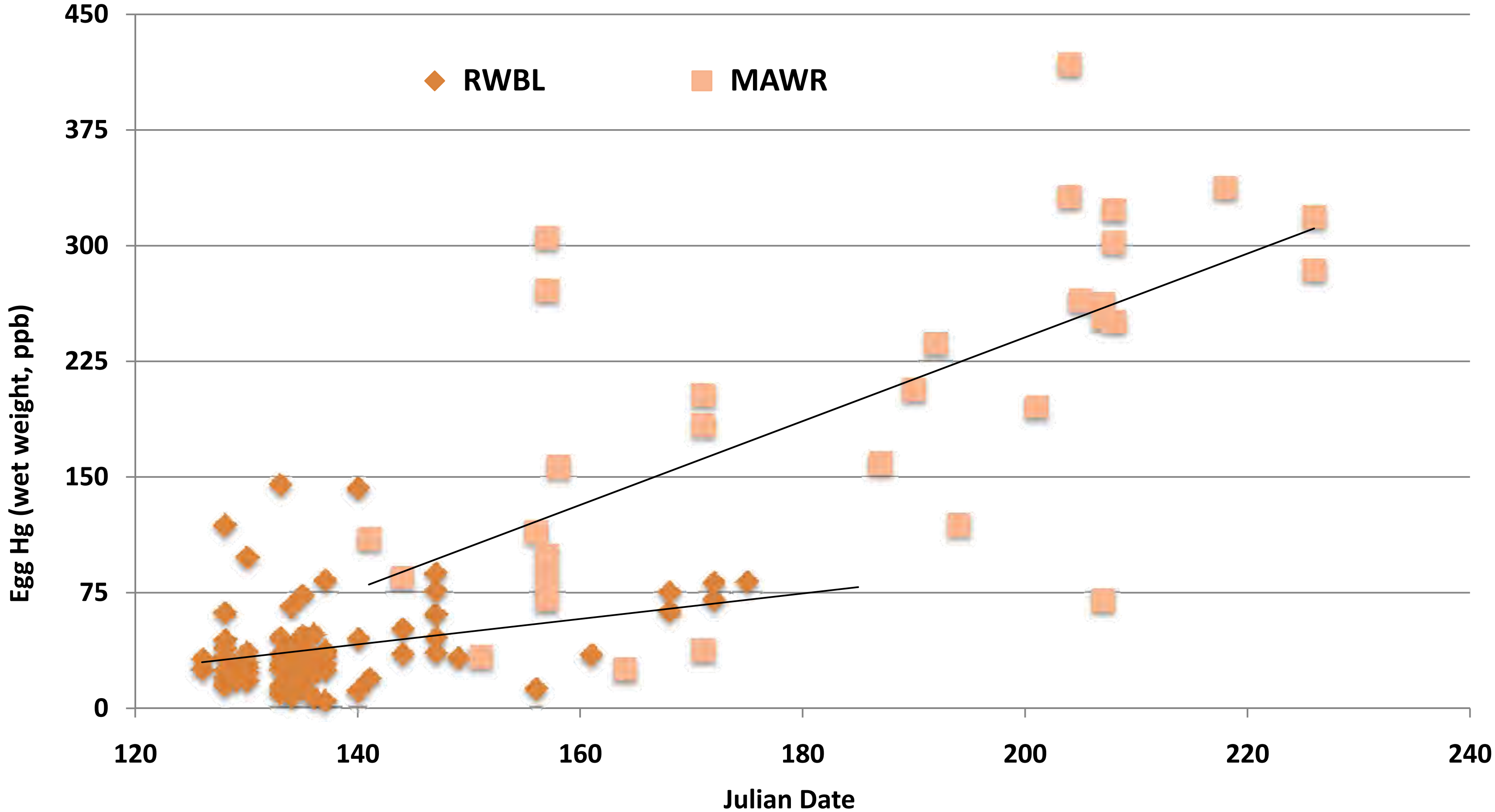
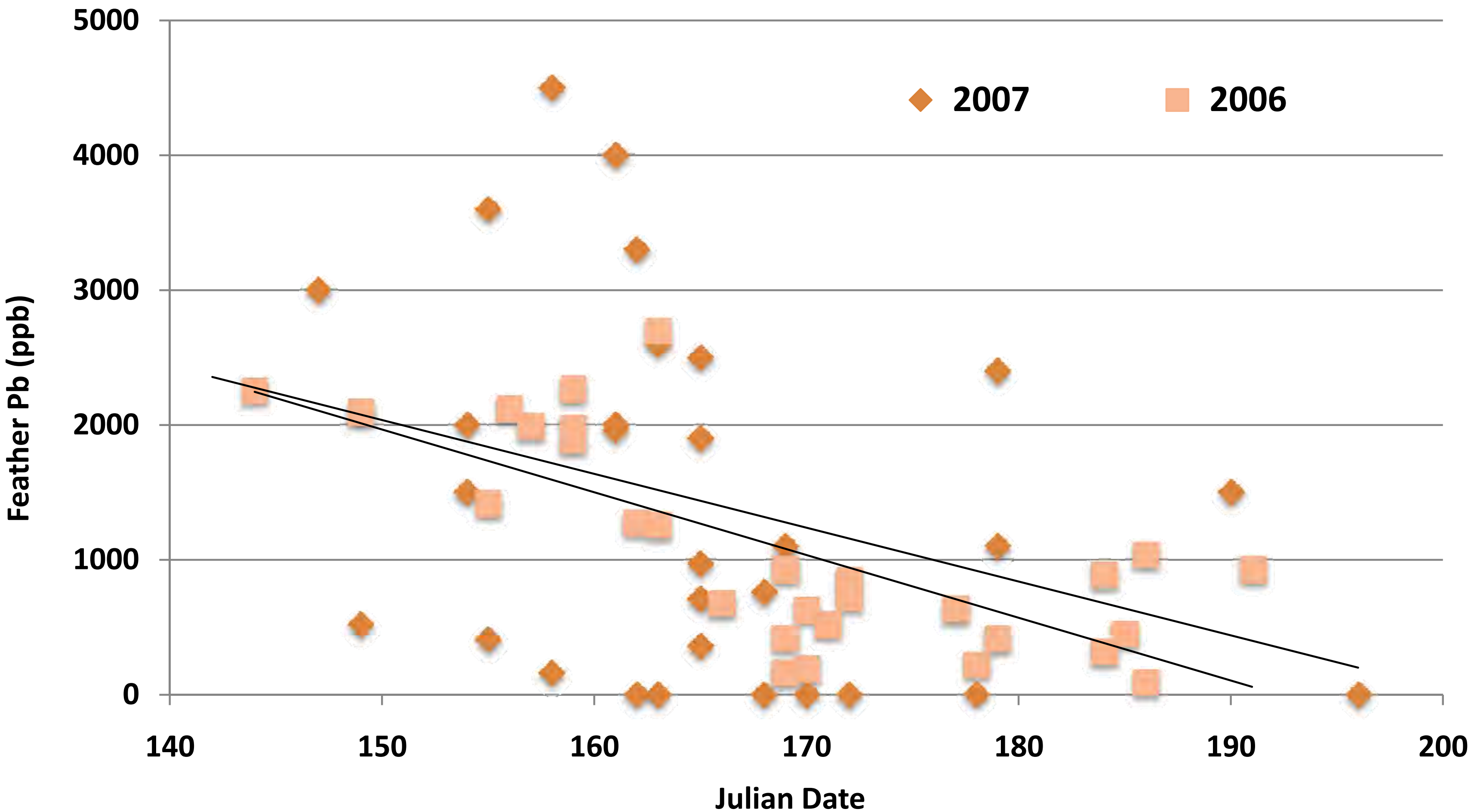


