5-2012

USING BALD EAGLES TO MONITOR HYDROELECTRIC PROJECTS LISCENSE REQUIREMENTS ALONG THE AU SABLE, MANISTEE AND MUSKEGON RIVER, MICHIGAN

Peter Datema
Clemson University, datemape@gmail.com

USING BALD EAGLES TO MONITOR HYDROELECTRIC PROJECTS LISCENSE REQUIREMENTS ALONG THE AU SABLE, MANISTEE AND MUSKEGON RIVER, MICHIGAN

A Thesis
Presented to
the Graduate School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science
Wildlife and Fisheries

---

by
Peter Philip Datema
May 2012

Accepted by:
Dr. William Bowerman, Committee Chair
Dr. Patrick Jodice, Committee Chair
Dr. William Bridges
Teryl Grubb

ABSTRACT

Consumers Energy operated hydroelectric projects located along the Au Sable, Manistee, and Muskegon Rivers underwent environmental studies in the late 1980s and early 1990s as part of the Federal Energy Regulatory Commission relicensing. One of the questions posed during these studies was, would passage of Great Lakes' fishes over barrier dams along these rivers cause detrimental impacts to sensitive wildlife species. Relicensing also required that the operation of all hydroelectric projects on the Au Sable, Manistee, and Muskegon rivers be maintained as run-of-river. Bald eagles (*Haliaeetus leucocephalus*) were chosen as a biomonitor. This risk assessment included calculating new hazard quotients (HQs) from toxic reference values (TRVs) to determine if it was safe for inland wildlife to be exposed to anadromous fish allowed past barrier dams. A risk assessment was conducted for contaminants of PCBs, DDT, dieldrin, TCDD-EQ and mercury in a fish diet comparing exposure in Great Lakes' accessible regions to interior regions of the Au Sable, Manistee and Muskegon rivers, using fish collected after 1990. The bald eagle population nesting in the study area increased throughout the study period. Mean mercury was greater in fishes in inland than Great Lakes influenced. Mean total PCBs, sum DDT and dieldrin were greater in Great Lakes influenced areas. Total PCBs and sum DDT were greater in Great Lakes influenced nesting areas than inland nesting areas. TCDD-EQ was the limiting factor for bald eagle reproduction on Great Lakes influenced areas with the greatest HQ, which was greater than the adverse population level. My data suggests that if protection of wildlife from environmental contaminants is the management goal, then fish passage should not be allowed past Foote, Tippy and Croton dams.

Concentrations of environmental contaminants in nestling bald eagle blood plasma confirm these results. Productivity and success increased on the Manistee and Muskegon Rivers after run-of-river implementation, but there was inconclusive supporting evidence that run-of-river was the factor for the increase.

AKNOWLEDGEMENTS

I would like to thank my committee Dr. William Bowerman, Dr. Patrick Jodice, Dr. William Bridges and Teryl Grubb. Also thank you to Latice Fuentes and Kendall Simon for their constant help with my steady flow of questions and my family and friends for their support throughout. Without the BAEA field crew my research would not be possible. Other key sources of help came from Gary Dawson for information relating to Consumers Energy and Lisa Williams for help from the United States Fish and Wildlife Service. I have the utmost appreciation for Dr. Bowerman for giving me a chance at graduate school and believing in me until the very end. My thesis would have never been completed in time if Teryl Grubb did not give me his confidence and time and I cannot thank him enough.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

GENERAL INTRODUCTION

Introduction

The Federal Power Act (1920) requires the study of environmental impacts prior to the relicensing of hydroelectric projects. Consumers Energy (Jackson, Michigan) operated hydroelectric projects located along the Au Sable, Manistee, and Muskegon Rivers underwent environmental studies in the late 1980s and early 1990s. One of the questions posed during these studies was, would passage of Great Lakes' fishes over barrier dams along these rivers cause detrimental impacts to sensitive wildlife species. Bald eagles (*Haliaeetus leucocephalus*) and mink (*Neovison vison*) were two of the sensitive wildlife species of concern. The result of these studies was that new licenses included the restriction of passage of Great Lakes fishes past the barrier dams on the three rivers until there were no negative affects to these species (Giesy et al. 1995). To determine when fish could be passed over the hydroelectric projects, the licenses required that a monitoring program be developed to periodically sample fishes from above and below the barrier dams to measure concentrations of environmental contaminants in these fish.

Great Lakes' anadromous fishes transport environmental contaminants from the more polluted Great Lakes to inland areas where background contamination in local fishes is much lower. These fishes, if eaten by eagles, pose a potential hazard from the effects of the environmental contaminants (Bowerman 1991; Kozie and Anderson 1991; Bowerman 1993; Giesy et al. 1994; Bowerman et al. 1998). Currently fish passage past barrier dams on the Au Sable, Manistee and Muskegon rivers is closed from the Great Lakes, protecting inland wildlife from fishes with greater concentrations of environmental contaminants.

The International Joint Commission proposed that the bald eagle be used as the piscivorous wildlife biomonitor for bioaccumulating organochlorine chemicals in the Great Lakes (IJC 1991). The bald eagle makes a good biomonitor species because it has a well-studied life history with a known population, and has been monitored in the state of Michigan since 1961. Any population effects due to organic or inorganic chemicals can be measured at the population level (Bowerman et al*.* 2002). Bald eagles are the tertiary piscivore on the Au Sable, Manistee, and Muskegon rivers with a diet comprised of 90% local fish (Bowerman 1993). Eagles are central place foragers meaning that nestling eagles only acquire environmental contaminants from the foraging range of their parents allowing for measure of local contaminants. Bioaccumulation from polychlorinated biphenyl (PCB) and its congeners, dieldrin, mercury and dichlorodiphenyltrichloroethane (DDT) and its degradation products can be measured in blood samples collected from nestling eagles (Geisy et al*.* 1995).

Relicensing also required that the operation of all hydroelectric projects on the Au Sable, Manistee, and Muskegon rivers be maintained as run-of-river. Run-of-river is when dam in flow is equal to out flow. Peaking flow regimes increase flow during times of high electricity consumption, normally in the morning and evening (Cushman 1985). Peaking flows simulate flood and drought periods on a daily basis, causing stress and decreased productivity, diversity, and abundance of aquatic species below hydroelectric operations (Cushman 1985).

The last review of the risk to bald eagles from exposure to environmental contaminants in Great Lakes fishes occurred using fish collected in 1990. With the increase in productivity of bald eagles nesting along the Great Lakes' shorelines, a re-evaluation of the risk of passed Great Lakes' fishes will help to determine if the restrictions on fish passage should continue. To determine if environmental contaminants from anadromous fish runs would have negative effects on bald eagle reproduction, a new environmental risk assessment is conducted. This risk assessment included calculating new hazard quotients (HQs) from toxic reference values (TRVs) to determine if it was safe for inland wildlife to be exposed to anadromous fish allowed past barrier dams. A risk assessment was conducted for contaminants of PCBs, DDT, dieldrin, 2,3,7,8-Tetrachlorodibenzo-p-dioxin equivalents (TCDD-EQ) and mercury in a fish diet comparing exposure in Great Lakes' accessible regions to interior regions of the Au Sable, Manistee and Muskegon rivers, using fish collected after 1990.

Study Area

My study area was in the northern part of Michigan's Lower Peninsula encompassing three watersheds, the Au Sable (AS), Manistee (MA) and Muskegon (MU) rivers (referred to collectively as Three Rivers) and two Great Lakes (GL), Lake Huron (LH) and Lake Michigan (LM) (Figure 1). The Three Rivers are home to large anadromous fish runs from the GL that seasonally bring a large quantity of food into the rivers with higher environmental contaminants than resident fishes. A total of 43 breeding areas were selected to be compared on the Three Rivers and surrounding GL.

The AS flows through the northeast part of the Lower Peninsula of Michigan. The river drains 5003 sq km with a main stream of 246 km that empties into LH at the city of Oscoda. The AS watershed is 80% forested but has changed from a coniferous old growth forest to now a mostly deciduous forest. The mainstream drops 200 m in elevation from start to finish with most of the high gradient rapids now impounded (Zorn and Sendek 2001). The river has been named a Blue Ribbon trout stream by the Michigan Department of Natural Resources (MDNR) and was also a National Wild and Scenic River. Trout Unlimited started its organization on the banks of the AS as well. The fishery has been considered the best brown trout (*Salmo trutta*) fishery east of the Rocky Mountains. The AS has 109 dams in its watershed with 7 dams on the mainstream, 6 of which are hydroelectric projects (Zorn and Sendek 2001).

The 6 hydroelectric projects on the river impound 38% of the linear surface of mainstream. Foote Dam was the barrier dam that blocks fish passage from LH and was located 16 km upstream. The other 5 hydroelectric projects are Mio, Alcona, Loud, Five Channels and Cooke in order from upstream to downstream. The first of these dams was Cooke, built in 1911 which was the first one to block fish passage (Zorn and Sendek 2001).

The AS was home to 10 bald eagle breeding areas. Hydroelectric impoundments have 7 of the 10 breeding areas located among them. OS-02 and OS-08 were on Mio Pond, AL-02 was on Alcona Dam Pond, IO-01 and IO-08 were on Loud Dam Pond, IO-05 was on Five Channels Dam Pond. IO-02 and IO-14 were on Cooke Dam Pond. AL-09 was above the Federal Route 4001 Bridge approximately 4 km. OS-

03 was on the river approximately 5 km above the County Highway 602 Bridge. No breeding areas were affected by anadromous fish runs.

