THE BIOACCUMULATION OF PERSISTENT CONTAMINANTS BY ZEBRA MUSSELS AND THEIR EFFECTS ON STATE- ENDANGERED COMMON TERNS

BY

CINDI JABLONSKI

THESIS

Submitted in partial fulfillment of the requirements
for the degree of Master of Science in Natural Resources and Environmental Sciences
in the Graduate College of the
University of Illinois at Urbana-Champaign, 2009

Urbana, Illinois

Master's Committee:

Dr. Michael P. Ward, Chair
Dr. David Soucek
Mr. Brad Semel, Illinois Department of Natural Resources

ABSTRACT

Common terns currently are listed as endangered or threatened in many states, including Illinois, Vermont, Pennsylvania, Ohio, Wisconsin, Michigan, and New York, and a species of special concern by the U.S. Fish and Wildlife Service (USFWS, 2002). The sole remaining nesting colony in Illinois is located at the Naval Station Great Lakes (NSGL) in Lake County where intensive management by the Illinois Department of Natural Resources has reduced nest predation and increased the number of eggs that hatch. However, the overall reproductive success (the number of young successfully reaching independence) has not improved. Observations of gross deformities in hatchlings (i.e. compromised feather development and cross-bill), lethargic behavior of young birds, and lesions, suggested the influence of environmental contaminants (Jablonski et al., 2005). I investigated if there were significant levels of environmental contaminants in eggs and nestlings of common terns. While there were minimal concentration of selenium, mercury, lead, and cadmium, there were large concentration of polychlorinated biphenyls (PCBs) in both the eggs and nestlings. The greater amounts of PCBs in older chicks than younger chicks suggest local contamination. In order to potentially manage the factors responsible for exposing the terns to PCBs I investigated the pathway by which PCBs were exposed to terns. The two most likely biological pathways as determined by research on Great Lake fishes were investigated. The first pathway is through atmospheric deposition of PCBs and resuspension of PCB-ladel sediment which are subsequently acquired by filter-feeding fish (e.g. alewives, *Alosa pseudoharengus*) and then pelagic fish (e.g. lake trout, *Salvelinus namaychus*) or in this case terns. The second pathway explored was via the biodeposits of zebra mussels which are consumed by round gobies (*Neogobius melanostromus*) and ultimately littoral fish (e.g. small-mouthed bass, *Micropterus dolomieui*) or terns. Because

common terns breed in near-shore sites where concentrations of zebra mussels are found, as well as forage in more pelagic environments it is possible that either or both pathways may be contributing to their PCB exposure. Field experiments and stable isotope analyses demonstrated that the most likely pathway by which terns are exposed to PCBs is via alewives, similar to how apex predators such as lake trout acquire PCBs. Biodeposits from zebra mussels do not appear to be a significant factor in PCB accumulation in terns.

The impact of PCB exposure on birds can vary widely, however in this situation we choise to investigate one specific behavior often affected by PCB exposure, parental attentiveness. PCBs are known to cause endocrine disruption which ultimately results in reduced brooding of young and incubation of eggs. I used temperature sensors to quantify nest temperatures and parental attentiveness during incubation. High concentrations of PCBs in our study population appear to be leading to poor parental attentiveness, and extended periods of absence during incubation and brooding, ultimately leading to poor reproductive success.

Common terns are perilously close to being extirpated in Illinois and management of PCB exposure will be difficult. I propose that additional testing should be conducted to locate a site with less PCB contamination and then to move the tern colony to this location, possibly using social cues as has been done with other tern species in Illinois. PCBs are having a profound impact on common tern populations in Illinois and without moving the colony it is likely that the population will continue to decline.

ACKNOWLEDGMENTS

This project would not have been possible without the support of many people. Many thanks to my adviser, Dr. Mike Ward, with his endless patience; he always gave me practical advice and was generous with his knowledge. Also thanks to my committee members, Dr. Dave Soucek and Brad Semel, who also offered guidance and support. A special thanks to Brad Semel for inspiring me to change careers and go into the field of Natural Resources; it turned out to be one of the most rewarding decisions that I ever made. Thanks to the University of Illinois for awarding me an assistantship which provided me with financial means to complete this project Thanks Illinois Department of Natural Resources for providing grant opportunities that were essential in funding this project. The cooperation of the Naval Station Great Lakes is deeply appreciated, in particular Bob Vanbendegom. And finally, I want to extend a debt of gratitude to my family and friends for their encouragement and support during the course of this study.

TABLE OF CONTENTS

CHAPTER 1: THE BIOLOGICAL PATHWAY AND EFFECT OF PCBS ON COMMON TERNS IN LAKE MICHIGAN………………………………………………………………...1

APPENDIX A: STATUS REVIEW & RECOVERY OUTLINE FOR COMMON TERNS IN ILLINOIS……………………………………………...…31

APPENDIX B: RECENT BREEDING DATA FOR COMMON TERNS AT NAVAL STATION GREAT LAKES…………………………………………………………………………39

APPENDIX C: CONTAMINANT TEST RESULTS……...…………………………………...40

SUMMARY……………………………………………………………………………...49

CHAPTER ONE

THE BIOLOGICAL PATHWAY AND EFFECT OF PCBS ON COMMON TERNS IN LAKE MICHIGAN

ABSTRACT

Poly-chlorinated biphenyls (PCBs) have been recognized as a significant contaminant in the Great Lakes ecosystem for the last several decades and continue to be an ecological concern today. Although PCBs have been implicated in the reduced survival and reproductive success of several piscivorous bird species, the biological pathway along which PCBs bioaccumulate and the effect of PCBs on avian reproductive success are largely unknown. This study investigated the two most likely biological pathways, suggested via research on Great Lake sport fish, by which PCBs would be acquired by common terns (*Sterna hirundo*), a piscivorous species of conservation concern throughout its range. The first pathway is through atmospheric deposition of PCBs which are subsequently acquired by filter-feeding fish (e.g. alewives, *Alosa pseudoharengus*) and then pelagic fish (e.g. lake trout, *Salvelinus namaychus*). An alternative pathway is via the biodeposits of zebra mussels which are consumed by round gobies (*Neogobius melanostromus*) and ultimately littoral fish (e.g. small-mouthed bass, *Micropterus dolomieui*). Because common terns breed in near-shore sites where concentrations of zebra mussels are found, as well as forage in more pelagic environments it is possible that either or both pathways may be contributing to their PCB exposure. Field experiments and stable isotope analyses demonstrated that the most likely pathway by which terns are exposed to PCBs is via alewives, similar to how apex predators such as lake trout acquire PCBs. Biodeposits from zebra mussels do not appear to be a significant factor in PCB accumulation in terns. Because PCBs are known to cause endocrine disruption, thermochrons were used to quantify nest temperatures and

parental attentiveness during incubation. High concentrations of PCBs in our study population appear to be leading to extended periods of absence during incubation and brooding, ultimately leading to poor reproductive success.

INTRODUCTION

The bioaccumulation of polychlorinated biphenyls (PCBs) can have significant affects on adult birds, eggs, and nestlings (Fox et al., 1991; Ludwig et al., 1996). The effect of PCBs on birds is variable but can include direct mortality, physical deformities, reduced hatching success, and aberrant behaviors (Custer et al., 1983; Ohlendorf et al., 1985; Becker et al., 1993; Yamashita et al., 1993; Bosveld et al., 1995; Lorenzen et al., 1997; Stapleton et al., 2001). Piscivorous birds appear to be particularly susceptible to the bioaccumulation of PCBs (Grasman et al., 1998; Kunisue and Tanabe, 2008). However, the biological pathways by which PCBs are accumulated by the birds are largely unknown. Many piscivorous birds that potentially could be impacted by environmental contaminants are found in the Great Lakes ecosystem. Although little is known about bird food webs in the Great Lakes, a large volume of research has been conducted on the biological pathways by which PCBs are accumulated in sport fish (e.g., Stapleton et al., 2001; Streets et al., 2006; Ng et al., 2008, Helm et al., 2008). These and other studies of the Great Lakes ecosystem have generally elucidated two pathways. The first involves the resuspension of contaminants in the sediment and/or atmospheric deposition of PCBs into the water column and assimilation by predatory fish through the food chain (Stapleton et al., 2001). Once associated with seston and detritus within the water column, PCBs are transferred to small pelagic fish such as alewives (*Alosa pseudoharengus*), and then on to the apex pelagic predators, such as lake trout (*Salvelinus namaychus*) and salmon (*Salmo salar*; Kiriluk et al., 1995; Stapleton et al., 2001). An alternate biological pathway was established following the introduction of two exotic species. The introduction of zebra mussels (*Dreissena polymorpha*) and round gobies (*Neogobius melanostomus*) into the Great Lakes basin has been found to facilitate the bioaccumulation of PCBs in piscivorous fish (Bruner et al., 1994; Cho et al., 2004; Kwon et al., 2006). Zebra mussels filter PCBs from the water column and sequester them in both their soft tissues and shells. However, the mussels deposit a significant proportion of the PCBs in their feces and psuedofeces (Cho et al., 2004; Kwon et al., 2006). These biodeposits are then ingested by round gobies, which in turn are preyed upon by piscivorous fish, most often small-mouth bass (*Micropterus dolomieu*).

For many fish species the pathway most likely to contribute to the bioaccumulation of PCBs can be elucidated by their primary forage items. Pelagic species, such as lake trout, acquire PCBs from filter feeding fish, while species that prefer shallow water with underwater structure (e.g. small-mouthed bass) bioaccumulate PCBs via fish that forage on or near the biodeposits of zebra mussels (Hubert and Lackey, 1980; Kwon et al., 2006). Zebra mussels are unlikely to be important to many pelagic species because they occur primarily in shallow areas with underwater structure. Many piscivorous birds such as the common terns (*Sterna hirundo*) breed on islands or peninsulas along the Great Lake. They forage not only in nearby shallow water where underwater structures support large colonies of zebra mussels, but also in open water where pelagic fish (e.g. alewives) are sought. Therefore, they may be exposed to PCBs by either or both pathways.

Although the mean concentration of PCBs in the Great Lakes fisheries stock continues to decline (Jackson et al., 1998; Lamon et al., 2000), atmospheric deposition and resuspension of PCB laden sediments pose a continuing hazard to both wildlife and humans (Baker, 1991; Turyk et al., 2006). Indeed, the bioaccumulation of PCBs in Great Lake sport fish poses a human health concern for those consuming fish (Turyk et al., 2006), as well as a conservation concern for piscivorous birds given the population declines of many of these species (e.g. common terns). Therefore, it is imperative to understand both the biological pathway of PCBs to the terns, and to identify the potential impacts of PCB consumption on piscivorous birds of conservation concern, and in particular the impacts on their reproductive success.