Figure 11. Lead (Pb) levels by julian date in Red-winged Blackbird feathers. Year effect was not significant.



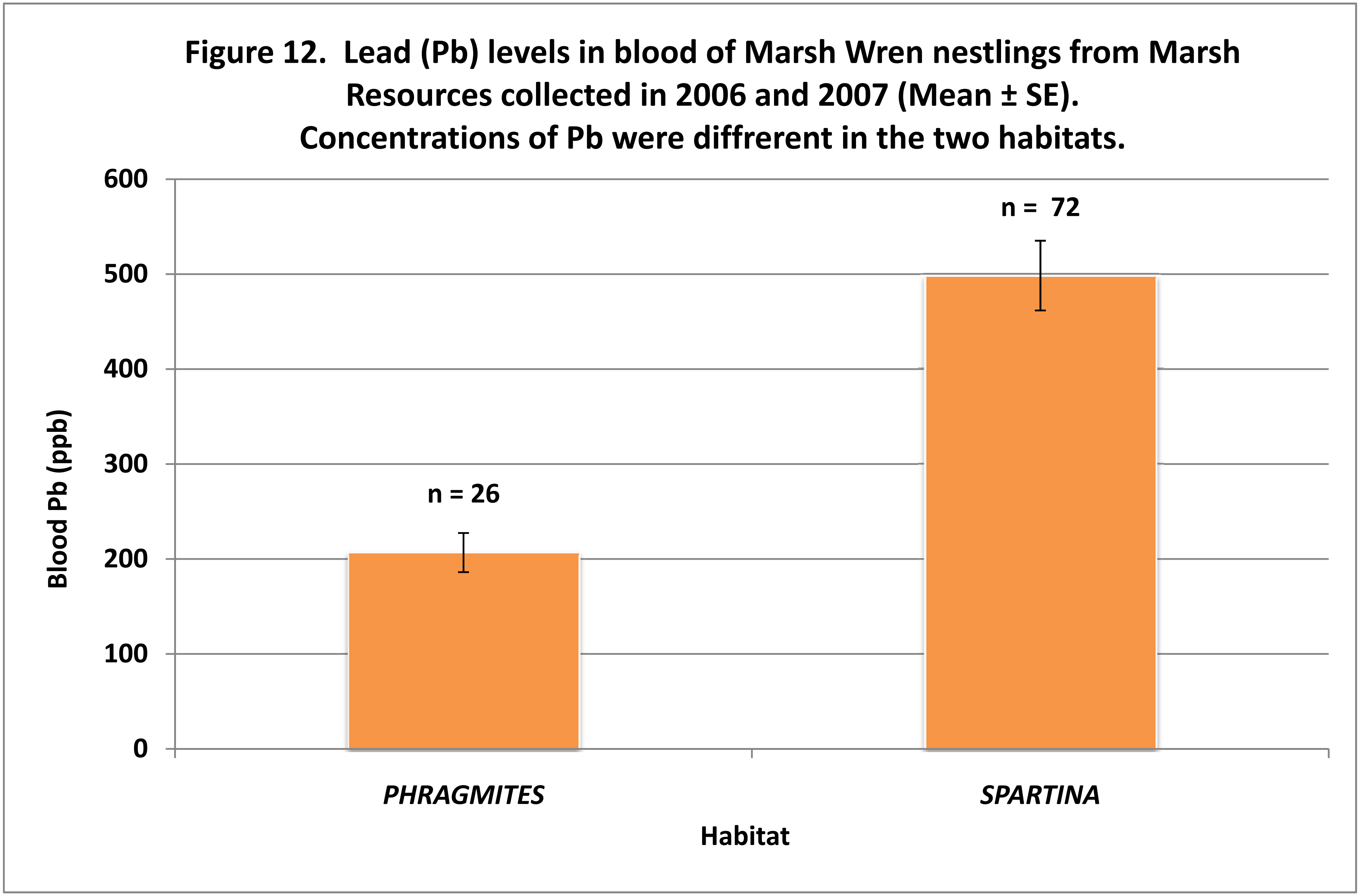


Figure 12. Lead (Pb) levels in blood of Marsh Wren nestlings from Marsh Resources collected in 2006 and 2007 (Mean ± SE).
Concentrations of Pb were diffrerent in the two habitats.
600
500
400
300
200
100
0
Blood Pb (ppb)
n = 26
n = 72
PHRAGMITES
SPARTINA
Habitat

Figure 13. Mercury (Hg) levels by date in Marsh Wren (MAWR), Red-winged Blackbird (RWBL), and Tree Swallow (TRES) blood samples. Since there was no year effect data from both years of the study were combined. There was a significant effect of date on MAWR (decreasing) and TRES (increasing) blood Hg levels