The MA is located in the northwest portion of Michigan's Lower Peninsula and drains into LM. The river drains 4,610 sq km with a main stream length of 373 km. There are 63 dams in the watershed with only two on the mainstream (Rozich 1998). The MA drops 204 m in elevation before emptying into LM. The land cover of the watershed is 54% forested, 39% agriculture although very little is cultivated crops with mostly pasture and fruit. Only 3.3% of the watershed is urban or suburban (Rozich 1998). The MA has a large anadromous fish run of steelhead (*Oncorhynchus mykiss*), Chinook salmon (*O. tshawytscha*) and Coho salmon (*O. kisutch*) that travel to Tippy Dam. Above Tippy Dam the hydroelectric project ponds have some fishing opportunities but the most famous fishing on the MA is the upper MA. The upper MA was designated by the MDNR as both a Natural River and as a Blue Ribbon Trout Stream (Rozich 1998).

Tippy Dam was built in 1918 and was the barrier dam. The Manistee runs 40 km below Tippy Dam before it reaches Manistee Lake and eventually in empties into LM. Hodenpyl Dam was the other hydroelectric project on the mainstream (Rozich 1998). The 2 hydroelectric projects impound 20% of the linear surface of the mainstream. Tippy Dam currently was protected under the Endangered Species Act because the Indiana bat (*Myotis sodali*) hibernates within the dam of the hydroelectric project (Kurta and Teramino 1994).

The MA had 9 bald eagle breeding areas during the study period. Three were on hydroelectric ponds. MN-06, MN-07 and MN-12 were on Tippy Dam Pond with breeding areas far enough way that their foraging areas were not affected by anadromous fish runs and WX-01 was on Hodenpyl Dam Pond. MN-04 was located on the MA below Tippy Dam but Tippy Dam Pond was within its foraging range. MN-05, MN-11, MN-03 and MN-02 were on the MA below Tippy Dam in order from LM to Tippy Dam and were affected by anadromous fish runs.

The MU, located south of the MA in the northwest part of the Lower Peninsula. The MU watershed drains 6086 sq km of land into LM. The MU is 341km long and flows from Higgins and Houghton Lake into Lake Muskegon and to LM. Below Croton Dam the river runs 75 km before reaching LM. Croton Dam was the barrier dam. Reedsburg Dam is closest to the head waters of the MU. It was built for a wildlife flooding. Rogers Dam was the next hydroelectric project on the MU followed by Hardy Dam. The dams on the mainstream impound 22% of the linear surface area of the river. The River drops 175 m in elevation before reaching LM (O'Neal 1997). The watershed was comprised of 49% forested and 33.4% agriculture. The watershed is 7.8% urban (Ray et al. 2010). The MU was the warmest of the Three Rivers with a predominantly warm water fishery compared to the cold water fisheries of the AS and MA rivers (O'Neal 1997).

The MU had 4 bald eagle breeding areas, 2 below Croton Dam and 2 above. The 2 breeding areas affected by anadromous fish runs were MU-02 and NE-01. MU-02 was located approximately 5 km upstream of US 31. NE-01 was located approximately 5km below Croton Dam. The breeding territories above Croton Dam were NE-03 located on the backwaters of Croton Dam and RO-03 was located on the Reedsburg Dam wildlife flooding area.

GL shoreline nests were compared to Three River nests. I included nests on LM and LH that were within 8 km of the lake shore (Best et al. 1994). On LM the southernmost breeding area was MU-03 between the confluences of the Grand River and MU. The northernmost breeding area was BZ-09 located in Sleeping Bear Dunes National Park. There were a total of 18 breeding areas on LM which encompassed the MA and MU deltas and surrounding shoreline.

On LH, breeding areas were sampled from AI-08 to the north, and south to IO-12 with a total of 9 nests on LH. Breeding areas were selected to avoid those associated with Saginaw Bay which had higher concentrations of environmental contaminants (Heaton et al., 1995; Giesy et al. 1996). The northern most breeding areas were chosen to not include breeding areas associated with the Thunder Bay River.

Evaluation of License Requirements

My study was a re-evaluation to determine if environmental contaminants in the GL had decreased since the original FERC re-licensing of hydroelectric projects on the AS, MA and MU in the late 1980s and early 1990s. A major population increase in bald eagles along the Three Rivers and GL brought into question the original study's conclusions that environmental contaminants from GL fishes were still causing adverse effects on nesting bald eagles foraging on GL fishes. Using the bald eagle as a biomonitor, a new study was conducted to determine if fish passage past the barrier dams on the Three Rivers would have adverse effects on Trustee resources. Hydroelectric projects had changed management of flow regime from peaking flow to run-of-river with the new license. Until now, no study had been conducted to determine if new water flow regimes had negatively affected bald eagles, so their productivity and success rates were used to evaluate whether run-of-river flows have led to increased or decreased bald eagle reproduction.

Objectives

This thesis is organized into a General Introduction, 2 intermediate chapters summarizing my research, and a General Conclusion. The 2 chapters focus on: 1) reevaluating potential risk to bald eagles from the passage of Great Lakes' fishes over hydroelectric projects on the Three Rivers; and 2) evaluating the effects of changing hydroelectric operations to run-of-river flow regimes on reproduction of bald eagles nesting along the Three Rivers. Specific objectives included:

1. Compare reproduction between inland and Great Lakes' nesting bald eagles.

2. Conduct a Hazard Assessment by calculating Hazard Quotients (HQs) to compare risks to .bald eagles for both areas accessible and not accessible to Great Lakes' fish runs for the Au Sable, Manistee and Muskegon rivers.

3. Determine if concentrations of environmental contaminants in Great Lakes' fishes are below thresholds for effects, in order to evaluate whether allowing fish passage over barrier dams on the Au Sable, Manistee and Muskegon rivers would negatively impact bald eagle reproduction.

4. Determine if the change from peaking to run-of-river flow regimes for hydroelectric projects along the Au Sable, Manistee, and Muskegon rivers influenced subsequent bald eagle productivity and success.

WORKS CITED

Bowerman W. W. 1991. Factors influencing breeding success of bald eagles in upper Michigan. M.A. Thesis, Northern Michigan Univ., Marquette. 113pp.

Bowerman, W. W. 1993. Regulation of bald eagle *(Haliaeetus leucocephalus)* productivity in the Great Lakes Basin: An ecological and toxicological approach. PhD dissertation, Michigan State University, East Lansing, MI.

Bowerman, W. W., D. A. Best, T. G. Grubb, G. M. Zimmerman and J. P. Giesy 1998. Trends of Contaminants and Effects in Bald Eagles of the Great Lakes Basin. Environmental Monitoring and Assessment 53(1): 197-212.

Bowerman, D. W., A. S. Roe, M. J. Gilbertons, D. A. Best, J. G. Sikarskie, R. S. Mitchell and C. L. Summer. 2002. Using bald eagles to indicate the health of the Great Lakes' environment. Lakes & Reservoirs: Research and Management 7: 183-187.

Cushman RM. 1985. Review of ecological effects of rapidly varying flows downstream from hydroelectric facilities. North American Journal of Fisheries Management 5: 330-339.

Giesy JP, Verbrugge DA, Othout R, Bowerman WW, Mora MA,Jones PD, Newsted JL, Vandervoort C, Heaton SN, Aulerich RJ, Bursian S J, Tillitt DS, Johnson J, Ludwig JP, Ludwig M, DawsonG, Kubiak TJ, Best DA, Welsh R. 1994. Contaminants in fishes from Great Lakes-influenced sections and above dams of three Michigan rivers: I. Concentrations of organochlorine insecticides,PCBs, dioxin equivalents, and mercury. Archives of Environmental Contamination and Toxicology. 27:202-212

Giesy, J. P., Bowerman, W. W., Mora, M. A., Verbrugge, D. A., Othoudt, R. A., Newsed, J. L., et al. 1995. Contaminants in fishes from Great Lakes-influenced sections and above dams of three Michigan rivers: III. Implications for health of bald eagles. Archives of Environmental Contamination and Toxicology, 29, 309–321.

Giesy J. P., Jude D. J., Tillitt, D. E., Gale R. W., Meadows J. C., Zajieck J. L., Peterman P. H., Verbrudge D. A., Sanderson J. T., Schwartz T. R. and Tuchman M. L. 1996 Polychlorinated dibenzo-p-dioxins, diberzofurans, biphenyls and 2,3,7,8-tetrachlorodibenzo-p-dioxin equivalents in fishes from Saginaw Bay, Michigan. Environmental Toxicology and Chemistry 16(4):713-724.

Heaton, S. N., Bursian, S. J., Giesy, J. P., Tillitt, D. E., Render, J. A., Jones, P. D., Verbrugge, D. A., Kubiak, T. J., and Aulerich, R. J. 1995. Dietary exposure of mink to carp from Saginaw Bay. 1. Effects on reproduction and survival, and the potential risks to wild mink populations. Archives of Environmental Contaminant Toxicology 28:334-343.

International Joint Commission. 1991. Proceedings of the Expert Consultation Meeting on Bald Eagles in the Great Lakes Basin (ed. M. Gilbertson). International Joint Commission, Windsor, Ontario, Canada.

Kozie, K. D. and R. K. Anderson .1991. Productivity, Diet, and Environmental Contaminants in Bald Eagles Nesting near the Wisconsin Shoreline of Lake-Superior. Archives of Environmental Contamination and Toxicology 20(1): 41-48.

Kurta, A., and Teramina, J. A. 1994. A novel hibernaculum and noteworthy records or the Indiana bat and Eastern pipistrelle (Chiroptera: Vespertilionidae). American Midland Naturalist 132(2):410-413.

O'Neal, R. P. 1997. Muskegon River Watershed Assessment. Michigan Department of Natural Resources, Fisheries Division. Special Report Number 19. Ann Arbor, Michigan.

Ray, D. K., Duckles, J. M. and Pijanowski, B. C. (2010) "The impact of future land use scenarios on runoff volumes in the Muskegon River watershed." Environmental Management 46:351-366.