Researchers have documented wide variations in how PCBs affect the physiology and behavior of different bird species (Hoffman et al., 1998). A number of others have measured PCBs in common tern tissues elsewhere, and have documented reduced hatching success, abnormal embryos, and congenital deformities due to elevated PCB loads (Hays and Risebrough, 1972; Gilbertson et al., 1976; Gilbertson et al., 1991; Hoffman et al., 1993; Becker et al., 1993; French et al., 2001). PCB exposure in adult birds has also been shown to cause endocrine disruption, which in turn may lead to reduced parental attentiveness and lower hatching success (Kubiak, 1989; Bustnes et al., 2001; Stapleton et al., 2001; Fisher et al., 2001).Although there has been a reduction in PCB concentrations and fewer observations of gross deformities in piscivorous birds over the last decade, there remains the potential for significant consequences of PCB consumption on bird populations.

Poor parental attentiveness can be particularly detrimental for species such as terns and gulls that nest in open areas of sand or rock. Studies of Forster's terns (*Sterna forsteri*) have found that eggs left unattended in the sun can reach 50º C within 25 minutes (Grant, 1982). Generally, once a bird egg reaches 40.5 º C some embryonic damage occurs (Dawson, 1984). Short periods of high temperatures can be fatal; the upper lethal internal egg temperature varies between 43-49 ºC (Barrett, 1980; Bergstrom, 1989). In addition, although nest temperatures are not a direct measure of egg temperature, Bergstrom (1989) estimated that when nest temperatures reached 43.2 ºC internal egg temperatures are 42 ºC. At the other extreme, embryos in eggs that drop below 26 º C simply stop developing (Webb, 1987). Research on parental attentiveness in common terns has shown that if adults are frequently flushed while incubating at night when temperatures are cool, the temperature of the eggs can drop (Arnold et al., 2006), extending the amount of time required for the egg to hatch (Wendeln and Becker, 1999).

This study was designed to determine whether common terns were being exposed to ecological contaminants at a colony in the southern portion of Lake Michigan. Field experiments were conducted to identify the biological pathway of PCBs to the terns; the suspected pathway was then further investigated using stable isotopes of carbon and nitrogen. Finally, parental attentiveness of common terns was quantified to determine if PCB contamination may be indirectly affecting hatching success of the common tern, implicating environmental contamination as a limiting factor for this species.

METHODS

Study Species and Study Location

The common tern is recognized as an endangered species in Illinois (Illinois Endangered Species Protection Board, 2004) and a species of federal concern (U.S. Fish and Wildlife Service, 2002). In Illinois, the sole remaining nesting colony is located at the Naval Station Great Lakes (NSGL), in northeastern Lake County (Figure 1.1). The colony has become established within the Lake Michigan harbor, a site with substantial amounts of underwater structures, including breakwaters and docks, which support large concentrations of zebra mussels. Despite intensive management efforts to exclude mammalian nest predators the survival of fledglings is low and renesting is common (Jablonski et al., 2005). Observations of deformities in hatchlings (i.e., compromised feather development and cross-bill), lethargic behavior of young birds, and lesions (Jablonski et al., 2005) suggested the influence of environmental contaminants. Common terns feed on a wide variety of items but their primary food source is small fish (<150mm), and generally they feed on fish in relation to their availability (Moore, 2005). Although no data has been systematically collected on which species common terns preferentially forage at NSGL, spottail shiners (*Notropis hudsonius*), alewives, and other small fish have been documented being brought to the colony to feed young (Jablonski et al., 2005).

Tern Exposure to Environmental Contaminants

The endangered status of common terns and the limited population precluded active collection of live material for study (i.e., chicks and eggs). Therefore samples collected fortuitously were utilized to assess environmental contamination. Morbid nestlings, unhatched eggs, and one adult were analyzed; samples were collected during the summers of 2005, 2006 and 2007. Carbon Dynamics, Inc., an independent laboratory located in Springfield, Illinois, analyzed all samples used in this study. Individual samples of each category were homogenized with a mechanical blender, dried with sodium sulfate, and aliquots transferred to cellulose extraction thimbles. Extracts were analyzed with a triple stage quadrupole mass spectrometer in a negative chemical ionization. All samples were tested for common PCB congeners; however, only "total PCB" values are presented in this study. In addition, a small number of samples were analyzed for selenium, mercury, lead, and cadmium by ion chromatography (Method 1636, U.S.EPA, 1996). Heavy metals have also been shown to affect the reproduction success and cause deformities in piscivorous birds (Hays and Risebrough, 1972; Burger and Gochfeld, 1997; Lam et al., 2005). The detection limit used for selenium was 0.200 mg/kg, cadmium 0.012 mg/kg, mercury 0.050 mg/kg, lead 0.002 mg/kg, and the detection limit for total PCBs was

0.50µg/kg.

Biological Pathway

Two field experiments were conducted to investigate the potential biological pathways of PCBs to terns. First, eight PVC cylinders 1.3m long by 20 cm in diameter that supported an inner metal mesh cylinder were constructed. Four of these cylinders housed zebra mussels collected from within the harbor, the other four contained gravel that approximated the same size as the mussels used in the study. The gravel cylinders served as controls and were used to replicate the flow of water through cylinders containing zebra mussels. Small slits were cut vertically along each PVC cylinder to allow water circulation through to the interior mesh, and a glass collection jar was attached at the bottom of each cylinder. The collection jars were emptied every two weeks. The cylinders were suspended in the water column in approximately 3 m of water. The PCB concentrations of material collected from the jars were compared between cylinders containing mussels (treatment) and those containing gravel. The intent was to evaluate mussel biodeposits, seston, detritus and other organic material gathered from the water column. If zebra mussels were facilitating the availability of PCBs it would be expected that the contents of the cylinders with mussels would have greater concentrations of PCBs compared to the cylinders with gravel.

The second experimental design employed six fish enclosures made of 1 cm^2 mesh hardware cloth measuring 3.0m x 0.67m x 0.67m. Each enclosure had a smaller secondary cage built into the top that contained either zebra mussels or similarly sized gravel; there were three treatment cages and three gravel control cages. Each fish enclosure was submerged in approximately 1.5m of water in an area of the harbor where common terns were known to forage. Spottail shiners and alewives were seined from the same area and placed in each of the cages. A sub-sample of the collected fish was analyzed to determine the contaminant levels prior to the start of the experiment. Sediment below the enclosures was tested before and after placement of the cages. The sediment was scrapped off the surface of the lake bottom with a collection jar. The mesh size of the cloth was chosen with the intention of keeping experimental fish inside and other fish outside the enclosures for the duration of the experiment. An unintended consequence of the experiment was the inclusion of gobies that presumably swam into the enclosures as small fry or larvae and later grew too large to escape. We allowed the cages remained in place from April 20, 2007 through October 5, 2007. The intent was to document whether zebra mussels were facilitating the exposure of PCBs to forage fish sought by common terns. If zebra mussels were facilitating the exposure to PCB contaminants, the fish within treatment cages would have higher levels of contaminants than the fish inside control cages.

Stable Isotope Analysis

Carbon (i.e. ^{13}C:^{12}C) and nitrogen isotope ratios (i.e. ^{15}N: ^{14}N) were used to analyze source links within the local food web. Samples of zebra mussel tissue, macroinvertebrates, phytoplankton, leaf litter, forage fish, and morbid young were used in the isotope analysis to establish the food pathway to the common terns. All sample types were placed in a desiccator, dried at 55^{o} C for 48 h and then ground with mortar and pestle. Samples were then packed into individual tin capsules and sent to the University of California at Davis Stable Isotope Lab for C and N isotope analysis. The mixing model Isosource® (Phillips and Gregg, 2001) was used to determine which potential food sources were most likely to explain the carbon and nitrogen isotope ratios of the fish: all possible combinations of each source contribution (0-100%) were examined in 1% increments. Stable isotope ratios are expressed in δ notation as parts per thousand according to the following:

$$\delta X = [(R_{sample} / R_{standard})-1] \times 1000,$$

Where X = ^{15}N or ^{13}C, R = ratio, $^{15}N/^{14}N$ or $^{13}C/^{12}C$. $R_{standard}$ for ^{15}N is atmospheric nitrogen, and for ^{13}C it is Pee Dee belemnite. Samples were also analyzed for total carbon and nitrogen. To normalize potential food items for trophic enrichment, a value of + 0.5 was used for δ^{13} C (France, 1996), and +3.4 was used for δ^{15} N (Minagawa and Wada, 1984). Combinations that sum to the observed mixture isotopic signatures with +/- 0.1% were considered feasible solutions. Percentages of source contributions to diet are presented as medians, 1st and 99th percentiles of all iterations for alewives.

Parental Attentiveness

Incubation patterns in breeding terns were investigated using temperature sensors placed directly beneath eggs in each active nest. Tern nests were located and numbered individually on a weekly basis, and the number of eggs and young in each nest was recorded. The temperature sensors recorded the nest temperature every 15 minutes for the duration that the nest was active. Common terns in the NSGL colony have consistently laid three egg clutches (Jablonski, 2005). The thermochrons (i-buttons ©), temperature sensors used for this study were developed by Dallas/Maxim (Sunnyvale, California), and used an embedded computer chip that integrates a 1-wire transmitter/receiver, thermometer, clock/calendar, and thermal history log. Individual nest temperature data from each thermochron were analyzed to determine when temperatures exceeded temperatures known to damage developing embryos. Minimum and maximum temperatures were documented for each nest during incubation. These data were compared with the number of live chicks that hatched from each monitored nest for the 2006 and 2007 breeding seasons. No adults were collected to compare potential PCB loads of the eggs or parents with parental attentiveness.

Statistical Analyses

Simple T-tests were used to compare contaminant concentrations between tern chicks of different age classes, contaminant loads between biodeposits and seston/detritus collected from suspended PVC cylinders, contaminants in the sediments and fish before and after enclosure were established, and contaminant concentrations in shiners, gobies, and amphipods (*Diporeia spp*) between treatment and control enclosures at the conclusion of that experiment. Also, T-tests were also used to compare the number of eggs that hatched from nests that recorded temperatures exceeding 40.5^{o}C and those that did not. Standard error is reported unless otherwise stated.