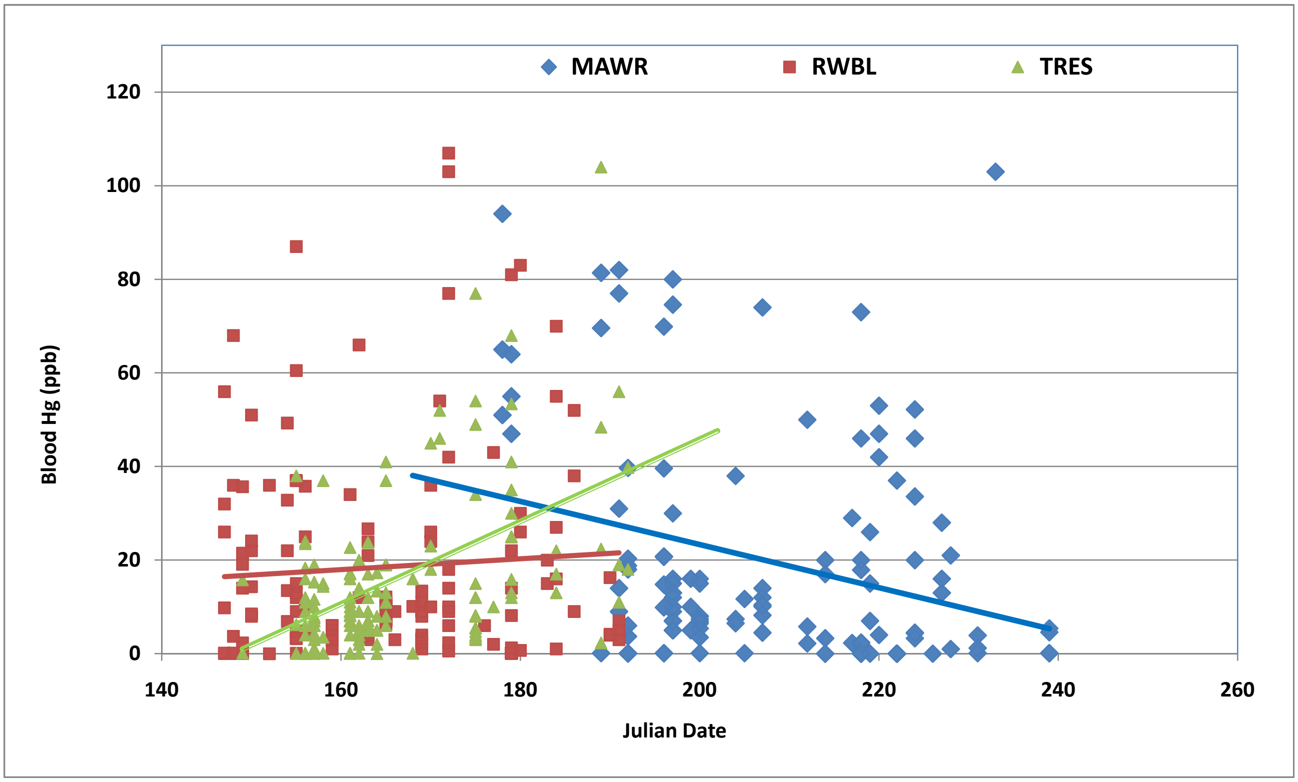


Figure 14. Lead (Pb) levels by date in Red-winged Blackbird (RWBL) blood samples. There was a significant effect of date on RWBL blood Pb levels (decreasing) in 2006

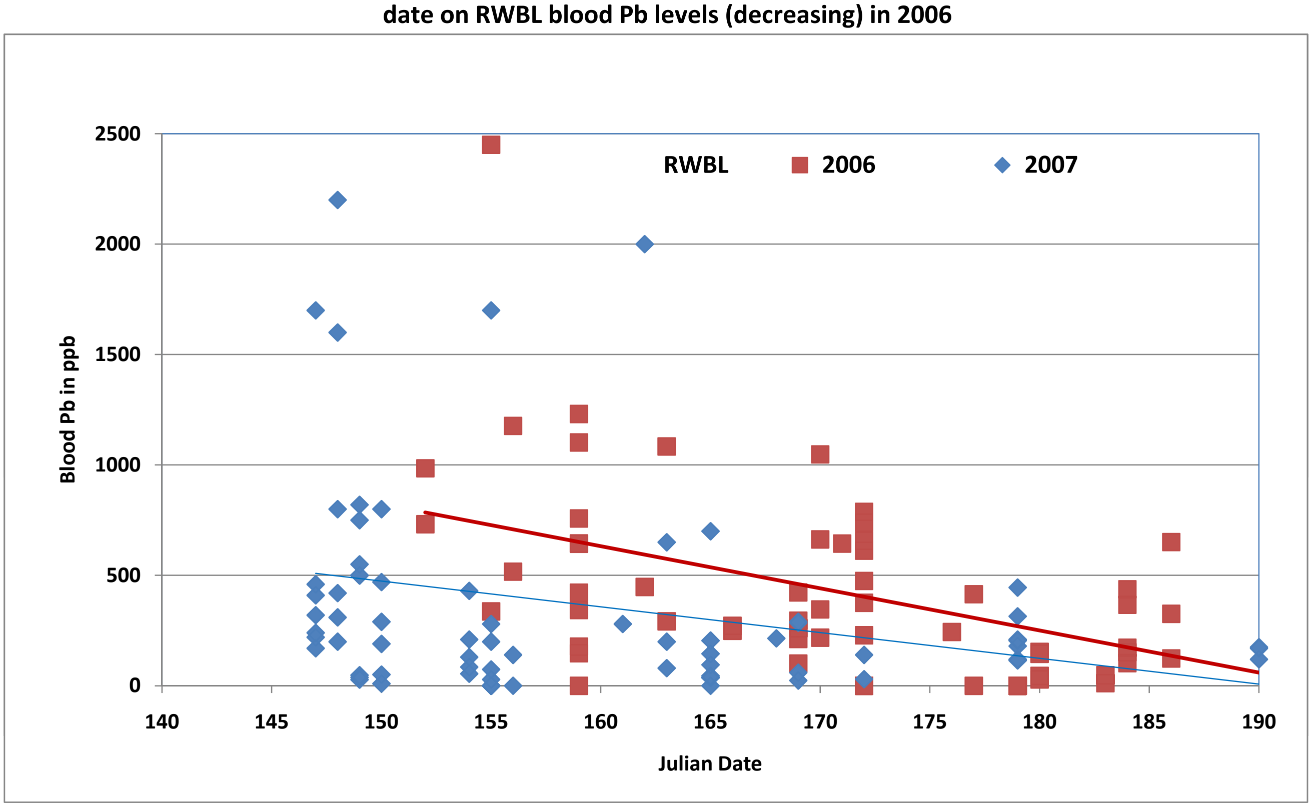
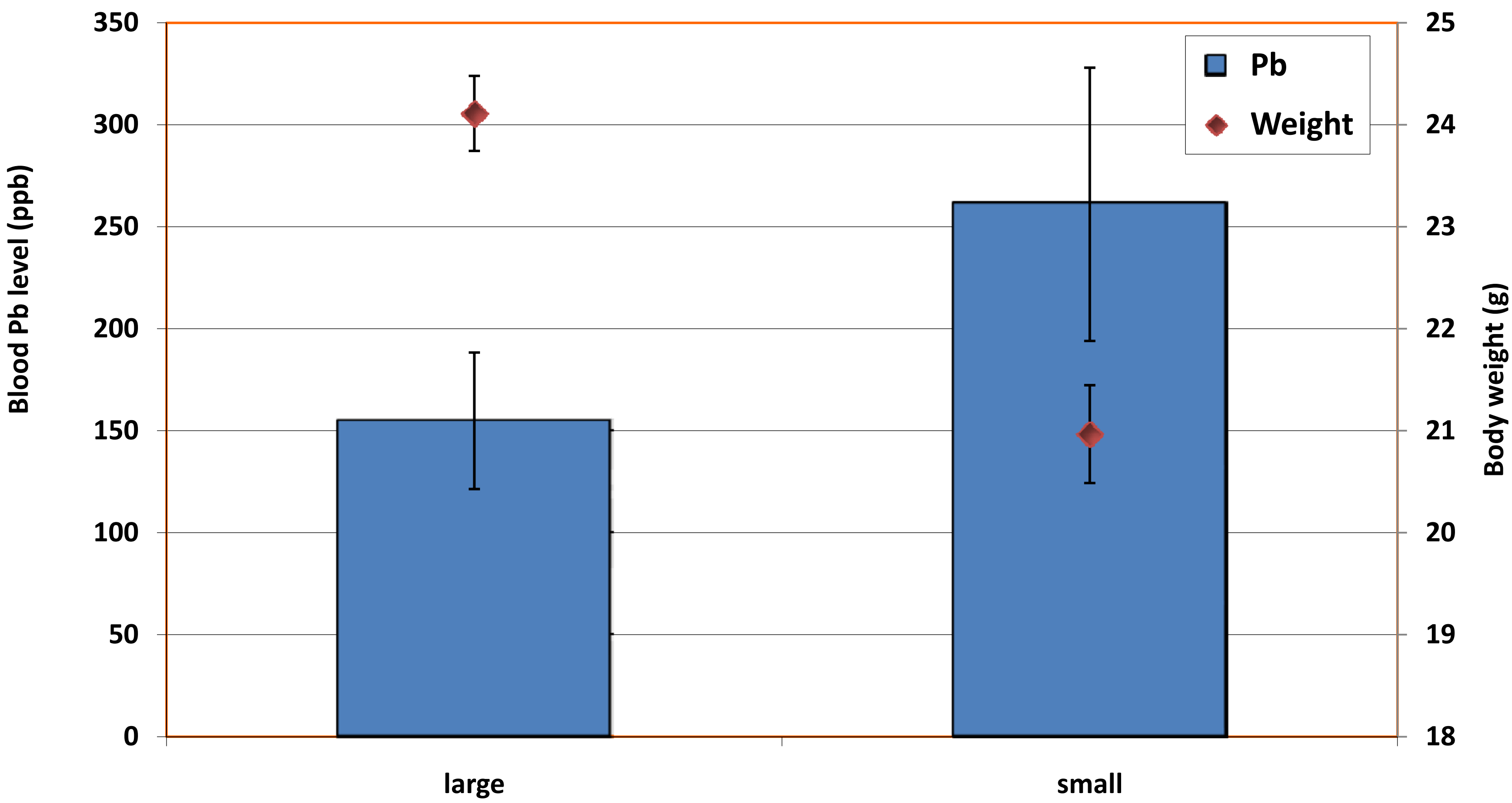