Rozich, T. J. 1998. Manistee River Assessment. Michigan Department of Natural Resources, Fisheries Division, Special Report Number 21. Ann Arbor, Michigan.

Zorn, T. G., and Sendek, S. P. 2001. Au Sable River Assessment. Michigan Department of Natural Resources, Fisheries Division, Special Report 26, Ann Arbor, Michigan.

CHAPTER TWO

A RE-EVALUATION OF GREAT LAKES FISH PASSAGE AND EFFECTS ON BALD EAGLES NESTING ALONG THE AU SABLE, MANISTEE AND MUSKEGON RIVERS

INTRODUCTION

The bald eagle (*Haliaeetus leucocephalus*) population in Michigan has been increasing since the ban of dichlorodiphenyltrichloroethane (DDT) in the 1970s. This increase has not been constant throughout the state. Bald eagles that feed on the Great Lakes' food web have had lower productivity (young-per-occupied-nest) than bald eagles that feed in inland areas (Bowerman et al. 1995; Giesy et al. 1995) Organochlorine pesticides and polychlorinated biphenyls (PCBs) have been greater in the tissues and unhatched eggs collected from eagles nesting along the Great Lakes than those from more interior nests, and have corresponded to depressed reproduction in nests along the lakes (Bowerman et al. 1995; Best et al. 1994; Best et al. 2010). In recent years, however, productivity of bald eagles nesting along the Great Lakes has increased and are now comparable to those of inland bald eagles. This increase is most likely due to the re-occupancy of available breeding areas along the lakes by immigration of relatively uncontaminated adults from more interior regions.

The International Joint Commission proposed the bald eagle as the piscivorous wildlife biomonitor for bioaccumulating organochlorine chemicals in the Great Lakes (IJC 1991). The bald eagle is useful as a biomonitor species because it has a well-studied life history with a known population, and has been monitored in the state of Michigan since 1961. Any population effects due to organic or inorganic chemicals can be measured at the population level because of the known population (Bowerman et al. 2002). Bald eagles are a tertiary piscivore on the Au Sable, Manistee and Muskegon rivers with 90% of their diet comprised of fish (Bowerman 1993). Eagles are central place foragers during the breeding season, hence nestling eagles only acquire environmental contaminants from the foraging range of their parents and can, thus provide a measure of local contaminants. Bioaccumulation from polychlorinated biphenyl (PCB) and its congeners, dieldrin, mercury, and DDT and its degradation products can be measured in blood samples collected from nestling eagles (Giesy et al. 1995).

The Great Lakes' bald eagle population has steadily increased since the 1980's despite significant contaminant loads in their prey. As inland breeding areas have become saturated, with nesting areas, leading to density dependent competition, the Great Lakes' breeding territories have increased (Best et al. 1994). Bowerman et al. (1995) theorized that the Great Lakes have acted as a population sink since eagles nesting there produced few to no young. In 1974 the productivity of bald eagles along the Great Lakes' shorelines was 0.59 young-per-occupied-nest which was below the 0.7 level needed for a stable population (Sprunt et al. 1974). In 2011 Great Lakes' nest site productivity was 1.02 which was above the 1.0 level needed for a healthy population (Sprunt et al. 1974). Great Lakes' nest site productivity has remained above the 1.0 level for a healthy population since 2005.

Great Lakes' anadromous fishes transport environmental contaminants from the more polluted Great Lakes to inland areas where background contamination in local fishes tends to be much lower. Great Lakes' fishes, if eaten by eagles, pose a potential hazard from the effects of the environmental contaminants (Kozie and Anderson 1991; Bowerman et al. 1995; Giesy et al. 1995; Bowerman et al. 1998). Recent studies along

Lake Michigan have shown that riverine brook trout (*Salvelinus fontinalis*) have greater accumulations of PCBs in streams where Pacific salmon spawn, which correspond with PCB levels above current human fish consumption advisories (Lamberti et al. 2011). Currently fish passage past barrier dams on the Au Sable, Manistee and Muskegon rivers was closed from the Great Lakes protecting inland wildlife with piscivorous diets from exposure to fishes with greater concentrations of environmental contaminants.

In the late 1980's and early 1990's the Federal Energy Regulatory Commission (FERC) reviewed environmental aspects of hydro-electric projects operations as part of relicensing dams along the Au Sable, Manistee and Muskegon rivers. When the licenses were issued for operation of the project, the United States Fish and Wildlife Service (USFWS) withheld the right of the federal government to require fish passage over these dams until concentrations of environmental contaminants would pose no threat to piscivorous wildlife. The license required continued monitoring of environmental contaminants in fish and bald eagle tissues (Giesy et al. 1995).

The last review of the risk to bald eagles from exposure to environmental contaminants in Great Lakes fishes occurred using fish collected in 1990. With the increase in productivity of bald eagles nesting along the Great Lakes' shorelines, a re-evaluation of the risk of passed Great Lakes' fishes will help to determine if the restrictions on fish passage should continue. To determine if environmental contaminants from anadromous fish runs would have negative effects on bald eagle reproduction, a new environmental risk assessment is conducted. This risk assessment included calculating new hazard quotients (HQs) from toxic reference values (TRVs) to determine if it was safe for inland wildlife to be exposed to anadromous fish allowed past barrier dams. A risk assessment was conducted for contaminants of PCBs, DDT, dieldrin, 2,3,7,8-Tetrachlorodibenzo-p-dioxin equivalents (TCDD-EQ) and mercury in a fish diet comparing exposure in Great Lakes' accessible regions to interior regions of the Au Sable, Manistee and Muskegon rivers, using fish collected after 1993.

Objectives for this study were:

1. Compare reproduction between inland and Great Lakes' nesting bald eagles.

2. Conduct a Hazard Assessment by calculating HQs to compare risks to .bald eagles for both areas accessible and not accessible to Great Lakes' fish runs for the Au Sable, Manistee and Muskegon Rivers.

3. Determine if concentrations of environmental contaminants in Great Lakes' fishes are below thresholds for effects, in order to allow fish passage over barrier dams on the Au Sable, Manistee and Muskegon Rivers without negatively impacting bald eagle reproduction.

Study Area

My study area was in the northern part of Michigan's Lower Peninsula encompassing three watersheds, the Au Sable (AS), Manistee (MA) and Muskegon (MU) rivers (referred to collectively as Three Rivers) and two Great Lakes (GL), Lake Huron (LH) and Lake Michigan (LM) (Figure 1). The Three Rivers are home to large anadromous fish runs from the GL that seasonally bring a large quantity of food into the rivers with higher environmental contaminants than resident fishes. A total of 43 breeding areas were selected to be compared on the Three Rivers and surrounding GL.

The AS flows through the northeast part of the Lower Peninsula of Michigan. The river drains 5003 sq km with a main stream of 246 km that empties into LH at the city of Oscoda. The AS watershed is 80% forested but has changed from a coniferous old growth forest to now a mostly deciduous forest. The mainstream drops 200 m in elevation from start to finish with most of the high gradient rapids now impounded (Zorn and Sendek 2001). The river has been named a Blue Ribbon trout stream by the Michigan Department of Natural Resources (MDNR) and was also a National Wild and Scenic River. Trout Unlimited started its organization on the banks of the AS as well. The fishery has been considered the best brown trout (*Salmo trutta*) fishery east of the Rocky Mountains. The AS has 109 dams in its watershed with 7 dams on the mainstream, 6 of which are hydroelectric projects (Zorn and Sendek 2001).

The 6 hydroelectric projects on the river impound 38% of the linear surface of mainstream. Foote Dam was the barrier dam that blocks fish passage from LH and was located 16 km upstream. The other 5 hydroelectric projects are Mio, Alcona, Loud, Five Channels and Cooke in order from upstream to downstream. The first of these dams was Cooke, built in 1911 which was the first one to block fish passage (Zorn and Sendek 2001).

The AS was home to 10 bald eagle breeding areas. Hydroelectric impoundments have 7 of the 10 breeding areas located among them. OS-02 and OS-08 were on Mio Pond, AL-02 was on Alcona Dam Pond, IO-01 and IO-08 were on Loud Dam Pond, IO-05 was on Five Channels Dam Pond. IO-02 and IO-14 were on Cooke Dam Pond. AL-09 was above the Federal Route 4001 Bridge approximately 4 km. OS-

03 was on the river approximately 5 km above the County Highway 602 Bridge. No breeding areas were affected by anadromous fish runs.

The MA is located in the northwest portion of Michigan's Lower Peninsula and drains into LM. The river drains 4,610 sq km with a main stream length of 373 km. There are 63 dams in the watershed with only two on the mainstream (Rozich 1998). The MA drops 204 m in elevation before emptying into LM. The land cover of the watershed is 54% forested, 39% agriculture although very little is cultivated crops with mostly pasture and fruit. Only 3.3% of the watershed is urban or suburban (Rozich 1998). The MA has a large anadromous fish run of steelhead (*Oncorhynchus mykiss*), Chinook salmon (*O. tshawytscha*) and Coho salmon (*O. kisutch*) that travel to Tippy Dam. Above Tippy Dam the hydroelectric project ponds have some fishing opportunities but the most famous fishing on the MA is the upper MA. The upper MA is designated by the MDNR as both a Natural River and as a Blue Ribbon Trout Stream (Rozich 1998).

Tippy Dam was built in 1918 and was the barrier dam. The Manistee runs 40 km below Tippy Dam before it reaches Manistee Lake and eventually in empties into LM. Hodenpyl Dam is the other hydroelectric project on the mainstream (Rozich 1998). The 2 hydroelectric projects impound 20% of the linear surface of the mainstream. Tippy Dam currently is protected under the Endangered Species Act because the Indiana bat (*Myotis sodali*) hibernates within the dam of the hydroelectric project (Kurta and Teramino 1994).