RESULTS

Tern Exposure to Environmental Contaminants

Common terns at NSGL have low tissue concentrations of selenium (n=36, 1.30 mg/kg) and a near absence of cadmium (n=3, < 0.02 mg/kg), mercury (n=3, < 0.18 mg/kg), and lead (n=3, < 0.36 mg/kg; Appendix B). In contrast, concentrations of PCBs was prevalent, and as chicks aged from newly hatched (< 2 days old) to near fledging (14-20 days old) average PCB loads increased from 2,449 ± 949 µg/kg to 4,336 ± 1362 µg/kg (t = 0.93, df = 7, P = 0.19; Table 1.1). All of the contaminants were measured in wet weights.

Biological Pathway

Concentrations of PCBs were detected in all field experiments within the NSGL harbor. In the first experiment involving suspended PVC tubes, there were higher concentrations of PCBs in the collection jars beneath control cores (i.e. with gravel: 50.21± 6.05 µg/kg) than those beneath treatment tubes containing mussel biodeposits (27.15 ± 7.93 µg/kg; t = 4.73, df = 3, P <

0.01; Figure 1.2).

For the experimental fish containment cages, analyses of sediment samples from below the cages showed no significant difference in PCB concentrations before and after the experiment in either the control cages (t = 0.39, df =8, P = 0.71) or the treatment cages (t = 1.17, df = 8, P =0.48; Figure 1.3). The selenium concentrations in both the sediment samples before and after the experiment showed no statistical difference (0.26 ± 0.18 mg/kg vs. 0.33 ± 0.33 mg/kg; t = 0.17, df = 11, P = 0.44). No alewives survived the 113 days of confinement and no remains were available for testing. Very few shiners survived, the concentrations were determined from live samples only. Although none of the alewives survived, it should be noted that the stock alewives had higher concentrations of PCBs (955.77 ± 368.11µg/kg) than stock shiners (102.80 ± 29.48µg/kg; t=2.32, df = 2, P = 0.07). While there was a trend that suggested accumulation of PCBs for the shiners in both the control the control and treatment enclosures (102.8± 29.4 µg/kg before vs. 242.58 ± 91.79 µg/kg after), the difference was not significant (t= 1.53, df = 6, P = 0.18; Figure 1.3). There was also a slight trend for the shiners to accumulate selenium after remaining in both the control and treatment cages; however the difference was not significant (0.25 ± 0.25mg/kg vs. 0.30 ± 0.20mg/kg; t = 0.29, df= 3, P = 0.39). There was no difference in the PCB concentrations of shiners between the treatment (248.88± 112.53 µg/kg) and control (234.18± 183.28µg/kg; t=0.08, df = 2, P=0.94) upon termination of the experiment. There was, however, a difference in the selenium concentrations in shiners between the treatment (0.53 ± 0.31 mg/kg) and control (0± 0 mg/kg; t = 1.70, df=2, P =0.09) upon termination. Round gobies, however, had a higher concentration of PCBs in the treatment cages (468.09 ± 97.19 µg/kg) as opposed to the control cages (45.78 ± 37.95 µg/kg; t= 9.76, df = 2, P =0.01). Only one comparable sample of gobies was tested for selenium: (0.70 mg/kg) from the control cages and an undetected amount from the treatment cages, not enough for statistical analysis.

Stable Isotope Analysis

Using a stepwise enrichment value of 3.4 for $\delta^{15}N$ and 0.5 for $\delta^{13}C$, it appeared that alewives were the primary local food source of the terns (figure 1.4). The mixing model Isosource® was then used to determine the alewife food sources. Table 1.2 lists the possible combinations ranging from the 1st to the 99th percentile. Based on the results, alewives appear to feed primarily on amphipods and rarely on the biodeposits of zebra mussels. The ratio of $\delta^{15}N$ to $\delta^{13}C$ illustrates that common terns were the apex predator of the food chain investigated (Figure 1.4).

Parental Attentiveness

The temperature sensors in the nests recorded very poor attentiveness in 20 nests (Figure 1.5). Assuming that temperatures above 40.5 º C impair embryonic development, we compared the number of eggs that hatched between nests that did and those that did not have temperatures reach $\geq$ 40.5 º C. The number of eggs that hatched in a nest that had temperatures above 40.5 º C (0.77 $\pm$ 0.28) was lower than those whose nest never reached 40.5 º C (1.90 $\pm$ 0.39; $t = 2.35$, df = 17, $P < 0.02$).

DISCUSSION

Common tern eggs and nestlings at the NSGL in southern Lake Michigan are highly contaminated with PCBs. Isotope analyses suggest alewives are the primary prey of common terns, which is consistent with anecdotal observations of fish being brought to nestlings in the colony. Thus, the pathway of environmental PCBs from Lake Michigan waters to terns appears to be similar to the pathway along which pelagic fish such as lake trout accumulate PCBs. Stapleton et al., 2001 quantified the PCB load of lake trout in Lake Michigan at approximately

1200 µg/kg, and Streets et al., (2006) found similar PCB levels in their sampling efforts of Lake Michigan lake trout 1,600 – 1,900 µg/kg. Although only one adult tern was analyzed in this study and comparisons between taxa are difficult due to differences in physiology and lipid-content, among other factors, it appears that common terns may have a greater PCB load than lake trout (2,530.47 mg/kg, n=1).

The lower PCB concentrations collected from suspended cylinders containing zebra mussels as compared to those cylinders containing gravel suggests that zebra mussels are sequestering PCBs from the water column and retaining them in their shell or tissue. It also appears that seston and other detritus in the water column are contaminated with PCBs. Although adult alewives are phyloplankton feeders, young alewives regularly feed on amphipods like Diporeia spp. (Mills et al., 1992; O'Gorman et al., 2000; Pothoven and Vanderploeg, 2004; Hondorp et al., 2005; Stewart et al., 2009). The amphipods sampled from the harbor had relatively high PCB concentrations, and the PCB concentrations were similar in amphipods whether from enclosures with or without zebra mussels.

Our isotope analyses suggest that zebra mussel biodeposits are at most a very small part of the food chain of common terns. This finding is supported by both the fish enclosure study and the natural history of the fish associated with the mussel biodeposits (round gobies). In the fish enclosure experiment, gobies exhibited the greatest difference in PCB levels between those enclosures with and without zebra mussels. This was not surprising considering that studies have shown that gobies readily ingest mussel biodeposits and bioaccumulate PCBs from these biodeposits (Cho et al., 2004; Kwon et al., 2006). Given that common terns are aerial, plunge foragers it is unlikely that gobies would constitute a significant portion of their diet given the gobies' tendency to forage at or near the lake bottom. Although the tern colony may be within a few meters of large zebra mussel colonies, terns likely are not exposed to this PCB source due to their preference for fish near the water's surface. The most likely pathway of PCBs to terns is via seston, amphipods, and alewives. Unfortunately, no alewives survived the cage experiment so it was impossible to completely examine this link in the food web.

Although there has been a general decline in PCB concentrations in the Great Lakes (Lamon, 2000) and gross deformities in birds are rare, the terns in this study population appear to be affected by PCBs, leading to reduced reproductive success. Impaired reproduction was due to both poor parental attentiveness (i.e. reduced hatching success) and direct mortality of young. Although we did not capture and inspect all nestlings, several individuals did have lesions and in some cases nestlings died within a day of hatching (Jablonski et. al., 2005). It should be noted that our sample of tern nestlings does not represent a random sample of nestlings because we only analyzed nestlings found dead. If nestlings with higher PCB concentrations were more likely to die it would skew our average PCB loads higher. However, half of the eggs we analyzed were first eggs in a clutch and randomly selected. The PCB loads we detected in those samples were much higher than other similar studies where PCBs impacted reproductive success. A study in Germany documented hatching failure in common tern eggs with an average PCB load of 5,451 µg/kg (Becker et al., 1993). The average concentration of PCBs in eggs that failed to hatch in our study was 12,839 µg/kg in 2007, well above that measured by Becker and his colleagues. Although only one adult was analyzed for PCBs (2,530.47 µg/kg), the high levels of PCBs in eggs suggest elevated levels in the parents as well.

High concentrations of PCBs in adult terns may lead to endocrine disruption and preternatural parental behavior which may in turn lead to failed eggs. High levels of PCBs have been documented to affect parental/nest attentiveness in birds that nest in similar habitat as the terns, larids, (glaucous gulls, *Larus hyperboreus*; Bustnes, 2001). The desirable nesting habitat in open sand makes the nests very susceptible to over-heating. We recorded temperatures of >55 º C in two nests, and in one of these nests, one egg hatched. It should be noted that nest temperatures can be greater than the actual temperature of the embryo in the egg. Poor attentiveness can also lead to prolonged incubation periods (Kubiak et al., 1989; Wendeln and Becker, 1999; Fisher et at., 2006), which we noticed on several occasions when monitored nests exceeded the anticipated 22 or 23 days of incubation.

Although most of the sampling occurred in 2007, a few young and eggs were collected in 2005 and 2006 for analysis. Concentrations of PCBs in young and eggs differed significantly between 2005(682.79 $\pm$ 353.70 µg/kg) and 2006, 2007 (9,134.67 $\pm$ 1,458.52 µg/kg; $t = 5.61$, df $=35$, $P < 0.01$). Although these differences could be due to our smaller sample size in 2005 (N=4 vs. N=33), there also may be large variation in contaminant levels between years. In years with a higher abundance of alewives, herring gulls (*L. argentatus*) were found to have higher concentrations of PCBs (Herbert et al., 1997). It is possible that a reduced alewife population in 2005 may have accounted for lower PCB concentrations. Behavioral observations suggested that the second most common prey after alewives were spottail shiners and our isotope analysis supports this. A comparison of the stock fish used in the enclosure study suggested that on average alewives had higher PCB loads than shiners. Therefore, a reduction in alewives may have reduced the terns' exposure to PCBs. Selective feeding to the young at different life stages may also be factor in the bioaccumulation of PCBs in young terns: younger, smaller chicks often are fed shiners and as they age and are able to accommodate larger fish, alewives are fed to the young more often than shiners (Jablonski et al., 2005).

Zebra mussels have been implicated in the decline of several avian species that feed directly on them. Waterfowl, including buffleheads *(Bucephala albeola)*, lesser scaups (*Aythya affinis*), and greater scaups (*A. marila*), have been shown to bioaccumulate PCBs and selenium after ingesting contaminated zebra mussels (Mazak et al., 1997). Scaup populations have dramatically declined since 1972, which may in part be the result of consuming zebra mussels as their primary food source (Petrie et al., 2007). While common terns also have declined over the last two decades it does not appear that the arrival of zebra mussels has hastened their decline. This study suggests that the fortunes of common terns as it relates to PCBs may be similar to that of the piscivorous fish that feed on alewives. Because direct monitoring and collection of adult terns is difficult and unwise given their conservation status, lake trout, which feed on alewives, may provide an indirect measure of PCB loads in common terns in the Great Lakes.