Figure 15. Paired comparisons of lood lead (Pb) levels and weights of the largest and smallest nestlings from each Tree Swallow nest (n = 31).



Appendix 1. Determining age of Red-winged Blackbird and Marsh Wren nestlings if hatch date is not known.

Wing length: Distance from last bend in the wing to the tip of the phalanges before feathers are present and to the tip of primary eight after feathers emerge (wing chord).

Marsh Wren

Day	Mean Wing Chord (in mm)
0	4
1	4.5
2	5
3	6
4	7
5	11
6	19
7	19
8	23
9	25
10	28
11	30
12	38

Red-Winged Blackbird

Day	Mean Wing Chord (in mm)	Degree of eye opening
0	8.2 ± 0.1	Eyes closed
1	10.0 ± 0.1	Eyes closed
2	13.2 ± 0.2	Eyes closed
3	18.1 ± 0.3	Eyes begin to open
4	24.8 ± 0.5	begin to open/ half open
5	33.0 ± 0.4	Eyes half open
6	39.7 ± 0.4	Eyes fully open
7	45.2 ± 0.5	Eyes fully open
8	50.3 ± 0.5	
9	54.7 ± 0.6	
10	58.2 ± 0.9	

Reference: (Holcolmb and Twiest 1971, Welter, 1936)


Appendix 2. NJAS Contaminants Study
Meadowlands 2006-2007 Survey Sites
Skeetkill Creek Marsh (2007 only)
Marsh Resources Meadowlands Mitigation Bank
Mill Creek Marsh (2007 only)
Harrier Meadows
Kingsland Impoundment (DeKorte)
Riverbend Wetland Preserve (2006 only)
Kearny Freshwater Marsh

Appendix 3

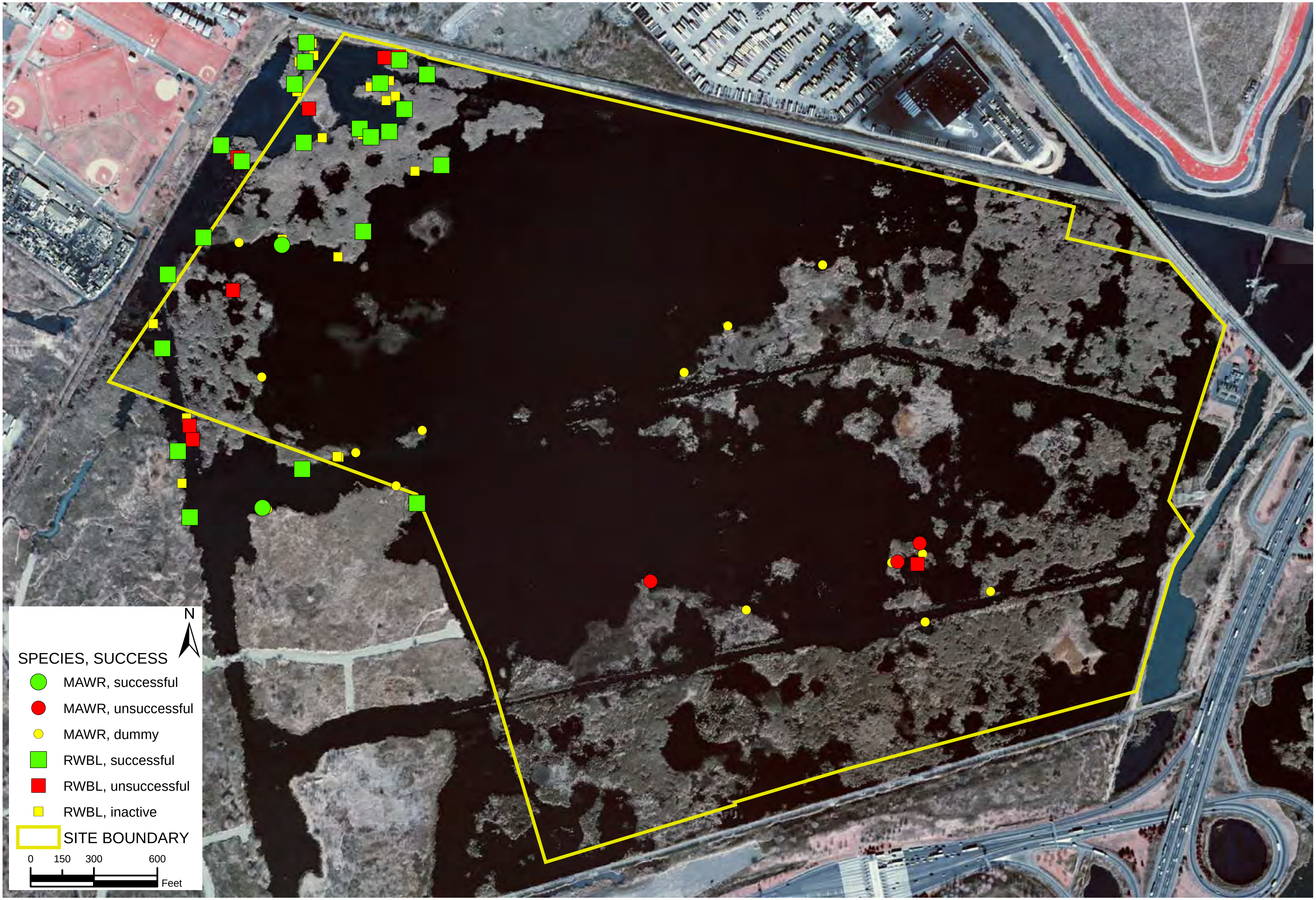
Harrier Meadow: 2006 Nest Locations for Mallard (MALL) and Red-winged Blackbird (RWBL)