The MA had 9 bald eagle breeding areas during the study period. Three were on hydroelectric ponds. MN-06, MN-07 and MN-12 were on Tippy Dam Pond with breeding areas far enough way that their foraging areas were not affected by anadromous fish runs and WX-01 was on Hodenpyl Dam Pond. MN-04 was located on the MA below Tippy Dam but Tippy Dam Pond was within its foraging range. MN-05, MN-11, MN-03 and MN-02 were on the MA below Tippy Dam in order from LM to Tippy Dam and were affected by anadromous fish runs.

The MU is located south of the MA in the northwest part of the Lower Peninsula. The MU watershed drains 6086 sq km of land into LM. The MU is 341km long and flows from Higgins and Houghton Lake into Lake Muskegon and to LM. Below Croton Dam the river runs 75 km before reaching LM. Croton Dam is the barrier dam. Reedsburg Dam is closest to the head waters of the MU. It was built for a wildlife flooding. Rogers Dam is the next hydroelectric project on the MU followed by Hardy Dam. The dams on the mainstream impound 22% of the linear surface area of the river. The River drops 175 m in elevation before reaching LM (O’Neal 1997). The watershed is comprised of 49% forested and 33.4% agriculture. The watershed is 7.8% urban (Ray et al. 2010). The MU is the warmest of the Three Rivers with a predominantly warm water fishery compared to the cold water fisheries of the AS and MA rivers (O’Neal 1997).

The MU had 4 bald eagle breeding areas, 2 below Croton Dam and 2 above. The 2 breeding areas affected by anadromous fish runs were MU-02 and NE-01. MU-02 was located approximately 5 km upstream of US 31. NE-01 was located approximately 5km below Croton Dam. The breeding territories above Croton Dam were NE-03 located on the backwaters of Croton Dam and RO-03 was located on the Reedsburg Dam wildlife flooding area.

GL shoreline nests were compared to Three River nests. I included nests on LM and LH that were within 8 km of the lake shore (Best et al. 1994). On LM the southernmost breeding area was MU-03 between the confluences of the Grand River and MU. The northernmost breeding area was BZ-09 located in Sleeping Bear Dunes National Park. There were a total of 18 breeding areas on LM which encompassed the MA and MU deltas and surrounding shoreline.

On LH, breeding areas were sampled from AI-08 to the north, and south to IO-12 with a total of 9 nests on LH. Breeding areas were selected to avoid those associated with Saginaw Bay which had higher concentrations of environmental contaminants (Heaton et al., 1995; Giesy et al. 1996). The northern most breeding areas were chosen to not include breeding areas associated with the Thunder Bay River.

METHODS

Fish Collection

Fish were collected above and below Foote, Tippy and Croton dams on the AS, MA and MU during 3 separate periods (1990, 2000, 2006). Consumers Energy contracted the Great Lakes Environmental Center to collect fish samples. The MDNR also collected fish during their annual spring walleye (*Sander vitreus*) egg-collection procedures on the MU below Croton dam (Consumers Energy 2008). The 1990 samples were collected above and below the hydroelectric projects, with an additional middle section sample on the AS collected with electro shocking techniques. Analytical methods and concentrations were previously reported (Giesy et al. 1994). Samples collected in 2000 and 2006 were analyzed at the Texas A&M GERG lab using high-resolution gas chromatography with electron capture detection (Consumers 2008). On the AS, white sucker (*Catostomus commersonii*), walleye, Chinook salmon and steelhead, were collected below the dam and white suckers and walleye collected above the barrier dam. On the MA white suckers, northern pike (*Esox Lucius*), walleye, and steelhead were collected below the barrier dam and white suckers, northern pike and walleye collected above the barrier dam. The MU fish collections included the common carp (*Cyprinus carpio*), walleye, white sucker and steelhead below the barrier dam and common carp, white sucker, and walleye above (Consumers 2008).

Bald Eagle Sampling and Analysis

Fixed wing aerial surveys were conducted in March or early April and using a pilot and an observer, who noted tree species, nest location using a Global Positioning System (GPS) unit and also reproductive status of adults, including number of eggs or chicks, and if the adults were brooding. Aerial surveys were conducted by the MDNR with experienced contract observers. The second aerial survey occurred in May and early June to determine nesting success or failure. For successful nests, the observer noted tree condition and age of nestling eagles. To be sampled nestlings need to be between 5 and 9 weeks post hatch and the tree must be safe to climb. Aerial survey data were released to field crews who found nests using the aerial GPS locations and recorded exact location at the base of the tree suing a GPS unit.

Once the team arrived at the nest site, a climber ascended the tree using ropes, harnesses, and spurs. The climber secured themselves at the nest then captured the nestlings individually and lowered the birds to the ground in a restraining bag. Once the bird was processed on the ground the climber pulled the bird back up in its restraining bag and released it back into the nest. After the birds have been processed the climber repelled back to the ground.

When the bird was on the ground morphological measurements were recorded including: bill depth, culmen length, footpad length, hallux claw length, weight and 8th primary length. Footpad length and bill depth were used to determine sex. The 8th primary was used to determine the age of the bird (Bortolotti 1984a; Bortolotti 1984b; Bortolotti 1984c). Nestling eagles were placed on their back and restrained with an ace bandage wrapped around their feet and a baseball cap placed over their head to help them remain calm by providing a dark environment. Three to four breast feathers were collected and placed in an envelope for mercury testing. Other observations that were taken when at the nest were the fullness of the crop, prey remains in and around the nest, presence of fishing tackle, health of the tree, nest height, tree height, and diameter at breast height (DBH). All nestlings were fitted with a size 9 USFWS rivet band before being returned to the nest.

A blood sample was collected from every nestling banded unless health problems were apparent. Sterile blood samples were taken using a size 22 gauge x 2.54 cm needle and up to 12 ml of blood was drawn from the brachial vein and transferred to heparinized vacuum tubes. Blood was stored in coolers until centrifuged within 48hrs of collection. Plasma was decanted and placed into another vacuum tube and stored at -20^{o}C. A splattering of blood was placed on a gauze pad, air dried and stored in a plastic bag to be used for DNA testing. Samples were transferred to pre-arranged MDNR, U.S. Forest Service or USFWS collection points and at the end of field season all samples are transferred to the USFWS East Lansing Field Office. A chain of custody tracking system was used and the samples are frozen at -20^{o}C. From the East Lansing Field Office samples were transferred to Clemson University for analysis. Sampling and handling methods were reviewed by IUCAC protocols and conducted under state and federal permits.

Extractions and analysis of PCBs, DDT, and dieldrin were conducted under Clemson Institute of Environmental Toxicology (CIET 401-78-01) standard operating procedures. Validations of recoveries of 70%-130% for matrix spikes were required under the Quality Assurance Project Plan (CIET 1996; 1999). Chicken plasma was used as a surrogate matrix to ensure data quality was met. Mercury analysis followed U.S. EPA Method 245.7 for total Hg by cold vapor Atomic Fluorescence Spectrometer (AFS Aurora AI 3200).

Population Analysis

Bald eagle population statistics were calculated for the AU, MA and MU rivers using the method of Postupalsky (1974). Productivity was defined as number of fledged young per occupied breeding territory. Success was defined as the proportion of breeding areas that had at least 1 fledged young divided by the total number of occupied breeding areas (Postupalsky 1974). Productivity of 1.0 or greater was indicative of a healthy population, while a productivity level of 0.7 was representative of a stable population (Sprunt et al. 1974). The recovery goals for productivity were 1.0

and success was 50% under the Northern States Bald Eagle Recovery Plan (Grier et al. 1983) and these were used as the No Observable Adverse Effect Levels (NOAELs) for the study.

I contrasted bald eagle reproduction between 4 regions along the Three Rivers. Great Lakes' influenced (GLI) was all areas within 8 km of the GL and anadromous fish runs. Great Lakes' areas (GLA) were located within 8 km of the GL shoreline. Anadromous areas (AN) were on sections of the Three Rivers below barrier dams. Inland areas (IN) were all areas not influenced by GL fish runs above the barrier dams on the Three Rivers. Areas accessible to GL fish runs (below barrier dams) and areas not accessible to GL fish runs (above the barrier dams) were compared to help determine if environmental contaminants from GL anadromous fish runs have effects on the bald eagle reproduction. Numbers of fledged young and occupied nests were calculated by riverine region and by time period using aerial survey data, corrected by field crews. Productivity was calculated from 1989 to 2008 in 5 year periods: period 1 (1989-1993), period 2 (1994-1998), period 3 (1999-2003), and period 4 (2004-2008). Five year increments are more accurate than single year productivity samples when testing for environmental contaminants because stochastic events may cause yearly variation (Weimeyer et al. 1993).

Contaminant Comparison

Nestling bald eagle plasma was available from 1999 to 2008. Samples were compared between 2 periods, period 1 (1999-2003) and period 2 (2004-2008) and between 2 locations GLI and IN areas.