LITERATURE CITED

Arnold JM, Saborn D, Nisbet ICT, and Hatch JJ. Use of temperature sensors to monitor patterns of nocturnal desertion by incubating common terns. Journal of Field Ornithology. **77**: 384-391.

Baker JE, Eisenreich SJ, and Eadie BJ. 1991. Sediment trap fluxes and benthic recycling of organic-carbon, polycyclic aromatic-hydrocarbons, and polychloro-biphenyl congeners in Lake Superior. Environmental Science & Technology. **25**: 500-509.

Barrett RT. 1980. Temperature of Kittiwake (*Rissa tridactyla*) eggs and nests during incubation. Ornis Scandinavica **11:** 50-59.

Becker PH, Schuhmann S, and Koepff C. 1993. Hatching failure in common terns (*Sterna hirunda*) in relation to environmental chemicals. Environmental Pollution **79:** 207-213.

Bergstrom PW. 1989. Incubation temperatures of Wilson's plovers and killdeers. The

Condor **91:** 634-641.

Beyersbergen GW, Niemuth ND and Norton MR. 2004. Northern Prairie & Parkland Waterbird Conservation Plan. A plan associated with the Waterbird Conservation for the Americas initiative. Published by the Prairie Pothole Joint Venture, Denver, Co. 183 pp.

Bosveld ATC, Gradener J, Murk AJ, Brouwer A, Van Kampen M, Evers EHG, and Vanden Berg M. 1995. Effects of PCDDs, PCDFs, and PCBs in common tern breeding in estuarine and coastal colonies in the Netherlands and Belgium. Environmental Toxicology and Chemistry, **14**: 99-115.

Burger J and Gochfeld M. 1997. Risk, mercury levels, and birds: relating adverse laboratory effects to field biomonitoring. Environmental Research. **75**: 160-172.

Bustnes JO, Bakken V, Erikstad KE, Mehlum F, and Skaare JU. Patterns of incubation and nest-site attentiveness in relation of organochlorine (PCB) contamination in glaucous gulls. Journal of Applied Ecology. **38**: 791-801.

Cho YC, Frohnhoefer RC, and Rhee GY. 2004. Bioconcentration and redeposition of polychlorinated biphenyls by zebra mussels (*Driessena polymorpha*) in the Hudson River. Water Research. **38**: 769-777.

Custer TW, Erwin RM, and Stafford C. 1983. Organochlorine residues in common tern eggs from nine Atlantic Coast Colonies, 1980. Colonial Waterbirds **6:** 197-204.

Fisher SA, Bortolotti GR, Fernie KJ, Bird DM, and Smits JE. 2006. Behavioral variation and its consequences during incubation for American kestrels exposed to polychlorinated biphenyls. Ecotoxicology and Environmental Safety. **63**: 226-235.

Fisher SA, Bortolotti GR, Fernie KJ, Smits JE, Marchant, TA, Drouillard, and Bird DM. 2001. Courtship behavior of captive American kestrels (*Falco sparveius*) exposed to polychlorinated biphenyls. Environmental Contaminant Toxicology. **41**: 215-220.

Fox GA, Weseloh DV, Kubiak TJ, and Erdman TC. 1991. Reproductive outcomes in colonial fish-eating birds: A biomarker for developmental toxicants in Great Lakes food chains. Journal of Great Lakes Research. **17**: 153-158.

France RL. 1996. Absence or masking of metabolic fractionations of ^{13}C in a freshwater benthic food web. Freshwater Biology **36**: 1-6.

Gilbertson M, Kubiak T, Ludwig J, and Fox G. 1991.Great Lake embryo mortality, edema, and deformities syndrome (GLEMEDS) in colonial fish-eating birds: similarity to chick-edema disease. Journal of Toxicology and Environmental Health. **33**: 455-520.

Gilbertson M, Morris RD, and Junter RA. 1976. Abnormal chicks and PCB residue levels in eggs of colonial birds on the lower Great Lakes (1971-1973). Auk. **93**: 434-442.

Grasman KA, Fox GA, and Scanlon PF. 1998. Reproductive and physiological effects of environmental contaminants in fish-eating birds of the Great Lakes: a review of historical trends. Environmental Monitoring and Assessment. **53**: 117-145.

Hays H and Risebrough RW. 1972. Pollutant concentrations in abnormal young terns from Long Island Sound. The Auk. **89**: 19-35.

Helm PA, Gewurtz SB, Whittle DM, Marvin CH, Fisk AT, and Tomy GT. Occurrence and biomagnifications of polychlorinated naphthalenes and non- and mono-ortho PCBs in Lake Ontario sediment and biota. 2008. Environmental Science & Technology. **42**: 1024-1031.

Herbert CE, Shutt JL, and Norstrom RJ. 1997. Dietary changes cause temporal fluctuations in polychlorinated biphenyl levels in herring gull eggs from Lake Ontario. Environmental Science & Technology. **31**: 1012-1017.

Hoffman DJ, Smith GJ, and Rattner BA. 1993. Biomarkers of contaminant exposure in common terns and black-crowned night herons in the Great Lakes. Environmental Toxicology and Chemistry. **12**: 1095-1103.

Hondorp DW, Pothoven SA. and Brandt SB. 2005. Influence of *Diporeia* density on diet composition, relative abundance, and energy density of planktivorous fishes in southeast Lake Michigan. Transactions of the American Fisheries Society.**134**: 588-601.

Hubert WA and Lackey RT. 1980. Habitat of adult smallmouth bass in a Tennessee river reservoir. Transactions of the American Fisheries Society. **109**: 364-370.

Illinois Department of Natural Resources. 2005. The Illinois Comprehensive Wildlife Conservation Plan and Strategy. Springfield. 380 pp.

Illinois Endangered Species Protection Board. 2004. Checklist of endangered and threatened animals and plants of Illinois. Illinois Department of Natural Resources. Springfield. 20 pp.

Jablonski C, Semel B and Ward MP. 2005. The reintroduction and conservation of breeding Forster's (*Sterna forsteri)* and common terns (*Sterna hirundo)* in Illinois. Illinois Department of Natural Resources. 21pp.

Jackson LJ, Carpenter SR, Manchester-Neesvig J, and Stow C. 1998. Current concentrations of PCBs in Lake Michigan invertebrates, a prediction test, and corroboration of hindcast concentrations. Journal of Great Lake Research. **24**: 808-821.

Kiriluk RM, Servos MR, Whittle DM, Cabana G, and Rasmussen JB. 1995. Using ratios of stable nitrogen and carbon isotopes to characterize the biomagnifications of DDE, mirix, and PCB in a Lake Ontario pelagic food web. Canadian Journal of Fisheries and Aquatic Sciences. **52**: 2660-2674.

Kubiak T, Harris H, Smith L, Schwartz T, Stalling D, Trick J, Sileo L, Docherty D, and Erdman T. 1989. Microcontaminants and reproductive impairment of the Forster's tern on Green Bay, Lake Michigan-1983. Archives Environmental Contaminants Toxicology. **18**: 706-27.

Kunisue T and Tanabe S. 2008. Contamination status and toxicological implications of persistent toxic substances in avian species. Journal of Disaster Research. **3**: 196-205.

Kwon TD, Fisher SW, Kim GW, Hwang H, and Kim JE. 2006. Trophic transfer and biotransformation of Polychlorinated bephenyls in zebra mussel round goby and smallmouth bass in Lake Erie USA. Environmental toxicology and Chemistry **25:**1068-78.

Lam JCW, Tanabe S, Lam MHW, and Lam PKS. 2005. Risk to breeding success of water birds by contaminants in Hong Kong: evidence from trace elements in eggs. Environmental Pollution. **135**: 481-490.

Lamon EC, Carpenter SR, and Stow CA. 2000. Depuration of PCBs in the Lake Michigan ecosystem. Ecosystems. **3**: 332-343.

Lorenzen A, Shutt JL, and Kennedy SW. 1997. Sensitivity of common tern (*Sterna hirundo)* embryo hepatocyte cultures to CYPIA induction and porphyrin accumulation by halogenated aromatic hydrocarbons and common tern egg extracts. Archives of Environmental Contamination and Toxicology. **32:** 126-134.

Ludwig JP, Kurita-Matsuba H, Auman HJ, Ludwig ME, Summer CL, Giesy JP, Tillitt DE, and Jones PD. 1996. Deformities, PCBs, and TCDD-equivalents in double-crested cormorants (*Phalacrocorax auritus*) and Caspian terns (*Hydroprogne caspia*) of the Upper Great Lakes 1986-1991: testing a cause-effect hypothesis. Journal of Great Lake Research.

22: 172-197.

Mazak E, MacIsaac H, Servos M, and Hesslein R. 1997. Influence of feeding habits on organochlorine contaminant accumulation in waterfowl on the Great Lakes. Ecological Applications. **7**: 1133-1143.

Mills EL, O'Gorman R, Degisi J, Heberger RF, and House RA. 1992. Food of the alewife (*Alosa Pseudoharengus*) in Lake Ontario before and after the establishment of *Bythotrephes Cederstroemi*. Canadian Journal of Fisheries and aquatic Science. **49**: 2009-2019.

Minagawa M. and Wada E. 1984. Stepwise enrichment of ^{15}N along food chains: further evidence and the relation between $\delta\ ^{15}$N and animal age. Geoshimica et Cosmochimica Acta. **48**: 1135-1140.

Moore DJ and Morris RD. 2005. The production of second clutches in the common tern: Proximate effects of timing and food supply. Waterbirds. **28**: 458-467.

Ng CA, Berg MB, Jude DJ, Janssen J, Charlebois PM, Amaral LAN ,and Gray KA.2008. Chemical amplification in an invaded food web: seasonality and ontogeny in a high-biomass, low-diversity ecosystem. Environmental Toxicology and Chemistry. **10**: 2186-95.

O' Gorman R, Elrod JH, and Owens RW. 2000. Shifts in the depth distributions of alewives, rainbow smelt, and age-2 lake trout in Southern Lake Ontario following establishment of dreissenids. Transactions of the American Fisheries Society. **129**: 1096-1106.

Ohlendorf HM, Schaffner FC, Custer TW, and Stafford CJ. 1985. Reproduction and organochlorine contaminants in terns at San Diego Bay. Colonial Waterbirds **8**: 42-53.

Petrie SA, Badzinski SS, and Drouillard KG**.**2007. Contaminants in lesser and greater scaup staging on the lower Great Lakes. Archives of Environmental contamination and

Toxicology. **52**: 580-589.

Phillips DL and Gregg JW. 2001. Uncertainty in source partitioning using stable isotopes. Oecologia. **127**: 171-179.