Appendix 4.

Harrier Meadow: 2007 Nest Locations for Red-winged Blackbird (RWBL)

Appendix 5

Kearny Freshwater Marsh: 2006 Nest Locations for Marsh Wren (MAWR) and Red-winged Blackbird (RWBL)

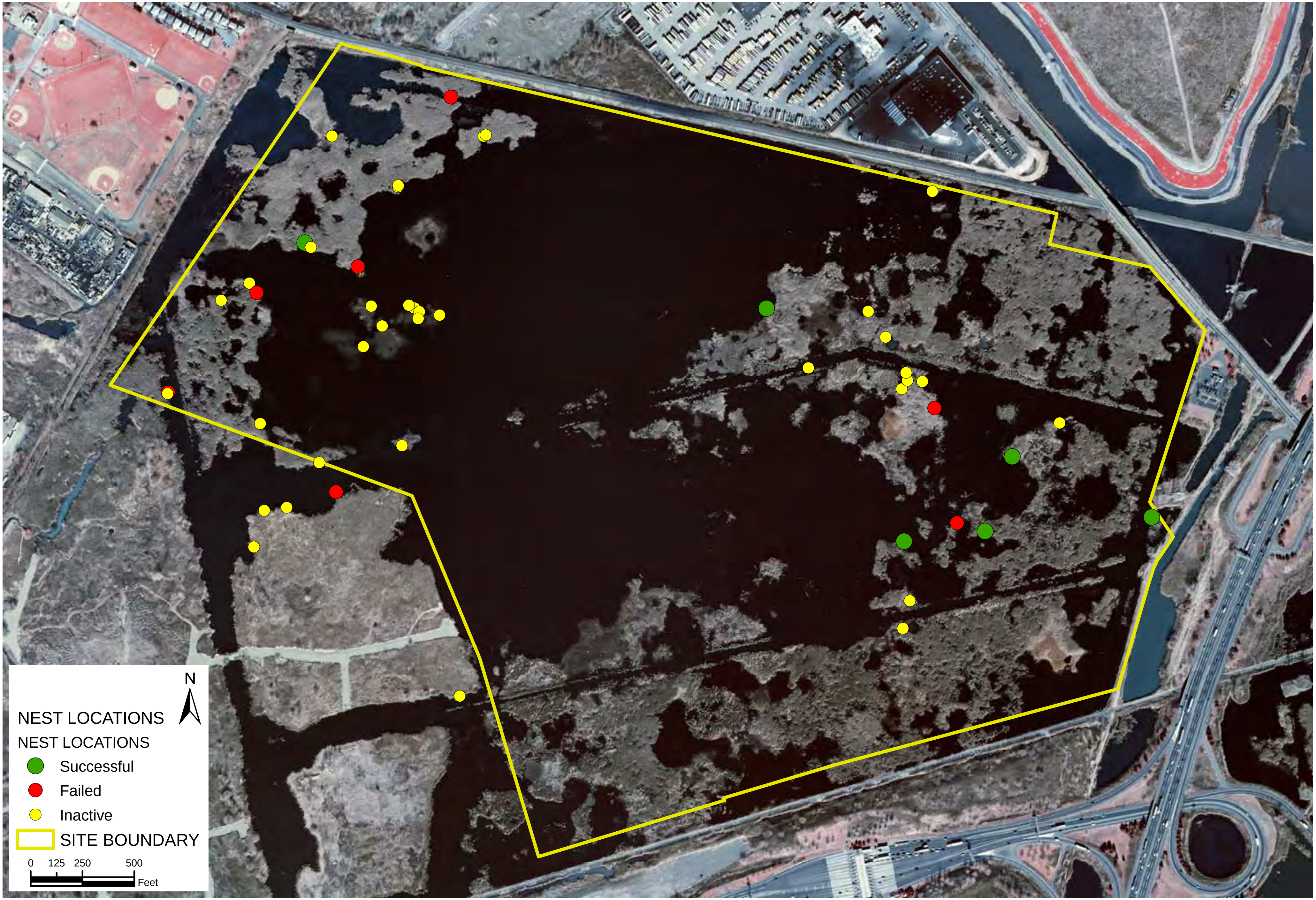


Appendix 6

Kearny Freshwater Marsh: 2007 Nest Locations for Least Bittern (LEBI)