Hazard Assessment

To determine if environmental contaminants from anadromous fish runs have negative effects on bald eagle nesting productivity a hazard assessment was used to assess environmental risk. I analyzed concentrations in potential fish prey for PCBs, dieldrin, DDE/DDT, TCDD-EQ and mercury above and below Foote Dam, Tippy Dam, and Croton Dam, the barrier dams along the Three Rivers, for fish collected during 1990, 2000 and 2006 time periods (Giesy et al. 1994; Consumers 2008). The PCBs were measured as total PCBs defined as the sum of all PCB congeners. A hazard quotient (HQ = [Fish Contaminant Concentration*Bio Magnification Factor(BMF)] / [Dietary No Observable Adverse Effect Concentration (NOAEC)]) was calculated for each of these environmental contaminants for only the fish portion of their diet. Toxic Reference Values (TRVs) were obtained from the literature for bald eagles to determine dietary NOAEC. Field derived TRVs were used for bald eagles since they were previously protected under the Endangered Species Act 1973 and now are protected under the Bald and Golden Eagle Protection Act 1940. Therefore, laboratory studies were not appropriate using this species, so surrogate species were used (Bowerman et al. 1995). TCDD-EQ was not sampled in 2000 and 2006. Concentrations of TCDD-EQ have been correlated with total PCB concentrations in Chinook salmon eggs (R^2 = 0.606) and fillets (R^2 = 0.77; Williams and Giesy 1992a; Williams and Giesy 1992b). A line of best fit was calculated for Total PCBs and extrapolated to determine predicted HQs for 2000 and 2006.

Statistical Analysis

The objective of the statistical analysis was to determine differences between contaminant plasma levels collected on the GLI and IN areas. Total PCBs, sum DDE and dieldrin were the environmental contaminants compared for bald eagle plasma samples. Samples were tested for mean differences among location for each period to determine if there were changes from period 1 and period 2 for the GL and IN Michigan. ANOVA tests followed by Fishers t Tests were used for testing mean differences in productivity and concentrations of contaminants between periods and locations. Chi-squared tests were used to determine differences in success rates. All calculations were performed using JMP 8 (JMP 1989-2007) using a simple least squares model.

RESULTS

Fish Contaminant Concentrations

Mean mercury was greater in fishes in IN than GLI ($t = -3.05$, d.f. = 47, $p < 0.002$). Fish collected from IN during 2000 had the greatest average concentration of mercury (0.69 ± 0.08 ug/kg wet weight (ww)) compared to other time periods while fish from GLI in 2006 had the lowest average concentration of mercury (0.15 ± 0.07 ug/kg ww; Table 2.1).

Mean total PCBs were greater in GLI than IN fishes ($t = 4.27$, d.f. = 47, $p < 0.0001$). Fishes collected in 1990 from GLI had the greatest average levels of PCBs (1.96 ± 0.27 ug/kg ww), while fish collected from IN during 2000 had the least (0.08 ± 0.36 ug/kg ww; Table 2.1).

Mean DDT/DDE was greater in GLI than IN fishes (t = 4.38, d.f. = 47, p < 0.001). Fishes collected from GLI 1990 had the greatest averages concentrations (0.35 ± 0.06 ug/kg ww), while collected from IN during 2006 had the least (0.02 ± 0.08 ug/kg ww; Table 2.1).

Mean Dieldrin was greater in GLI than IN (t = 2.38, d.f. = 47, p < 0.01). Fishes from GLI 1990 had the highest average concentration (0.29 ± 0.04 ug/kg ww), while fish collected from IN during 2006 had the least (0.0001 ± 0.05 ug/kg ww; Table 2.1).

Nestling Bald Eagle Contaminant Concentrations

Mean concentrations of total PCBs found in nestling bald eagle blood plasma were greater in GLI than IN (t = 6.94, d.f. = 1, p < 0.0001). Average concentrations of total PCBs in GLI eaglets were 40.3 ± 4.68 ug/kg in period 1 and 44.6 ± 4.01 ug/kg in period 2 which are greater than the No Observable Adverse Effect Level (NOAEL) of 33 ug/kg for nestling bald eagles (Bowerman et al. 2003). IN averages in period 1 and period 2 were below the NOAELs for total PCBs.

Total PCBs in nestling bald eagles were greater in GLI than IN nesting sites in both period 1 and period 2 (t = -5.36, d.f. 91, p < 0.0001;t = -5.87, d.f. = 91, p < 0.0001, respectively). There were no differences between periods on GL nesting bald eagles (t = 0.70, d.f. = 91, p < 0.76) or on IN nesting bald eagles (t = -0.58, d.f. = 91, p < 0.28; Table 2.2).

Mean concentrations of Sum DDT found in nestling bald eagle blood plasma were greater in GLI than IN. Sum DDT was greater in period 1 (28.13 ug/kg ± 2.39) and period 2 (24.2 ug/kg ± 2.05) for GLI nestlings than the NOAEL of 11 ug/kg for nestling bald eagles (Bowerman et al. 2003). IN averages in period 1 (4.5 ± 2.1) and period 2 (2.9 ± 3.0) were less than NOAELs for sum DDE.

Concentrations of Sum DDT in nestling bald eagles was greater in period 1 ($t = -7.44$, d.f. = 91, $p < 0.0001$) than period 2 IN ($t = -5.86$, d.f. = 91, $p < 0.0001$). There were no differences between period 1 and period 2 for GL ($t = -1.24$, d.f. = 91, $p < 0.11$) or IN ($t = -0.44$, d.f. = 91, $p < 0.33$; Table 2.3).

For period 2, concentrations of dieldrin were greater in GL nestling bald eagles ($t = -3.19$, d.f. = 91, $p < 0.001$). In period 1 there were no differences in concentrations of dieldrin in plasma of GL nestling bald eagles compared to concentrations in nestling bald eagles IN ($t = -1.31$, d.f.= 91, $p < 0.10$). Concentrations were greater in period 2 then period 1 for GL nestlings ($t = 2.84$, d.f. = 91, $p < 0.003$; Table 2.4).

Population Analysis

Among all periods and locations GLI productivity was only less than IN in period 1($F = 11.88$, d.f. = 1, $p < 0.001$). All time periods besides GLI period 1 were equal to or greater than 1.0 (Table 2.5).

Productivity for GLA, AN and IN were compared for the 4 periods. In period 1 productivity at IN was greater than AN ($t = 2.36$, d.f. = 65, $p < 0.01$) and GLA ($t = 2.84$, d.f. = 65, $p < 0.003$). Productivity did not differ among any other periods by location. AN period 1 and GLA period 1 were less than the 0.7 productivity rate for a stable population and GLA period 3 was less than a productivity of 1.0 (Table 2.5).

IN and GLI nesting success were compared over 4 periods. IN nesting success was only greater than GLI for period 1 ($X^2 = 10.84$, d.f. = 1, $p < .001$). GLA, AN and IN were compared over 4 periods. GLA and AN were less than IN for period 1 ($X^2 = 11.57$, d.f. = 2, $p < .003$; Table 2.5).

Hazard Assessment

TCDD-EQ was projected for all locations and time periods for fish sampled. HQs were greater than 1 for all locations and time periods. HQs were greater than 10 for all GLI locations and time periods. There were no HQs greater than 10 for IN samples (Table 2.6).

PCBs were found at all locations and time periods for fish sampled for this study. HQs were greater than 1 for GLI on all Three Rivers in 1990, 2000 and 2006, and MU IN in 1990. HQs greater than 10 were for GLI on the MA and MU in 1990. MU IN 1990 was the only IN HQ greater than 1 (Table 2.6).

DDT/DDE was found at all locations and time periods for fish sampled for this study. HQs were greater than 1 for GLI on the MA and MU 1990, 2000 and 2006. There were no HQs greater than 10 for any location and time period. HQ did not exceed either threshold for any time period for IN samples (Table 2.6).

Dieldrin was found at all locations and time periods for fish sampled for this study. HQs were greater than 1 for GLI on the MA and MU in 1990 and on the MU in 2000 (Table 2.6). There were no HQs greater than 10 for any location and time period. HQs did not exceed population or individual adverse effect levels for any time period for and IN samples (Table 2.6).

Mercury was found at all locations and time periods for fish sampled for this study. HQs were greater than 1 for IN for all Three Rivers in 2000. There were no HQs greater than 10 for any location and time period. There were no HQs greater than 10 for any location and time period. HQs did not exceed population or individual adverse effect levels for any time period for and IN samples (Table 2.6).

DISCUSSION

The bald eagle population nesting along the AS, MA and IN increased throughout the study period. Nesting populations along the GLA and GLI sections of river have increased more so than IN Michigan nesting areas. Enhanced productivity and success at IN areas indicate that nesting bald eagles there are not limited by environmental contaminants and that suitable nesting areas may now be the limiting factor. IN areas have no HQs at levels detrimental to bald eagle populations. IN populations have expanded to unoccupied nesting areas. Because the GLA nesting bald eagle population is still recovering from environmental contaminants, shorelines are not saturated with nesting eagles. IN nesting eagles are now moving into these open territories. The IN bald eagles that have moved to the GLA have less contaminants, which is the most likely explanation for the increased productivity and success rates observed.

Mean concentrations of environmental contaminants in GLI were greater than IN. Mean concentrations of PCBs and DDT for GLI from 2000 to 2006 in MA and MU for white suckers and AS, MA and MU walleye increased. Steelhead decreased on the Three Rivers during the same time period (Table 2.1). Steelhead only occupy the rivers as smolts and when spawning, while there are native populations of white suckers and walleye below the barrier dams. The increasing trend in white suckers threatens bald eagles more than other fish because they comprise 51.5% of their diet on the Three Rivers (Bowerman 1993). Mercury was greatest for all locations in the 2000 samples with MA IN steelhead and MU IN walleye being outliers that were greater in another period. Deildrin decreased from 2000 to 2006 for all samples besides MA IN white suckers and walleye and MU GLI walleye. Dieldrin decreased in fish samples, besides a few outliers, and if the trend continues it will become non detectable in the near future.