Pothaven SA and Vanderploeg HA. 2004. Diet and prey selection of alewives in Lake Michigan: Seasonal, depth, and interannual patterns. Transactions of the American Fisheries Society. **133**: 1068-1077.

Stapleton HM, Masterson C, Skubinna J, Ostrom P, Ostrom NE, and Baker JE. 2001. Accumulation of atmospheric and sedimentary PCBs and toxaphene in a Lake Michigan food web. Environmental Science Technology. **35**: 3287-3293.

Stapleton M, Dunn P, McCarty J, Secord A, and Whittingham L. 2001. Polychlorinated biphenyl contamination and minisatellite DNA mutation rates of tree swallows. Environmental Toxicology and Chemistry. **20:** 2263-2267.

Stewart TJ, Sprules WG, and O'Gorman R. 2009. Shifts in the diet of Lake Ontario alewife in response to ecosystem change. Journal of Great Lakes Research. **35**: 241-249.

Streets SE, Henderson SA, Stoner AD, Carlson DL, Simcik MF, and Swackhaner DL. 2006. Partitioning and bioaccumulation of PBDEs and PCBs in Lake Michigan. Environmental Science Technology. **40**:7263-7269.

Turyk M, Anereson HA, Hanrahan LP, Falk C, Steenport CF, Needham LL, Paterson DG, Freels S, Persky V, and the Great Lakes Consortium. 2006. Relationship of serum levels of individual PCBs, dioxin, and furan congeners and DDE with Great Lakes sport-caught fish consumption. Environmental Research. **100**: 173-183.

U.S. Environmental Protection Agency. 1996. Method 1636: determination of hexavalent Chromium by ion chromatography. USEPA, Washington, D.C. 35pp.

U. S. Fish and Wildlife Service. 2002. Birds of conservation concern 2002. Division of Migratory Bird Management, Arlington, Virginia. 99 pp. Region 3. Table 43 and 48.

Webb DR. 1987. Thermal tolerance of avian embryos: a review. The Condor. **89**: 874-898.

Wendeln H and Becker PH. 1999. Does disturbance by nocturnal predators affect body mass of adult common terns? **22**: 401-410.

Yamashita N, Tanabe S, Ludwig JP, Kurita H, Ludwig ME, and Tatsukawa R. 1993. Embryonic abnormalities and organochlorine contamination in double-crested cormorants (*Phalacrocorax auritus*) and caspian terns (*Hydroprogne caspia*) from the Upper Great Lakes in 1988. 1993. Environmental Pollution. **79**: 163-173.

TABLES AND FIGURES

Table 1.1. Concentrations of PCBs and Selenium in common terns and eggs. Small young were less than one day old while large young were nearly fledged, > 20 days old; collected after they were found dead following a storm event. All of these samples were collected in 2006 and 2007.

Source	**Total PCBs (µg/kg; wet weight)**	**Se (mg/kg; wet weight)**
Small Young	2,449.58 (SE± 948.94; n=8)	1.47 (SE ± 0.21; n=6)
Large Young (n=8)	4,336.49 (SE± 1,351.59)	2.70 (SE ± 0.19)
Eggs (n=18)	13,862.61 (SE ± 2,056.09)	0.55 (SE ± 0.15)
Adult (n=1)	2,530.47	2.4

Table 1.2. The mixing model Isosource® was used to determine the alewife food sources. This represents the possible diet composition for alewives; combinations ranging from the 1^{st} to the 99^{th} percentile. Based on the results, alewives appear to feed primarily on amphipods and rarely on the biodeposits of zebra mussels.

Food Source	**Median**	**1^{st} percentile**	**99^{th} percentile**
Biodeposits	0.5%	0%	2%
Amphipods	69%	68%	72%
Leaf litter	29.5%	28%	72%
Algae	0.5%	0%	2%

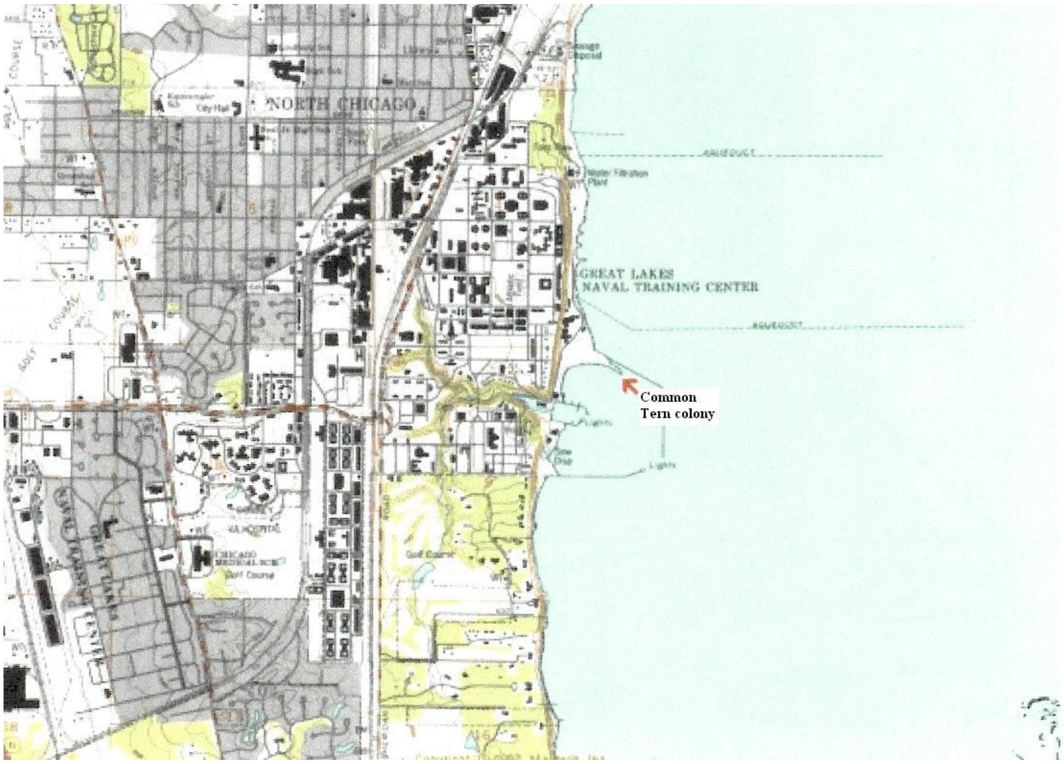

Figure 1.1. Location of the common tern colony at the Naval Station Great Lakes in Lake County, Illinois.

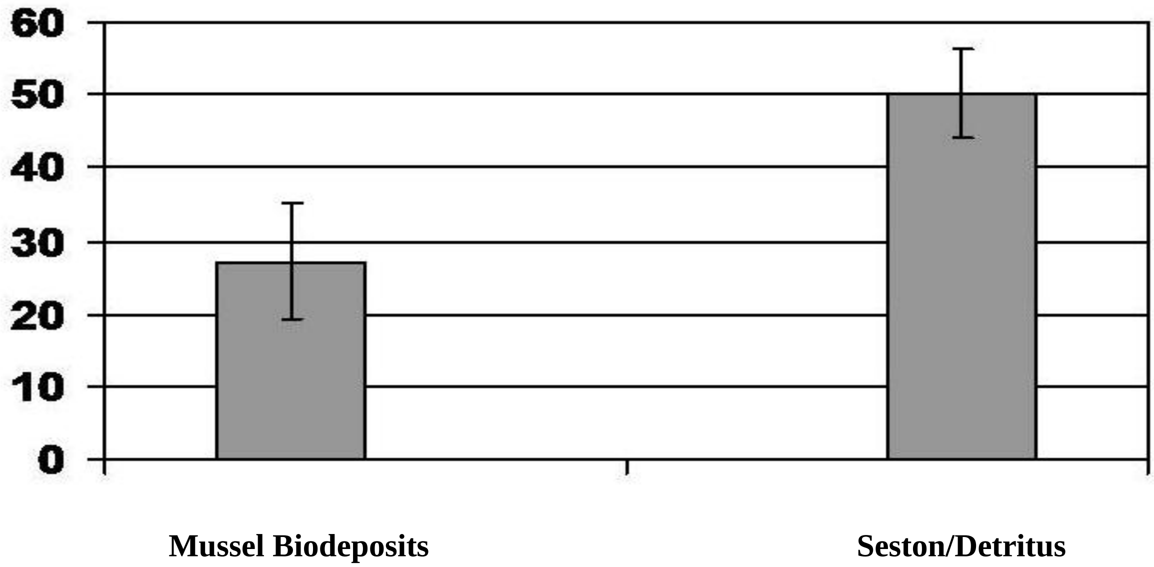

Figure 1.2. Total PCB concentrations (µg/kg) in the collection jars below suspended mussel colonies and controls represented by gravel. Values illustrated are means + SE.