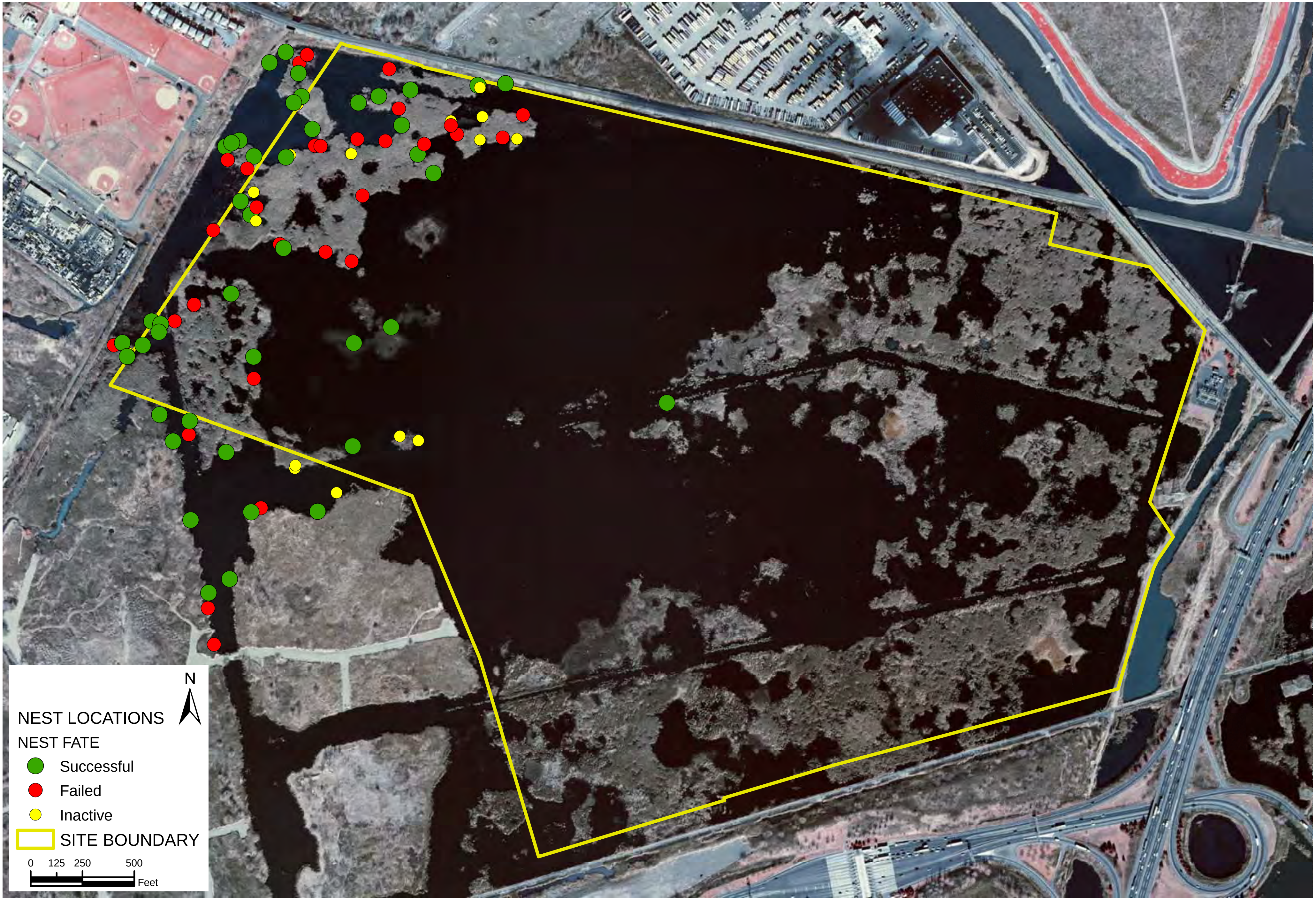
Appendix 7

Kearny Freshwater Marsh: 2007 Nest Locations for Marsh Wren (MAWR)



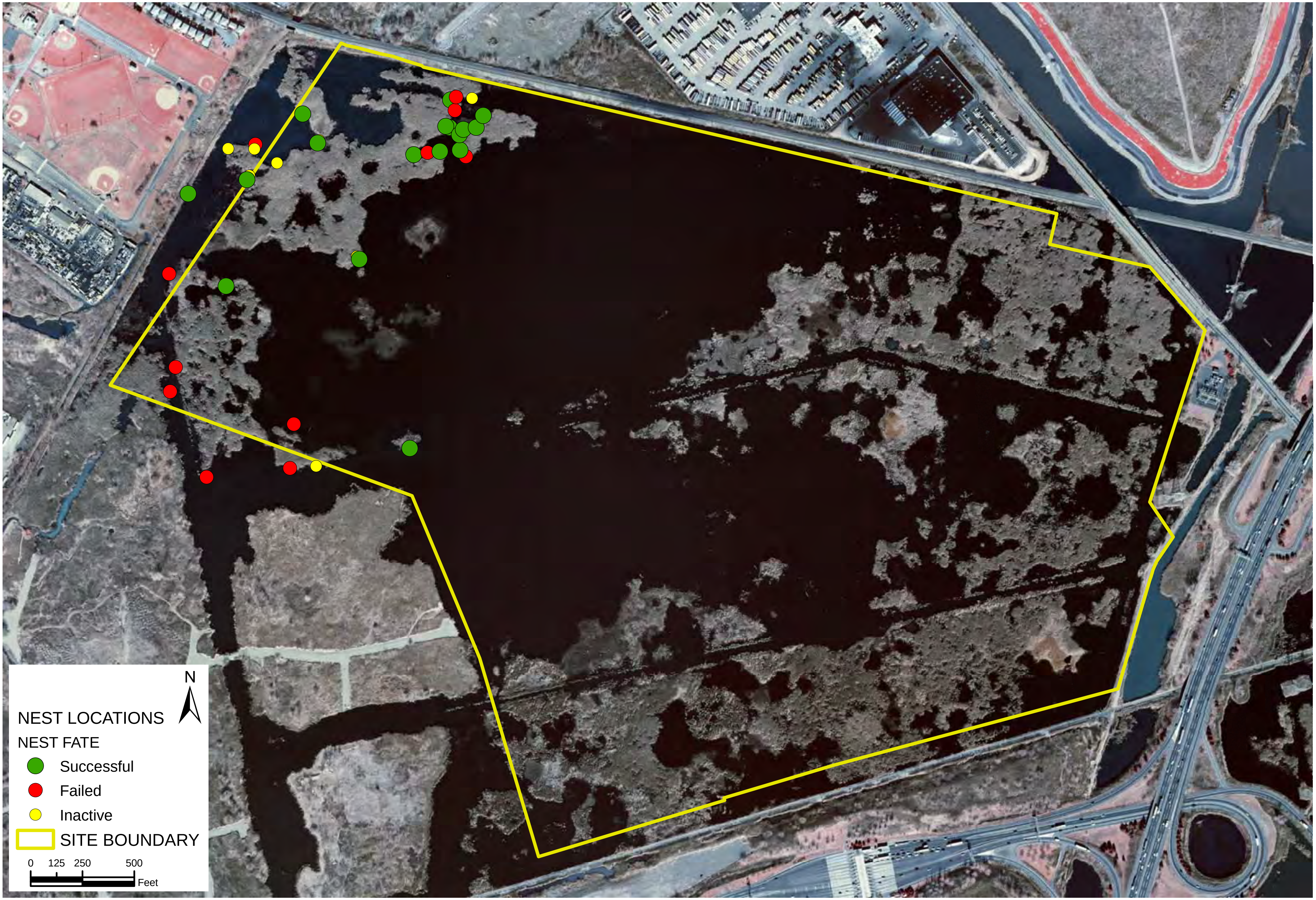
Appendix 8

Kearny Freshwater Marsh: 2007 Nest Locations for Red-winged Blackbird (RWBL)