Mean concentrations of environmental contaminants in 2010 fish sampled by the MDNR indicate greater concentrations of environmental contaminants in GL fish and GLI fish samples. MDNR found that total PCB concentrations were declining and may lead to relaxation of consumption advisories (Bohr and VanDusen 2011). With MDNR total PCBs declining, the 2006 total PCBs increase from 2000 fish samples may indicate a spike in total PCBs rather than an upward trend. The United States Environmental Protection Agency (EPA) sampled lake trout (*Salvelinus namaycush*) from 1978 to 2002 in the GL. Total PCB concentrations for the GL in 2002 were 0.16 ppm. Sum DDT results for LM and LH were below 0.1 ppm. Both Total PCB and Sum DDT declined through the EPA study (EPA 2011). These total PCB and sum DDT results corroborate the decline in my study in 1990 and 2000 fish samples.

Mean concentrations of environmental contaminants in nestling bald eagle blood plasma were greater than the NOAELs for total PCBs and sum DDT for GLI nestlings. Means for Total PCBs and sum DDT were less than the NOAELs for IN nestling bald eagles. . The averages of sum DDT were in the range reported from samples collected in the GL watershed which were 2.85 to 62.6 ng g_1 ww, with an average of 19.9 ± 4.9 ng g_1 ww (Venier et al. 2010). IN averages were less than the mean concentrations of 22 to 35 ng g_1 ww reported from the GL region (Bowerman et al. 2003).

Total PCB concentrations in nestling bald eagle blood plasma were greater than the NOAEL for PCB in the GLI. Other total PCB averages reported ranged between 5.46 to 254 ng g_1 ww with an overall average of 73.8 ± 23.2 ng g_1 ww for the GL watershed (Venier et al. 2010). My samples were less than the average reported for the GL watershed. Bowerman et al. 2003 reported an average concentration of total PCBs for Green Bay, Lake Michigan of 207 ng g_1 ww. Green Bay was listed as an area of concern for greater levels of PCBs explaining why their average was greater than expected. The samples in the study are within the range of other studies, confirming that higher concentrations of PCBs are still in the GL.

Environmental contaminants had similar trends in fishes sampled and nestling bald eagle plasma collected. PCBs appeared greater for AS and MA GLI 2006 for fishes and GLI period 1 for plasma samples, than AS and MA 2000 fishes and GLI period 2 for plasma, although not statistically significant. IN was less than GLI for PCBs, DDT and Dieldrin for combined fishes and plasma samples for all periods. DDT decreased among all periods and locations besides IN, MA and AS combined fishes which remained constant. All contaminants are decreasing in the study area or plateauing (with the exception of PCBs) and these trends likely are relieving the negative effects previously experienced by nesting bald eagles from contaminant concentrations.

Productivity and success rates in all locations were greater than or equal to the NOAEL for period 4. The productivity rates for period 3 and 4 were similar to the value reported from 2000-2006 for the entire state of Michigan (0.95; Weirda 2010). Productivity from all locations in the study area for period 3 and 4 were greater than or above that rate (Table 2.5).

TCDD-EQ is a limiting factor for bald eagle and white tailed sea eagle (*Haliaeetus albicilla*) reproduction because of their fish diet (Bowerman et al. 1995; Koistinen et al. 1997). TCDD-EQ is the combination of many compounds including Polychlorinated dibenzodioxins (PCDD), Polychlorinated dibenzofurans PCDF, and planar PCBs. In the Great Lakes the majority of TCDD-EQ is PCB congeners, which improved the accuracy of extrapolation (Bowerman et al. 1995). The LOAEC determined for the surrogate species American kestrel (*Falco sparverius*) was between 7 and 10 ng TCDD-EQ/kg ww in egg, (Henshel et al. 1993a). The LOAEC in white leghorn chickens (*Gallus gallus*) is approximately 100 ng TCDD-EQ/kg ww in egg (Henshel et al. 1993b). The NOAEC of 7ng TCDD-EQ/kg ww determined from wood duck (*Aix sponsa*) egg shell thinning (White and Setinack 1994;Table 2.7). Assuming With HQs greater than 10 on the Three Rivers, allowing fish passage over the barrier dams would have negative population effects on bald eagle reproduction.

PCBs have negative effects on bald eagle reproduction (Sprunt et al. 1973; Kozie and Anderson 1991; Weimeyer et al. 1993). Determining the NOAEC is difficult because of the correlation between DDE and PCBs but a NOAEC of 4.0 mg PCB/kg ww was determined through a nationwide bald eagle environmental contaminant assessment (Weimeyer et al. 1984; Table 2.7). With all the HQs greater than 1, passage of fish over barrier dams would have a negative effect on individual nesting bald eagles above the barrier dams.

DDT and its DDE isomers, have been linked to reproductive failure for many species of birds (Weimeyer et al. 1970; Weimeyer et al. 1984; Lincer 1975; Tucker and Haegele 1971; McLain and Hall 1972). p’p’DDE is the isomer that is the most toxic and causes eggshell thinning. The NOAEC for DDT/DDE is 4.2 DDE/kg ww resulting in15% eggshell thinning determined from osprey (*Pandion haliaetus*; Weimeyer et al. 1988) and observed in the field for bald eagles (Weimeyer et al. 1984; Table 2.7). Determining the NOAEC for DDT/DDE is difficult because it is interrelated with negative effects from concentrations of PCBs (Weimeyer et al. 1984). With HQs still greater than 1, the passage of fish over barrier dams would have a negative effect on individual nesting bald eagles above the barrier dams.

Dieldrin causes population level effects on birds of prey. In Eastern England 29% of sparrowhawk (*Accipiter nisus*) mortality was directly related to dieldrin (Sibley et al. 2000). Dieldrin had a greater impact on adult bald eagle survival than reproductive productivity, with a NOAEC of 0.1 for egg failure (Weimeyer et al. 1984; Table 2.7). Although IN concentrations are less than GLI concentrations, dieldrin at its current concentrations does not have any adverse effects on the bald eagle population along the Three Rivers.

Although HQs of mercury were greater than 1 on the Three Rivers, there has yet to be any conclusive evidence that links bald eagle reproduction to mercury (Bowerman et al. 1994; Pittman et al. 2011). However, mercury has been shown to have a negative effect on productivity in other avian species such as the common loon (*Gavia immer*) (Chan et al. 2003; Scheuhammer et al. 2007). Bald eagles convert mercury in their brain into less harmful organic forms (Scheuhammer et al. 2007). A NOAEC 0.5mg Hg/kg ww for failure of eggs to hatch has been previously used for bald eagles. The NOAEC was derived from mallard ducks (*Anas platyrhynchus*; Weimeyer et al. 1984; Table 2.7).

With only 3 periods of HQs it is difficult to determine trends in contaminants. The only HQ that increased in every period was the AS IN total PCB HQ which increased from 0.4 in 1990 to 0.6 in 2000 and 0.9 in 2006. However, in 2006 it was still below the threshold for negative effects on individual bald eagles. Dieldrin HQs decreased at all Three River GLI locations. From 1990 to 2000 total PCB decreased at all GLI locations. Total PCBs remained constant for 2006 AS and MU while the MA jumped from an HQ of 4.1 in 2000 to 8.8 in 2006. HQs of 0 in 2006 were only found for MA IN DDT/DDE, AS IN and GLI for dieldrin and dieldrin for the MA and MU IN. MU GLI IN for dieldrin and AS IN and MA IN for mercury went from HQs above the threshold for adverse effects to individuals in 2000, to below the threshold for adverse effects in 2006. Total PCBs were greater than individual adverse effects in 1990, 2000 and 2006 GLI. An EPA study supports those HQs. Total PCBs in the GL were 0.16 ppm which was above the wildlife protection value of 0.1 ppm set by the Great Lakes Water Quality Agreement referenced in the study (EPA 2011).

The HQ equation used in this chapter did not yield any measure of standard error or of likely variation in environmental contaminants from tested fish concentrations. Bald eagles preying upon fish higher on the trophic level would have greater environmental contamination than eagles preying on lower trophic level fish because of bio-magnification. For this current study, average HQ for environmental contaminants was used in the risk assessment.

HQs indicate that the GL fishes still have concentrations of contaminants at levels that can negatively affect breeding bald eagles. TCDD-EQ HQs for GLI sections on the Three Rivers were above the threshold for adverse effects at the population level. HQs for PCBs below barrier dams were at great enough concentrations to negatively affect individual bald eagle reproduction on the Three Rivers. HQs for DDE were at great enough concentrations to negatively affect individual bald eagles nesting on the MA and MU. Using the bald eagle as a biomonitor, the risk assessment based on my data concludes that wildlife exposure would be significantly greater to environmental contaminants, transported by GL fishes, if fish passage is allowed past the barrier dams on the AS, MA and MU. Therefore, my data suggests that if protection of wildlife from environmental contaminants is the management goal, then fish passage should not be allowed past Foote, Tippy and Croton dams. Concentrations of environmental contaminants in nestling bald eagle blood plasma confirm these results.

WORKS CITED

Best DA, Bowerman WW, Kubiak TJ, Winterstein SR, Postupalsky S, Shieldcastle M. 1994 Reproductive impairment of bald eagles along the Great Lakes shorelines of Michigan and Ohio. In: Raptor Conservation Today. East Sussex, U.K.:World Working Group on Birds of Prey and The Pica Press 697-702.

Bohr, J., and J. VanDusen. 2011. Michigan Fish Contaminant Monitoring Program: 2009 Annual Edible Portion Report. MDEQ-WRD Report #MI/DEQ/WRD-11/019.

Bortolotti, G. R. 1984a. Physical development of nestling bald eagles with emphasis on the timing of growth events. Wilson Bulletin 96: 524-542.

Bortolotti, G. R. 1984b. Sexual size dimorphism and age-related variation in bald eagles. Journal of Wildlife Management 48: 72-81.

Bortolotti, G. R. 1984c. Criteria for determining age and sex of nestling bald eagles. Journal of Field Ornithology 55: 467-481.