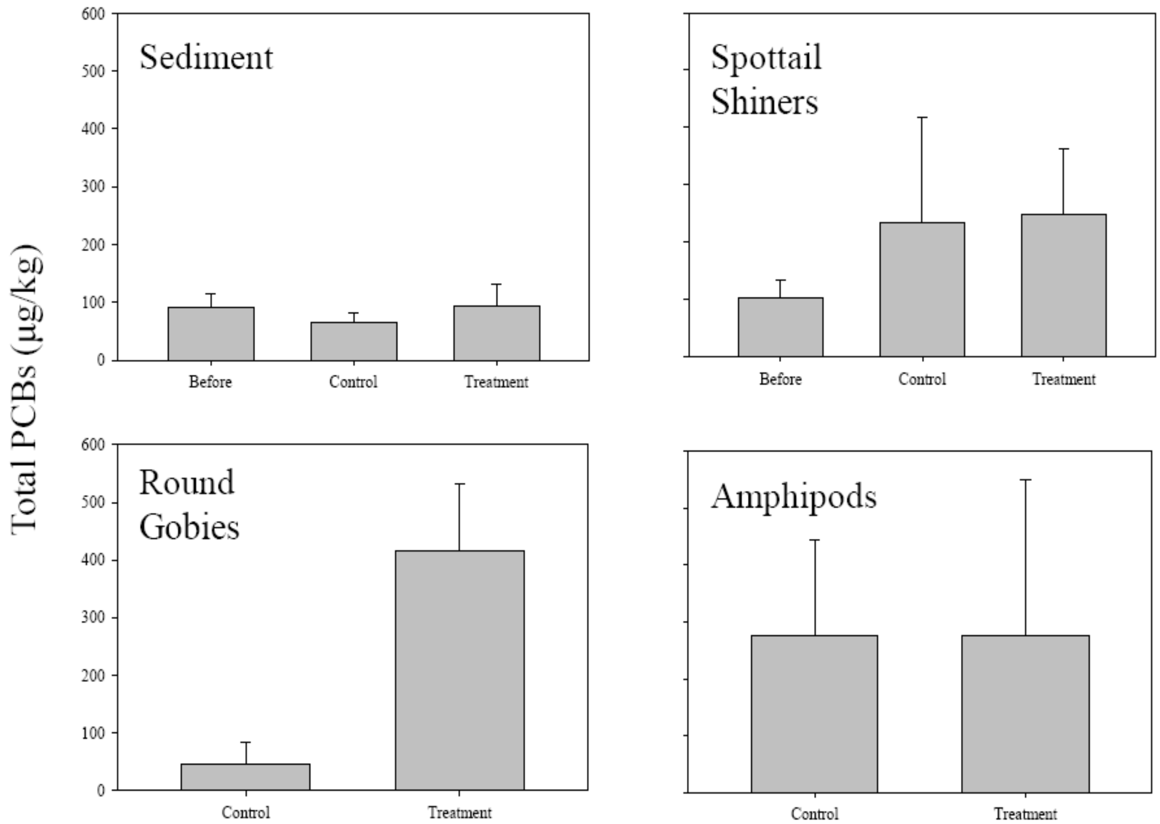

Figure 1.3. PCB loads (µg/kg) within sediment, spottail shiners before confinement and after (169 days) in the treatment (with zebra mussels) and control (without zebra mussels) enclosures, and round gobies and amphipods (*Diporeia* spp.) in the treatment and control enclosures. Values illustrated are means ± SE.

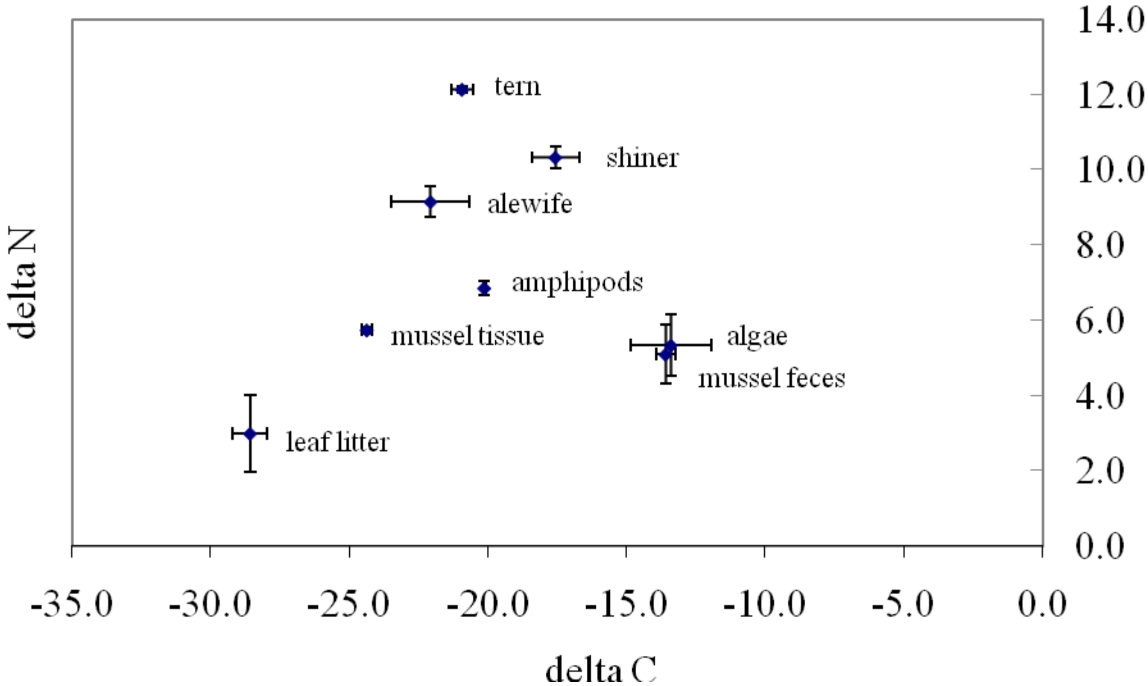

Figure 1.4. $\delta^{15}N$ and $\delta^{13}C$ values for common terns, alewives, spot-tailed shiners, amphipods (*Diporeia* spp.), zebra mussel tissue, algae, zebra mussel biodeposits, and leaf litter. Values illustrated are means ± SD.

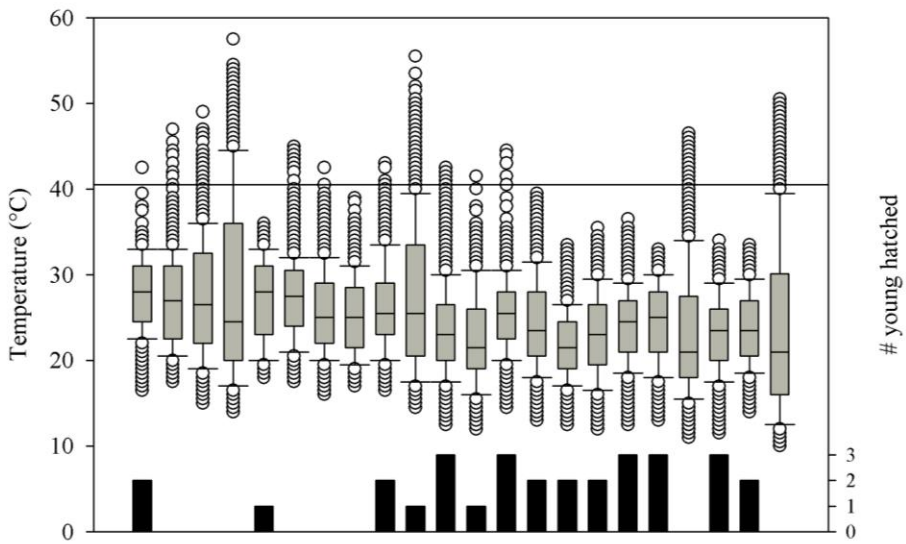

Figure 1.5. Median nest temperature recorded via thermochronic sensors in common tern nests. Temperatures were recorded every 15 minutes throughout the course of the incubation period. The line at 40.5 ºC represents the temperature at which embryotic egg development has been shown to be influenced. The solid bars at the bottom of the graph are the number of tern chicks that successfully hatched from each nest (all nests had three-egg clutches).

APPENDIX A: STATUS REVIEW & RECOVERY OUTLINE FOR COMMON TERNS IN ILLINOIS

CURRENT STATUS

The Great Lakes ecosystem provides much of the key nesting and foraging habitat for common terns (*Sterna hirundo*) in the Midwestern United States. Although common terns occur throughout the region, natural nesting habitat is limited; artificial sites such as navigational aids, artificial islands, and pier remnants provide much of their current habitat (U.S. Fish and Wildlife Service, 2005). Although common terns have consistently nested in Illinois along Lake Michigan (Table 2.1), currently there is one active colony of breeding common terns in Illinois. The colony is on an island located inside the Naval Station Great Lakes (NSGL) harbor, in Waukegan, Illinois. The nesting area is enclosed by a woven wire fence with three strands of electric fence, and has been intensely managed by the Illinois Department of Natural Resources since 2001. The numbers of breeding terns and the rate of reproductive success have been sporadic over the years (Jablonski et al., 2008). The common tern is listed as state-endangered in Illinois and a species of special concern by the U.S. Fish and Wildlife Service (USFWS, 2002) throughout its range.

HISTORICAL STATUS

The common tern was so-named because it was once the most abundant tern in much of the coastal regions of the United States. Major population declines started occurring in the late 1800’s as they were hunted to near extinction for their fashionable feathers. By the early 1900’s populations rebounded in most regions of the country following conservation actions and public awareness. However, recreational use of their preferred nesting habitat continues to displace many nesting colonies. In addition, as the human population continued to increase, larger predatory gulls learned to co-exist with humans and their refuse and mammalian predator population associated with human habitation also increased. Together these factors led to steady population decline in the latter half of the century. Population decline continues today (National Audubon Society, 2009).

REASONS FOR DECLINE

Common terns are affected by a diversity of threats. The primary factors limiting reproductive success of this species in the Great Lakes region have been susceptibility of nests to mammalian predators, habitat loss, human disturbance, and interference by humans. The development and recreational use of shorelines, the competition for limited nesting space with ring-billed gulls (*Larus delawarensis*), and the increase in invasive exotics (e.g., purple loosestrife *Lythrum salicaria* and common reed *Phragmites australis*) has severely limited available tern breeding habitat. The remaining available habitat often is in close proximity to human activity. Such encroachment increases the chances of disturbance by humans, as well as supports an increase in predator populations closely associated with human habitation, such as gulls (*Larus* sp.), coyotes (*Canis latrans*), raccoons (*Procyon lotor*), and rats (*Rattus norveginicus*).

Contaminants have recently played a role in the reduced number of common terns fledging at the sole remaining nesting colony in Illinois. High levels of poly-chlorinated-biphenyls (PCBs) and selenium have been detected in failed eggs and morbid young (Jablonski, et al., 2008). PCBs and selenium have been shown to cause immunosuppression, endocrine disruption (Grasman et al., 1996), hatching failure (Becker et al., 1992), and deformities in terns (Bosveld et al., 1995; Custer et al., 1983). The most likely point source for the contamination is north of the NSGL population at the Waukegan Harbor, the former site of Outboard Marine

Corporation (OMC). Prior to 1980, hydraulic fluids containing PCBs were discharged through floor drains at OMC and released into Waukegan Harbor. The United States Environmental Protection Agency estimated that 300.00 pounds of PCBs were in the sediment in the Waukegan Harbor before remediation began in 1990 (USEPA, 2009). Additionally, atmospheric deposition and resuspension of PCB laden sediments continues to be a non-point source of contamination (Baker, 1991; Turyk et al., 2006).

RECOVERY ACTIONS

Although the addition of a woven wire fence with strand electric has helped secure active nests from mammalian predation, the colony continues to be threatened by avian predators (great-horned owl, *Bubo virginianus* and black-crowned night-heron, *Nycticorax* nycticorax) and exotic species invasion and requires intensive annual management. A long-term conservation plan will be necessary to maintain the common tern as a viable breeding species in Illinois. For example, fencing must be checked regularly during the nesting season for electrical malfunction and disrepair, and changes in sand distribution within the harbor, due to seasonal water level changes, have resulted in extensive erosion of the island: the perimeter fence is threatened by eroding beach and current undercut. In addition, the fence has not been successful in excluding all mammalian predators, such as mink (*Neovision vison*). Long term, this intensive management effort is not a practical solution to maintaining the breeding status of common terns at NSGL.