Appendix 9

Kearny Freshwater Marsh: 2007 Nest Locations for Tree Swallow (TRES)



Appendix 10

Marsh Resources Meadowlands Mitigation Bank: 2006 Nest Locations for Mallard (MALL) and Red-winged Blackbird (RWBL)

Appendix 11

Marsh Resources Meadowlands Mitigation Bank: 2006 Nest Locations for Marsh Wren (MAWR)

Appendix 12

Marsh Resources Meadowlands Mitigation Bank: 2007 Nest Locations for Marsh Wren (MAWR)

Appendix 13

Marsh Resources Meadowlands Mitigation Bank: 2007 Nest Locations for Red-winged Blackbird (RWBL)

Appendix 14

Marsh Resources Meadowlands Mitigation Bank: 2007 Nest Locations for Tree Swallow (TRES)

Appendix 15

Riverbend Wetlands Preserve: 2006 Nest Locations for Marsh Wren (MAWR)

Appendix 16
DeKorte Park: 2006 Nest Box Locations for Tree Swallows

Appendix 17

DeKorte Park: 2007 Nest Locations for Tree Swallow (TRES)

Appendix 18

Mill Creek Marsh: 2007 Nest Locations for Tree Swallow (TRES)

Appendix 19. Egg metal levels in ppb of samples collected in 2006 and 2007 in the Meadowlands District - descriptive statistics, presented as ppb for both wet and dry weight measurements (CAGO = Canada Goose; MAWR = Marsh Wren; RWBL = Red-winged Blackbird; TRES = Tree Swallow; ND = Not detectable)

Species=CAGO year=2007

Variable	N	Mean	Std Dev	Minimum	Maximum
AS_wet	34	5.47	14.87	ND	60.53
CD_wet	34	0.22	0.45	ND	1.75
CR_wet	34	37.29	36.66	6.37	187.96
PB_wet	34	161.10	214.08	20.39	796.43
HG_wet	34	4.29	1.77	1.64	9.10

Variable	N	Mean	Std Dev	Minimum	Maximum
AS_dry	34	17.17	46.68	ND	190.00
CD_dry	34	0.70	1.41	ND	5.50
CR_dry	34	117.06	115.08	20.00	590.00
PB_dry	34	505.71	671.98	64.00	2500.00
HG_dry	34	13.48	5.54	5.16	28.57

Species=MALL year=2006

Variable	N	Mean	Std Dev	Minimum	Maximum
AS_wet	6	16.23	14.72	ND	32.54
CD_wet	6	0.29	0.34	ND	0.95
CR_wet	6	42.60	50.27	13.27	142.81
PB_wet	6	62.14	31.02	21.17	103.95
HG_wet	6	75.14	31.25	25.91	103.95

Variable	N	Mean	Std Dev	Minimum	Maximum
AS_dry	6	51.37	46.59	ND	103.00
CD_dry	6	0.92	1.09	ND	3.00
CR_dry	6	134.83	159.10	42.00	452.00
PB_dry	6	196.67	98.18	67.00	329.00
HG_dry	6	237.83	98.91	82.00	329.00

Appendix 19. Egg metal levels (cont.)

Species=MAWR year=2006

Variable	N	Mean	Std Dev	Minimum	Maximum
AS_wet	31	10.07	20.13	ND	86.83
CD_wet	31	0.37	0.93	ND	3.97
CR_wet	31	59.08	93.84	ND	483.61
PB_wet	31	34.71	29.38	ND	116.03
HG_wet	31	197.07	107.00	24.84	417.84

Variable	N	Mean	Std Dev	Minimum	Maximum
AS_dry	31	50.67	101.30	ND	437.00
CD_dry	31	1.87	4.69	ND	20.00
CR_dry	31	297.33	472.30	ND	2434.00
PB_dry	31	174.68	147.85	ND	584.00
HG_dry	31	991.87	538.52	125.00	2103.00

Species=MAWR year=2007

Variable	N	Mean	Std Dev	Minimum	Maximum
AS_wet	24	1.12	2.78	ND	12.16
CD_wet	24	0.31	0.67	ND	2.27
CR_wet	24	74.32	79.12	15.46	329.76
PB_wet	24	10.90	16.34	ND	59.77
HG_wet	24	121.05	52.83	27.12	270.61

Variable	N	Mean	Std Dev	Minimum	Maximum
AS_dry	24	5.45	13.49	ND	59.00
CD_dry	24	1.50	3.27	ND	11.00
CR_dry	24	360.63	383.89	75.00	1600.00
PB_dry	24	52.87	79.28	ND	290.00
HG_dry	24	587.34	256.34	131.60	1313.00

Appendix 19. Egg metal levels (cont.)

Species=RWBL year=2006

Variable	N	Mean	Std Dev	Minimum	Maximum
AS_wet	35	6.15	9.75	ND	42.52
CD_wet	35	0.27	0.51	ND	1.80
CR_wet	34	127.40	167.61	14.95	681.80
PB_wet	35	39.57	31.77	ND	154.23
HG_wet	35	49.59	38.19	11.17	193.15

Variable	N	Mean	Std Dev	Minimum	Maximum
AS_dry	35	34.14	54.13	ND	236.00
CD_dry	35	1.47	2.83	ND	10.00
CR_dry	34	707.09	930.23	83.00	3784.00
PB_dry	35	219.60	176.30	ND	856.00
HG_dry	35	275.20	211.93	62.00	1072.00

Species=RWBL year=2007

Variable	N	Mean	Std Dev	Minimum	Maximum
AS_wet	76	5.83	11.68	ND	53.25
CD_wet	76	0.79	1.48	ND	7.46
CR_wet	76	50.92	27.87	11.72	133.13
PB_wet	76	27.73	17.77	ND	102.95
HG_wet	76	39.49	28.98	4.23	144.93

Variable	N	Mean	Std Dev	Minimum	Maximum
AS_dry	76	32.84	65.81	ND	300.00
CD_dry	76	4.45	8.36	ND	42.00
CR_dry	76	286.86	157.04	66.00	750.00
PB_dry	76	156.21	100.12	ND	580.00
HG_dry	76	222.49	163.27	23.85	816.50

Appendix 19. Egg metal levels (cont.)