Bowerman, W. W. 1993. Regulation of bald eagle *(Haliaeetus leucocephalus)* productivity in the Great Lakes Basin: An ecological and toxicological approach. PhD dissertation, Michigan State University, East Lansing, MI.

Bowerman, W. W., E. D. Evans, J.P. Giesy and S. Postupalsky 1994. Using feathers to assess risk of mercury and selenium to bald eagle reproduction in the Great Lakes region. Archives of Environmental Contamination and Toxicology 27(3):294-298.

Bowerman, W. W., J. P. Giesy, D. Best and V. J. Kramer. 1995. A review of factors affecting productivity of bald eagles in the Great Lakes region: Implications for recovery. Environmental Health Perspectives 103: 51-59.

Bowerman, W. W., D. A. Best, T. G. Grubb, G. M. Zimmerman and J. P. Giesy 1998. Trends of Contaminants and Effects in Bald Eagles of the Great Lakes Basin. Environmental Monitoring and Assessment 53(1): 197-212.

Bowerman, D. W., A. S. Roe, M. J. Gilbertons, D. A. Best, J. G. Sikarskie, R. S. Mitchell and C. L. Summer. 2002. Using bald eagles to indicate the health of the Great Lakes' environment. Lakes & Reservoirs: Research and Management 7: 183-187.

Carlson, D. L., Swackhamer, D. L. 2006. Results from the U.S. Great Lakes fish monitoring program and effects of lake processes on bioaccumulative contaminant concentrations. Journal of Great Lakes Research *32*:370-385.

Chan HM, Scheuhammer AM, Ferran A, Loupelle C, Holloway J, Weech S. 2003. Impacts of mercury on freshwater fish-eating wildlife and humans. Hum Ecological Risk Assessment 9(4):867–883.

Consumers Energy. 2008. Report on the second periodic fish contaminant monitoring for Au Sable, Manistee and Muskegon River hydroelectric project nos. 2436 (Foote), 2468 (Croton), 2599 Hodenpyl) and 2580 (Tippy)--Michigan.

Giesy JP, Verbrugge DA, Othout R, Bowerman WW, Mora MA,Jones PD, Newsted JL, Vandervoort C, Heaton SN, Aulerich RJ, Bursian S J, Tillitt DS, Johnson J, Ludwig JP, Ludwig M, DawsonG, Kubiak TJ, Best DA, Welsh R. 1994. Contaminants in fishes from Great Lakes-influenced sections and above dams of three Michigan rivers: I. Concentrations of organochlorine insecticides,PCBs, dioxin equivalents, and mercury. Archives of Environmental Contamination and Toxicology. 27:202-212.

Giesy, J. P., Bowerman, W. W., Mora, M. A., Verbrugge, D. A., Othoudt, R. A., Newsed, J. L., et al. (1995). Contaminants in fishes from Great Lakes-influenced sections and above dams of three Michigan rivers: III. Implications for health of bald eagles. Archives of Environmental Contamination and Toxicology, 29, 309–321.

Giesy J. P., Jude D. J., Tillitt, D. E., Gale R. W., Meadows J. C., Zajieck J. L., Peterman P. H., Verbrudge D. A., Sanderson J. T., Schwartz T. R. and Tuchman M. L. 1996 Polychlorinated dibenzo-p-dioxins, diberzofurans, biphenyls and 2,3,7,8-tetrachlorodibenzo-p-dioxin equivalents in fishes from Saginaw Bay, Michigan. Environmental Toxicology and Chemistry 16(4):713-724.

Heaton, S. N., Bursian, S. J., Giesy, J. P., Tillitt, D. E., Render, J. A., Jones, P. D., Verbrugge, D. A., Kubiak, T. J., and Aulerich, R. J. 1995. Dietary exposure of mink to carp from Saginaw Bay. 1. Effects on reproduction and survival, and the potential risks to wild mink populations. Archives of Environmental Contaminant Toxicology 28:334-343.

Henshel D. S., 1993. LD50 and teratogenicity studies of the effects of TCDD on chicken embryos. Publish Abstract., 14th Annual Meeting, Society of Environmental Toxicology and Chemistry, Houston, Texas.

Henshel DS, Hehn BM, Vo MT, Steeves JD. A short-term test for dioxin teratogenicity using chicken embryos. In: Environmental Toxicology and Risk Assessment, Vol 2, ASTM-STP 1216

International Joint Commission. 1991. Proceedings of the Expert Consultation Meeting on Bald Eagles in the Great Lakes Basin (ed. M. Gilbertson). International Joint Commission, Windsor, Ontario, Canada.

JMP (1989–2007) Version 8. SAS Institute Inc., Cary

Koistinen, J., Koivusaari, J., Nuuja, I., Vuorinen, P. J., Paasivirta, J., and Giesy, J. P. 1997. 2,3,7,8-Tetrachlorodibenzo-p-dioxin equivalents in extracts of Baltic white-tailed sea eagles. Environmental Toxicology and Chemistry 16(7):1533-1544.

Kozie, K. D. and R. K. Anderson .1991. Productivity, Diet, and Environmental Contaminants in Bald Eagles Nesting near the Wisconsin Shoreline of Lake-Superior. Archives of Environmental Contamination and Toxicology 20(1): 41-48.

Kurta, A., and Teramina, J. A. 1994. A novel hibernaculum and noteworthy records or the Indiana bat and Eastern pipistrelle (Chiroptera: Vespertilionidae). American Midland Naturalist 132(2):410-413.

Lamberti, G. D. Chaloner,A. Moerke, and D. Janetski. 2011. Impacts of Introduced Pacific Salmon on Ecological Communities of Great Lakes Tributaries GLFT Project Number 2007.857

Lincer, J. L. 1975. DDE-induced eggshell-thinning in the American Kestrel: A comparison of the field situation and laboratory results. Journal of Applied Ecology 12:781-193.

O'Neal, R. P. 1997. Muskegon River Watershed Assessment. Michigan Department of Natural Resources, Fisheries Division. Special Report Number 19. Ann Arbor, Michigan.

Pittman, H. T., Bowerman, W. W., Grim, L. H., and Grubb, T. G., 2011. Using nestling feathers to assess spatial and temporal concentrations in mercury in bald eagles at Voyageurs National Park, Minnesota, USA. Ecotoxicology 20:1625-1635,

Postupalsky S. 1974. Raptor reproductive success: Some problems with methods,criteria and terminology. In: Hamerstorm FN, Harrell BE, Ohlendorff RR (eds) Management of Raptors, Proc. Conf. Raptor Cinserv. Techniques, Raptor Res. Report No. 2, 21-31.

Ray, D. K., Duckles, J. M. and Pijanowski, B. C. (2010) "The impact of future land use scenarios on runoff volumes in the Muskegon River watershed." Environmental Management 46:351-366.

Ross, A. M. and Hall, L. C. 1972. DDE Thins screech owl eggshell. Bulletin of Environmental Contamination and Toxicology 8(2):65-68.

Rozich, T. J. 1998. Manistee River Assessment. Michigan Department of Natural Resources, Fisheries Division, Special Report Number 21. Ann Arbor, Michigan.

Scheuhammer, A., M. Meyer, M. Sandheinrich and M. Murray 2007. Effects of environmental methylmercury on the health of wild birds, mammals, and fish. Ambio 36(1):12-18.

Sibly, R. M.,Newton, I. and Walker, C. H. 2000. Effects of dieldrin on population growth rates of sparrowhawks 1963-1986. Journal of Applied Ecology 37:540-546.

Sprunt A IV, Robertson WB Jr, Postupalsky S, Hensel RJ, Knoder CE, Ligas FJ. 1973. Comparative productivity of six bald eagle populations. Transactions North America Wildlife Natural Recourses Conference 38:96-106.

Tucker, R. K., and Heagele H. A. 1970. Eggshell thinning as influenced by method of DDT exposure." Bulletin of Environmental Contamination and Toxicology 5(3):191-194.

Venier, M., M. Wierda, W. W. Bowerman and R. A. Hites. 2010. Flame retardants and organochlorine pollutants in bald eagle plasma from the Great Lakes region. Chemosphere 80: 1234–1240.

Weimeyer S. N., Porter R. D. 1970. DDE thins eggshells of captive American kestrels. Nature 227:737-738

Wiemeyer, S. N., Bunck, C. M., Krynitsky, A. J. 1988. Organochlorine pesticides, polychlorinated biphenyls, and mercury in Osprey eggs-1970-79-and their relationships to shell thinning and productivity. Archive Environmental Contaminants Toxicology 17:767-787.

Wiemeyer, S. N., Lamont, T. G., Bunck, C. M., Sindelar, C. R., Gramlich, F. J., Fraser, J. D. 1984. Organochlorine pesticides, polychlorobiphenyl, and mercury residues in bald eagle eggs-1969–1979-and their relationships to shell thinning and reproduction. Arch Environmental Contaminant Toxicology 13:529–549.

Wiemeyer S. N., Bunck, C. M., Stafford, C. J. 1993. Environmental contaminants in bald eagle eggs-1980-84-and further interpetations of relationships to productivity and shell thickness. Arch Environmental Contaminant Toxicology 24:213-227.

Williams, L. L. and J. P. Giesy. 1992a. Relationships among concetrations of invividual polychlorinated biphenyl (PCB) congeners, 2,3,7,8-tetrachlorodibenzo-p-dioxin equivalents (TCDD-EQ), and rearing mortality of Chinook salmon (Oncorhynchus tshawytscha) eggs from Lake Michigan. Journal Great Lakes Restoration 18(1):108-124.

Williams, L. L., J. P. Giesy, N. DeGaian, D. A. Verbrugge, D. E. Tillett and G.T. Ankley. 1992b. Prediction of concentrations of 2,3,7,8-tetrachlorodibenzo-p-dioxin equivalents from total concentrations of polychlorinated biphenyls in fish fillets. Environmental Science and Technology 26:1151-1159.