The ultimate solution to establishing a secure, long-term, a viable breeding population is to create multiple colony sites along the Lake Michigan coastline. Artificial nest sites such as dredged material islands have been very successful alternatives to shoreline colony sites (Parnell et al., 1991; Shugart and Scharf, 1983). Through the construction of artificial islands consisting of a 5-6 foot steel seawall perimeter filled with dredge spoil, nesting colonies would be protected from periodic flooding, human disturbance, and make the sites nearly impenetrable to mammalian predators. Potential colony relocations should be relocated north of Waukegan Harbor, where sediment samples have yielded undetected levels of PCBs or selenium (Jablonski et al., 2008).

Establishing multiple populations is a critical consideration in the management of endangered species. A single catastrophic event would imperil the survival of a single population. Aerial reconnaissance along the Lake Michigan shoreline to find suitable areas that are away from human activity is the best approach to scouting for a new site. A number of criteria need to be considered when choosing a site:

1. Any site chosen will need regular management. If possible, state or federals facilities should be given higher priority, as they would be more likely to cooperate long term.
2. Contamination threats need to be addressed. Toxicological samples will need to be performed on lake sediment, small fish in the immediate area, and on zebra mussel colonies on underwater structures prior to selecting a suitable site.
3. Habitat recreation or modifications will need to done on most potential breeding sites. The site needs open sand for establishing nesting and sporadic vegetation to provide suitable habitat for the young.
4. Protection from mammalian predators needs to be addressed, either by establishing a site on a moderately remote island or by installing a fence with strand electric.
5. Potential sites need to be screened for existing peregrine falcon (*Falco peregrinus*) breeding sites and great horned owl habitat. Peregrines have been known to prey on adult terns and great horned owls depredate young common terns.

Once a site is chosen, conspecific attraction using decoys and common tern calls should be utilized to attract migrating terns to the site in early spring (Jablonski et al., 2005). The sites will need to be continually managed for vegetation succession, encroachment by breeding gulls, and avian predators.

New colony establishment at multiple sites should not be attempted until current sites are stable (four years of successful reproduction) with at least 150 nesting pairs of common terns. It has been found that in a similar species, least terns (*Sterna antillarum*) colonies with less than that are very effective at defending their nests from predators (Brunton, 1999). Current research on environmental contamination to common terns needs to continue. Reproductive success needs to be recorded yearly. Studies have shown that a stable colony is maintained when at least one young per breeding pair reach independence (Nisbet, 1973; DiCostanzo, 1980). The state-endangered status should be moved to threatened status for common terns when there are no less than three separate breeding colonies along Illinois' Lake Michigan shore with at least 150 terns in each and 50 percent reach independence for five consecutive years. The state-threatened status should subsequently remain in place until there are a total of five separate breeding colonies along Illinois' Lake Michigan shore with at least 150 terns in each and 50 percent reach independence for another five consecutive years.

LITERATURE CITED

Baker JE, Eisenreich SJ, and Eadie BJ. 1991. Sediment trap fluxes and benthic recycling of organic-carbon, polycyclic aromatic-hydrocarbons, and polychloro-biphenyl congeners in Lake Superior. Environmental Science & Technology. **25**: 500-509.

Becker PH, Schuhmann S, and Koepff C**.** 1992. Hatching failure in common terns (*Sterna hirunda*) in relation to environmental chemicals. Environmental Pollution **79:** 207-213.

Bosveld ATC, Gradener J, Murk AJ, Brouwer A, Van Kampen M, Evers EHG, and Vanden Berg

M. 1995. Effects of PCDDs, PCDFs, and PCBs in common tern breeding in estuarine and coastal colonies in the Netherlands and Belgium. Environmental Toxicology and Chemistry, **14**: 99-115.

Brunton, D. 1999. “Optimal” colony size for least terns: an inter-colony study of opposing selective pressures by predators. The Condor. **101**: 607-615.

Custer TW, Erwin RM, and Stafford C. 1983. Organochlorine residues in common tern eggs from nine Atlantic Coast Colonies, 1980. Colonial Waterbirds **6:** 197-204.

DiCostanzo, J. 1980. Population dynamics of a common tern colony. Journal of Field Ornithology. **51**: 229-243.

Grasman KA, Fox GA, Scanlon PF, and Ludwig JP. 1996. Organochlorine-associated immunosuppression in prefledgling Caspian Terns and Herring Gulls from the Great Lake: an ecoepidemiological study. Environmental Health Perspectives. **104**: 829-842.

Jablonski C, Semel B and Ward MP. 2005. The reintroduction and conservation of breeding Forster’s (*Sterna forsteri)* and common terns (*Sterna hirundo)* in Illinois. Illinois Department of Natural Resources. 21pp.

Jablonski C, Semel B, and Ward MP. 2008. Reintroduction and conservation of terns in Illinois: 2006-08 Summary report. Illinois Department of Natural Resources. 31 pp.

National Audubon Society. 2009. Common birds in decline. State of the Birds. http://stateofthebirds.audubon.org

Nisbet, ICT. 1973. Terns in Massachusetts: present numbers and historical changes. Bird-banding **44**: 27-55.

Parnell JF, Ainley DG, Blokpoel H, Cain B, Custer TW, Dusi JL, Kress S, Kushan JA, Southern WE, Stenzel LE, and Thompson BC. 1988. Colonial waterbird management in North America.

Colonial Waterbirds **11**: 129-169.

Shugart GW and Scharf WC. 1983. Common terns in the northern Great Lakes: current status and population trends. Journal of Field Ornithology. **54**: 160-169.

Turyk M, Anereson HA, Hanrahan LP, Falk C, Steenport CF, Needham LL, Paterson DG, Freels S, Persky V, and the Great Lakes Consortium. 2006. Relationship of serum levels of individual PCBs, dioxin, and furan congeners and DDE with Great Lakes sport-caught fish consumption. Environmental Research. **100**: 173-183.

U.S. Environmental Protection Agency. 2009. Outboard Marine Corporation. EPA ID# ILD0008287. Region 5 Superfund.

U.S. Fish and Wildlife Service (USFWS). 2005.Upper Mississippi Valley/Great Lakes Waterbird Conservation Plan. Draft 3.

U. S. Fish and Wildlife Service. 2002. Birds of conservation concern 2002. Division of Migratory Bird Management, Arlington, Virginia. 99 pp. Region 3. Table 43 and 48.

Table A.1. Common tern (*Sterna hirundo*) nesting summaries for Illinois. The location of each known nesting colony and the associated number of nesting birds, number of nest attempts, and the number of young fledged.

Year	Site	Maximum Tern Number	Maximum Nesting Attempts	Maximum Eggs Laid	Total Young Fledged
1948	Midwest Generation		4		0
	Johns-Mansville	30		36	33
1975	Unknown				
1976	Johns-Mansville		2		0
	Midwest Generation		8		0
1977	Waukegan Harbor	16	9		0
	Waukegan Island		12		9
1978	Waukegan Harbor		16		0
1979	Midwest Generation	43	15		35
1980	Midwest Generation	60	29	52	0
1981	Midwest Generation	70	33	98	0
1982	Midwest Generation	50	25	70	16
1983	Midwest Generation	64	32	87	21
1984	Midwest Generation	22	17	41	0
1997	Midwest Generation	26	10		0
	Johns-Mansville	6	3	9	0
1998	Midwest Generation	17	9		7
1999	Midwest Generation	35	8		0
2000	Midwest Generation	17	1	1	0
	Naval Station	42	12	27	0
2001	Naval Station	49	54	109	0
2002	Naval Station	49	18	44	26
2003	Naval Station	49	46	129	43
2004	Naval Station	66	26	67	32
2005	Naval Station	96	23	67	6
2006	Naval Station	63	38	99	2
2007	Naval Station	120	49	136	5

APPENDIX B: RECENT BREEDING DATA FOR COMMON TERNS AT NAVAL STATION GREAT LAKES

Table B.1.Recent number of nesting attempts, eggs laid and nesting success documented for common terns using the harbor island of Naval Station Great Lakes (NSGL).

Year	Maximum Tern Number at Site	Maximum Nesting Attempts	Maximum Eggs Laid	Total Young Fledged
2001	49	54	109	0
2002	49	18	44	26
2003	49	46	129	43
2004	66	26	67	32
2005	96	23	67	6
2006	63	38	99	2
2007	120	49	136	5

APPENDIX C: CONTAMINANT TEST RESULTS

Table C.1.Test results for morbid young and one morbid adult collected from Naval Station Great Lakes (NSGL) common tern colony in 2005, 2006 and 2007. The large young were all approximately the same size. They were nearly fledged and apparently died from hypothermia following an intensive rain storm that took place on 25 June 2006. The small young all died shortly after hatching, most within 24 hours of pipping. The adult was found dead within the colony, with no apparent sign of trauma. A t-test showed the older young had significantly higher concentrations of PCBs ($p<0.05$). All concentrations are wet weights. ND indicates not determined.

source	date collected	Aroclor 1254(μg/kg)	total PCBs (μg/kg)	Se (mg/kg)
large young	26-Jun-06	8,647.00	8,685.14	1.7
large young	26-Jun-06	4,967.00	4,975.21	2.8
large young	26-Jun-06	1,822.00	1,830.41	3.3
large young	26-Jun-06	10,736.00	10,770.23	2.7
large young	26-Jun-06	141.00	142.58	3.2
large young	26-Jun-06	1.38	1.39	2.5
large young	26-Jun-06	3,701.00	3,712.62	2.3
large young	26-Jun-06	4,554.00	4,574.32	3.1
small young	6-Jul-05	ND	149.00	ND
small young	6-Jul-05	ND	1391.0	ND
small young	6-Jun-07	7,485.00	7,528.11	1.0
small young	11-Jun-07	238.00	240.20	0.8
small young	25-Jun-07	16.07	26.50	1.3
small young	13-Jul-07	5,092.00	5,173.67	1.9
small young	14-Jul-07	2,393.00	2,417.92	1.6
small young	25-Jun-07	2,645.00	2,670.21	1.3
1 adult	13-Jul-07	2,497.00	2,530.47	2.4

Table C.2.Toxicological test results for zebra mussels and amphipods collected from within NSGL harbor. U indicates undetected. All concentrations are wet weights. The zebra mussels that were sampled came from the experimental cages and only the soft tissue was tested. The amphipods were opportunistically scrapped off of experimental structures and were not confined within the structures in any way, thus were free to come and go.