Species=TRES year=2007

Variable	N	Mean	Std Dev	Minimum	Maximum
AS_wet	57	6.78	12.20	ND	59.09
CD_wet	57	0.39	1.27	ND	7.74
CR_wet	57	47.68	50.14	5.09	305.63
PB_wet	57	19.99	12.88	2.24	52.98
HG_wet	57	76.66	39.77	12.70	195.18

Variable	N	Mean	Std Dev	Minimum	Maximum
AS_dry	57	33.27	59.90	ND	290.00
CD_dry	57	1.93	6.21	ND	38.00
CR_dry	57	234.00	246.07	25.00	1500.00
PB_dry	57	98.11	63.22	11.00	260.00
HG_dry	57	376.24	195.19	62.33	957.90

Appendix 20. Feather metal levels in ppb of samples collected in 2006 and 2007 in the Meadowlands District - descriptive statistics (CAGO = Canada Goose; MAWR = Marsh Wren; RWBL = Red-winged Blackbird; TRES = Tree Swallow; ND = not-detected)

Species=CAGO Year=2007

Variable	N	Mean	Std Dev	Minimum	Maximum
AS	26	67.46	162.92	ND	550.00
CD	26	85.58	52.11	21.00	230.00
CR	26	1358.08	1228.09	330.00	4700.00
PB	26	1908.85	1966.84	ND	6800.00
HG	26	258.02	213.28	ND	730.00

Species=MAWR Year=2006

Variable	N	Mean	Std Dev	Minimum	Maximum
AS	15	7.01	16.54	ND	60.00
CD	15	30.93	27.35	6.00	114.00
CR	15	1043.27	423.25	501.00	1880.00
PB	15	431.87	285.17	ND	868.00
HG	15	3231.47	916.17	1811.00	4584.00

Species=MAWR Year=2007

Variable	N	Mean	Std Dev	Minimum	Maximum
AS	9	0.10	0.00	ND	ND
CD	9	83.89	48.59	33.00	180.00
CR	9	970.00	866.86	120.00	3100.00
PB	9	172.28	402.40	ND	1200.00
HG	9	298.57	225.56	ND	623.00

Appendix 20. Feather metal levels (cont.)

Species=RWBL Year=2006

Variable	N	Mean	Std Dev	Minimum	Maximum
AS	29	142.18	162.20	ND	461.00
CD	29	18.59	35.58	ND	191.00
CR	29	606.83	286.55	212.00	1493.00
PB	29	1077.62	763.86	88.00	2695.00
HG	29	825.97	619.03	85.00	2331.00

Species=RWBL Year=2007

Variable	N	Mean	Std Dev	Minimum	Maximum
AS	31	102.49	181.73	ND	700.00
CD	31	63.40	94.88	ND	320.00
CR	31	1276.48	490.27	173.00	2500.00
PB	31	1450.11	1317.58	ND	4500.00
HG	31	620.94	445.29	70.00	1834.00

Species=TRES Year=2006

Variable	N	Mean	Std Dev	Minimum	Maximum
AS	5	70.24	87.77	ND	215.00
CD	5	11.40	9.58	ND	25.00
CR	5	658.80	489.99	362.00	1527.00
PB	5	1364.60	1735.60	60.00	4276.00
HG	5	2043.80	794.17	1007.00	2882.00

Species=TRES Year=2007

Variable	N	Mean	Std Dev	Minimum	Maximum
AS	32	0.10	0.00	ND	ND
CD	32	91.72	120.62	ND	410.00
CR	32	1181.41	1011.52	140.00	4000.00
PB	31	571.32	982.36	ND	4200.00
HG	32	658.94	477.22	ND	1751.00

Appendix 21. Blood metal levels in ppb of samples collected in 2006 and 2007 in the Meadowlands District - descriptive statistics (MAWR = Marsh Wren; RWBL = Red-winged Blackbird; TRES = Tree Swallow; ND = not detected)

SPECIES=MAWR Year=2006

Variable	N	Mean	Std Dev	Minimum	Maximum
As	38	3.73	16.08	ND	86.00
Cd	37	26.89	41.00	ND	214.00
Cr	38	504.77	484.64	ND	1739.00
Pb	38	795.64	876.91	ND	3338.00
Hg	38	35.32	59.77	ND	347.00

SPECIES=MAWR Year=2007

Variable	N	Mean	Std Dev	Minimum	Maximum
As	91	19.57	25.30	ND	95.00
Cd	91	14.11	19.51	ND	98.00
Cr	91	275.25	192.55	ND	950.00
Pb	91	348.02	489.33	ND	3900.00
Hg	91	16.85	20.88	ND	82.00

SPECIES=RWBL Year=2006

Variable	N	Mean	Std Dev	Minimum	Maximum
As	63	4.65	15.74	ND	82.00
Cd	63	13.56	26.57	ND	174.00
Cr	63	517.81	821.94	ND	4595.00
Pb	63	418.61	415.61	ND	2450.00
Hg	62	23.19	27.05	0.70	107.00

SPECIES=RWBL Year=2007

Variable	N	Mean	Std Dev	Minimum	Maximum
As	77	2.03	5.13	ND	29.00
Cd	77	13.58	21.54	ND	96.00
Cr	77	259.63	152.56	62.52	789.25
Pb	77	363.92	522.34	ND	2600.00
Hg	77	15.28	17.12	ND	68.00

Appendix 21. Blood metal levels (cont.)

SPECIES=TRES Year=2006

Variable	N	Mean	Std Dev	Minimum	Maximum
As	14	0.95	3.18	ND	12.00
Cd	14	3.58	4.08	ND	11.00
Cr	14	1032.43	794.01	213.00	2534.00
Pb	14	944.15	847.23	ND	3529.00
Hg	14	19.43	20.37	ND	56.00

SPECIES=TRES Year=2007

Variable	N	Mean	Std Dev	Minimum	Maximum
As	131	1.12	4.46	ND	29.00
Cd	131	3.53	8.03	ND	45.00
Cr	131	288.38	228.41	4.00	950.00
Pb	131	202.27	313.04	ND	2100.00
Hg	131	15.58	20.24	ND	158.00

Appendix 22. Metal levels in ppb of samples collected in 2007 from Canada Geese in the Meadowlands District - descriptive statistics (ND = not-detected).

TISSUE=Muscle

Variable	N	Mean	Std Dev	Minimum	Maximum
As	26	0.60	2.00	ND	9.90
Cd	26	5.70	4.70	0.17	24
Cr	26	71.95	94.87	4.4	350
Pb	26	14.29	39.37	ND	190
Hg	26	12.45	13.41	1.5	62

TISSUE=Liver

Variable	N	Mean	Std Dev	Minimum	Maximum
As	26	3.73	11.60	ND	54
Cd	26	199.12	152.08	0.2	450
Cr	26	163.12	203.79	14	900
Pb	26	249.13	227.97	1.5	940
Hg	26	40.93	34.26	5	135