source	**date collected**	**Aroclor 1254(µg/kg)**	**total PCBs (µg/kg)**	**Se (mg/kg)**
zebra mussels	5-Oct-07	118.00	126.478	0.80
zebra mussels	5-Oct-07	66.80	72.937	U
zebra mussels	5-Oct-07	159.00	169.116	U
zebra mussels	5-Oct-07	605.00	621.17	1.00
zebra mussels	5-Oct-07	391.00	404.893	0.90
zebra mussels	5-Oct-07	170.00	180.369	1.00
zebra mussels	5-Oct-07	115.00	119.607	U
zebra mussels	5-Oct-07	108.00	114.071	U
zebra mussels	5-Oct-07	214.00	217.727	U
Amphipods	5-Oct-07	444.00	455.03	U
Amphipods	5-Oct-07	1.31	1.321	U
Amphipods	5-Oct-07	551.00	563.715	U
Amphipods	5-Oct-07	108.00	110.887	U

Table C.3.Toxicological test results for failed eggs collected from NSGL common tern colony. Statistical analysis (t-test) showed no significant difference between the first and second egg ($p > 0.46$). An egg composite refers to a small number of eggs (two or three) combined. All concentrations are wet weights.

source	Nest #	date collected	Aroclor 1254(µg/kg)	total PCBs (µg/kg)	Se (mg/kg)
*first egg	6	15-May-07	7,456.00	7,634.52	1.3
after 1st egg	6	11-Jun-07	13,599.00	13,812.91	1.0
*first egg	8	17-May-07	14,998.00	15,279.29	0.7
after 1st egg	8	11-Jun-07	107.00	108.08	0.9
*first egg	26	11-Jun-07	15,871.00	16,068.14	U
after 1st egg	26	25-Jul-07	22,344.00	22,741.21	U
*first egg	9	16-May-07	8,456.00	8,642.03	0.9
*first egg	14	18-May-07	7,459.00	7,590.86	U
*first egg	7	18-May-07	37,235.00	37,479.63	U
*first egg	12	18-May-07	16,921.00	17,002.87	U
*first egg	19	25-May-07	8,541.00	8,649.61	1.3
*first egg	24	7-Jun-07	11,695.00	11,870.64	U
*first egg	25	8-Jun-07	12,962.00	13,144.74	1.8
egg composite$_a$	41	25-Jul-07	16,235.00	16,339.93	U
egg	44	25-Jul-07	10,789.00	10,899.71	1.3
egg composite	26	25-Jul-07	24,213.00	24,586.23	U
egg composite	38	25-Jul-07	16,847.00	17,010.69	U
egg composite	42	26-Jul-07	658.00	665.96	0.8

*a permit was granted to retrieve the first laid egg in a designated number of nests to note the difference in levels of contaminants between the first egg and any subsequently laid eggs that may fail.

Table C.4. PCB concentrations in fecal collection jars and controls. ANOVA analysis showed a significant difference in the treatment and control jars ($p < 0.06$). The detritus collected from the water column had higher concentrations of contaminants than the fecal matter collected from the zebra mussels. All concentrations are wet weights.

Collection Jar	date collected	Aroclor 1254(µg/kg)	total PCBs (µg/kg)	Se (mg/kg)	Volume (cm^3)
#2 control	20-Oct-06	64.40	68.323	U	222.7
#5 control	20-Oct-06	40.60	43.134	U	719.2
#1control	11-May-07	42.50	44.123	U	89.1
#5 control	11-May-07	43.20	45.253	U	82.7
#1 mussels	20-Oct-06	19.30	20.092	U	636.4
#6 mussels	20-Oct-06	42.70	45.322	U	946.4
#4 mussels	11-May-07	8.70	9.083	U	394.6
#6 mussels	11-May-07	32.50	34.085	U	496.4

Table C.5. The samples of morbid young and failed eggs that were tested in 2006 for select heavy metals. U indicates undetected. All concentrations are wet weights.

Source	**date collected**	**^{78}Se (mg/kg)**	**^{111}Cd (mg'kg)**	**^{202}Hg (mg/kg)**	**^{208}Pb (mg/kg)**
small young	6-Jul-05	2.90	0.03	0.15	0.31
egg	15-Jul-05	1.50	U	0.12	0.04
egg	13-Jul-05	0.62	0.012	0.26	U

Table C.6. PCB and selenium concentrations in the various sediment samples taken within the harbor at NSGL. U indicates undetected. ND indicates not determined. All concentrations are wet weights.

source	date collected	comments	Aroclor 1254(µg/kg)	total PCBs (µg/kg)	Se (mg/kg)
sediment under cage #1	20-Apr-07	before putting out cage (control)	22.70	23.84	U
sediment under cage #2	20-Apr-07	before putting out cage (control)	85.40	87.89	U
sediment under cage #3	20-Apr-07	before putting out cage (control)	102.00	110.73	U
sediment under cage #4	20-Apr-07	before putting out cage (control)	66.60	71.14	U
sediment under cage #5	20-Apr-07	before putting out cage (control)	20.30	21.06	1.60
sediment under cage #6	20-Apr-07	before putting out cage (control)	21.50	23.15	U
sediment inside cage #1	5-Oct-07	sub-sample for #1 (treatment)	104.00	109.55	U
sediment under cage #1	5-Oct-07	sub-sample for #1 (treatment)	44.60	47.58	U
sediment under cage #1	5-Oct-07	sub-sample for #1 (treatment)	380.00	394.79	ND
sediment inside cage #2	5-Oct-07	sub-sample for #2	33.60	35.86	4.00
sediment under cage #2	5-Oct-07	sub-sample for #2	175.00	185.85	U
sediment under cage #2	5-Oct-07	sub-sample for #2	79.20	84.95	ND
sediment inside cage #3	5-Oct-07	sub-sample for #3 (treatment)	17.30	17.94	U
sediment under cage #3	5-Oct-07	sub-sample for #3 (treatment)	25.40	35.51	U
sediment under cage #3	5-Oct-07	sub-sample for #3 (treatment)	24.70	33.11	ND
sediment inside cage #4	5-Oct-07	sub-sample for #4	35.70	37.44	U
sediment under cage #4	5-Oct-07	sub-sample for #4	70.60	74.76	U
sediment under cage #4	5-Oct-07	sub-sample for #4	51.50	53.49	ND

Table C.6. Continued.

source	date collected	comments	Aroclor 1254(µg/kg)	total PCBs (µg/kg)	Se (mg/kg)
sediment inside cage #5	5-Oct-07	sub-sample for #5(treatment)	9.900	12.49	U
sediment under cage #5	5-Oct-07	sub-sample for #5(treatment)	82.00	87.50	U
sediment under cage #5	5-Oct-07	sub-sample for #5(treatment)	86.30	92.37	ND
sediment inside cage #6	5-Oct-07	sub-sample for #6	24.40	25.24	U
sediment under cage #6	5-Oct-07	sub-sample for #6	22.70	24.54	U
sediment under cage #6	5-Oct-07	sub-sample for #6	47.70	56.97	ND
control sediment	5-Oct-07	elswhere in the harbor	204.00	224.41	U
control sediment	5-Oct-07	elswhere in the harbor	163.00	178.01	U
control sediment	5-Oct-07	elswhere in the harbor	68.30	69.10	ND

Table C.7. PCB and selenium concentrations in the various fish samples taken within the harbor at NSGL. U indicates undetected. ND indicates not determined. All concentrations are wet weights.

source	**date collected**	**comments**	**Aroclor 1254(µg/kg)**	**total PCBs (µg/kg)**	**Se (mg/kg)**
alewife stock for cages	20-Apr-07	cage stock	234.00	236.49	U
alewife stock for cages	20-Apr-07	cage stock	1,449.00	1,451.37	U
alewife stock for cages	20-Apr-07	cage stock	1,177.00	1,179.45	ND
spottail shiner stock for cages	15-Jun-07	cage stock	71.40	88.16	0.50
spottail shiner stock for cages	15-Jun-07	cage stock	29.50	60.65	U
spottail shiner stock for cages	15-Jun-07	cage stock	144.00	159.59	ND
gobies cage #1	5-Oct-07	sub-sample for #1(treatment)	212.00	223.30	U
shiners in cage #1 (only 9.43 oz)	5-Oct-07	sub-sample for #1(treatment)	274.00	293.86	U
gobies cage #2	5-Oct-07	sub-sample for #2	108.00	121.67	0.70
shiners in cage #2 (only 11.57 oz)	5-Oct-07	sub-sample for #2	578.00	595.98	U
shiners in cage #3 (only9.54 oz)	5-Oct-07	sub-sample for #3(treatment)	548.00	548.75	0.90
gobies cage #3	5-Oct-07	sub-sample for #3(treatment)	624.00	624.36	ND
gobies cage #4	5-Oct-07	sub-sample for #4	6.24	7.67	ND
Shiners in cage #4 (9.54 0z)	5-Oct-07	sub-sample for #4	79.90	104.36	U
shiners in cage #4 (8.80 0z)	5-Oct-07	sub-sample for #4	1.85	2.21	U
shiners in cage #5 (9.54 oz)	5-Oct-07	sub-sample for #5(treatment)	55.90	59.93	1.20
shiners in cage #5 (9.38 oz)	5-Oct-07	sub-sample for #5(treatment)	91.90	92.98	U
gobies cage #5	5-Oct-07	sub-sample for #5(treatment)	364.00	400.33	ND

Table C.7. Continued.

gobies cage #6	5-Oct-07	sub-sample for #6	5.89	7.99	ND
alewives from colony	18-May-06	composite fish sample from colony	ND	1.52	U
misc. fish from colony	21-Jun-06	composite fish sample from colony	ND	6.85	0.80
misc. fish from colony	21-Jun-06	composite fish sample from colony	ND	102.58	U

SUMMARY

Common terns are state-endangered in Illinois (Illinois Endangered Species Protection Board, 2004) and although the Illinois Department of Natural Resources was invested a great deal of resources into the colony, the species is still highly threatened in the state. The overall reproductive success (the number of young successfully reaching independence) of the Illinois breeding population has been severely impaired. I have established that the levels of PCBs in the young and eggs of the terns was very high, and the biological pathway of PCBs to terns is via a forage fish (Alewife). The PCB exposure may be affecting the species in many ways, but in one of the experiment I conducted the species appears to have very poor partental attentivenss that is likely associated with PCB exposure. I suggest that the most effective path to improving common tern populations in Illinois is to move the last colony to a new location and create two to four additional colonies. This will require collecting data on the prevalence of PCBs are other locations as well as ensuring the new sites are protected from both nest predators and human recreation. Without additional research and intensive management it is likely common terns will soon be extirpated from the state.