White DT, Setinak JT (1994) Dioxins and furans linked to reproductive impairment in Wood ducks. Journal of Wildlife Management 58:100-106.

Zorn, T. G., and Sendek, S. P. 2001. Au Sable River Assessment. Michigan Department of Natural Resources, Fisheries Division, Special Report 26, Ann Arbor, Michigan.

CHAPTER THREE

ANAYLYSIS OF RUN-OF-RIVER VERSUS PEAKING OPERATIONS ON NESTING OF BALD EAGLES ALONG THE AU SABLE, MANISTEE AND MUSKEGON RIVERS

INTRODUCTION

One of the primary keys to successful rearing and fledging of nestling bald eagles (*Haliaeetus leucocephalus*) is the quantity and availability of prey (Stalmaster 1985). Numerous studies have found a strong relationship between prey quantity and nesting success (Shapiro et al. 1982; Hansen 1984; Bowerman 1991). The creation of hydroelectric impoundments along rivers increases fish populations within these impounded areas, providing an available and abundant source of food for nesting bald eagles. The flow regime through these hydroelectric projects can greatly affect the fisheries downstream of the project. In general, peaking operations (i.e., outflow is determined by electrical needs) produce fewer fish than run-of-river (i.e., inflow is equal to outflow), due to the potential for rivers to either have a great amount or little to no water within the river bed during the peaking cycle.

Bald eagle populations have increased since the ban of dichlorodiphenyltrichloroethane (DDT) and other organochlorine compounds in the 1970s. Increased productivity (fledged young-per-occupied-nest) has led to expanding populations with many new breeding territories, which in turn has resulted in greater competition for prey and other resources. As a result, regional bald eagle populations across Michigan have not increased at comparable rates (Bowerman 1995; Best et al. 1994).

The International Joint Commission (IJC) proposed the bald eagle as a piscivorous wildlife biomonitor for water quality in the Great Lakes (IJC 1991). The bald eagle is a useful as a biomonitor because its life history is well studied, and the Michigan population has been monitored since 1961. Any population effects due to environmental changes can be measured at the population level (Bowerman et al. 2002). Bald eagles are the tertiary piscivore on the Au Sable, Manistee and Muskegon Rivers with 90% of their diet comprised of local fish (Boweman 1993).

In the late 1980's and early 1990's the Federal Energy Regulatory Commission (FERC) reviewed environmental aspects of hydro-electric project operations as part of the relicensing of projects owned by Consumers Power Company along the Au Sable, Manistee and Muskegon rivers (i.e., Three Rivers;Giesy et al. 1995). The license required that the operation of the hydroelectric projects on the Three Rivers be maintained as run-of-river, i.e., inflow of water into the dam pond is equal to out flow at all times. In contrast, peaking regimes increase flow during times of high electricity consumption, normally in the morning and evening (Cushman 1985). Peaking flows simulate flood and drought periods on a daily basis causing stress and decreased productivity, diversity, and abundance of aquatic species below the hydroelectric operations (Cushman 1985).

The objective of this study was to determine if the change from peaking to run-of-river flow regime for hydroelectric projects along the Au Sable, Manistee, and Muskegon rivers influenced subsequent bald eagle productivity and success.

Study Area

The study area for this project was located in Michigan's northern Lower Peninsula. I focused on the hydroelectric projects along the Au Sable (AS), Manistee (MA) and Muskegon (MU) rivers because of changes in flow regime management implemented in 1989 and 1994, in response to environmental studies for relicensure (Figure 1).

The AS flows through the northeastern Lower Peninsula of Michigan. The river drains 5003 sq km with a main stream of 246 km that empties into Lake Huron at the city of Oscoda. The AS watershed is 80% forested but has changed from a coniferous old growth forest to now a mostly deciduous forest. The AS has 109 dams in its watershed with 7 dams on the main stream, 6 of which are hydroelectric projects (Zorn and Sendek 2001).

The 6 hydroelectric projects on the river impound 38% of the linear surface of main stream. Foote Dam is the barrier dam that blocks fish passage from Lake Huron and is located 16 km upstream from the Lake. The other 5 hydroelectric projects are Mio, Alcona, Loud, Five Channels and Cooke in order from upstream to downstream. (Zorn and Sendek 2001). Mio Dam has operated as a run-of-river facility since 1966. Alcona, Loud, Five Channels, and Cooke hydroelectric projects have maintained run-of-river flows from 1994 after the FERC relicensing. Foote Dam converted from peaking to run-of-river in 1989 (Zorn and Sendek 2001).

Mio, Alcona, Loud, Five Channels and Cooke Dam all have bald eagle breeding territories. The AS had 10 bald eagle breeding territories during the study period. OS-

02 and OS-08 were on Mio Dam Pond, AL-02 was on Alcona Dam Pond, IO-01 and IO-08 were on Loud Dam Pond, IO-05 was on Five Channels Dam Pond. IO-02 and IO-14 were on Cooke Dam Pond. AL-09 was above the Federal Route 4001 bridge approximately 4 km. OS-03 was on the river approximately 5 km above the County Highway 602 bridge. OS-02 and OS-03 were the only active breeding areas on Mio Dam Pond or below the hydroelectric project prior to 1966 when run-of-river was implemented.

The MA is located in the northwestern Lower Peninsula and drains into Lake Michigan.   The river drains 4,610 sq km with a main stream length of 373 km. There are 63 dams in the watershed with only two on the mainstream (Rozich 1998). The MA drops 204 m in elevation before emptying into Lake Michigan. The land cover of the watershed is 54% forested and 39% agriculture, mostly pasture and fruit orchards with very little cultivated crops. Only 3.3% of the watershed is urban or suburban (Rozich 1998). Above Tippy Dam the hydroelectric project ponds have some fishing opportunities but the most famous fishing on the MA is the Upper Manistee River. The Upper MA is designated by the Michigan Department of Natural Resources (MDNR) as both a Natural River and as a Blue Ribbon Trout Stream.

Tippy Dam was built in 1918 and is the barrier dam. The MA flows 40 km below Tippy Dam before it reaches Manistee Lake and eventually empties into Lake Michigan. Hodenpyl Dam is the other hydroelectric project on the mainstream (Rozich 1998). The two hydroelectric projects impound 20% of the linear surface of the mainstream. Tippy Dam currently is protected under the Endangered Species Act (year) because the Indiana bat (*Myotis sodali*) hibernates within the dam of the hydroelectric project (Kurta and Teramino, 1994). Hodenpyl and Tippy hydroelectric projects on the MA have operated as run-of-river since 1989 (Rozich 1998).

The MA had 8 bald eagle breeding territories. There were 3 breeding areas on hydroelectric ponds and 1 nest location near an impoundment. MN-06 and MN-07 were both on Tippy Dam Pond. WX-01 was on Hodenpyl Dam Pond. MN-04 was located on the MA below Tippy Dam but Tippy Dam Pond was within its foraging range. MN-11 was in the headwaters 1km south of Manistee County-Blacker Airport. MN-03 and MN-02 were below Tippy Dam 10 km with MN-03 farther downstream. MN-05 was 3.5 km inland from Manistee Lake.

The MU is located south of the MA in the northwestern Lower Peninsula. The Muskegon Watershed drains 6086 sq km of land into Lake Michigan. The MU is 341km long and flows from Higgins and Houghton Lake into Lake Muskegon and to Lake Michigan. Below Croton Dam the river runs 75 km before reaching Lake Michigan. Croton Dam is the barrier dam. Reedsburg Dam is closest to the head waters of the MU. It was built for a wildlife flooding. Rogers Dam is the next hydroelectric project on the MU followed by Hardy Dam. The dams on the mainstream impound 22% of the linear surface area of the river. The River drops 175 m in elevation before reaching Lake Michigan. The watershed is comprised of 49% forested and 33.4% agriculture and 7.8% urban (Ray et al. 2010). The MU is the warmest of the Three Rivers with a predominantly warm water fishery compared to the cold water fisheries of the AS and MA rivers (O'Neal 1997). Rogers Dam has operated as run-of-river since 1994. Hardy Dam operates as peaking but it discharges into Croton Dam Pond. Croton Dam operates so the inflow into Hardy Dam equals the outflow from Croton Dam making the system still run-of-river (O'Neal 1997).

There were 3 breeding territories on the MU. NE-03 was located on the backwaters of Croton Dam. MU-02 was located approximately 5 km upstream of US 31. NE-01 was located approximately 5km below Croton Dam.

METHODS

Population Surveys

Fixed wing aerial surveys were conducted in March or early April by a pilot and an observer, who noted the tree species, nest location using a Global Positioning System (GPS) unit and also the reproductive status of adults. Reproductive status included number of eggs or chicks, or if adults are brooding. Aerial surveys were conducted by the MDNR with experienced contract observers. A second aerial survey occurred in May and early June to determine nesting success or failure. For successful nests, the observer noted tree condition and age of nestlings. For nestlings to be sampled from the ground, they needed to be between 5 and 9 weeks post hatch and the tree must be safe to climb. Aerial survey data were released to field crews who found nests using aerial GPS locations and recorded exact locations at the base of nest trees with a handheld GPS unit. Field crews visited selected breeding areas and recorded any changes in reproductive statuses upon arrival.

Measures of Reproduction

Productivity is defined as the number of fledged young-per-occupied-breeding-territory. A productivity level of 0.7 is indicative of a stable bald eagle population and a reproductive level greater than 1.0 indicates a healthy population (Sprunt et al. 1973). Success is defined as the number of bald eagle breeding areas that produce 1 young or more divided by the number of occupied breeding areas. The Northern States Bald Eagle Recovery Plan (Grier et al. 1983) set a goal for productivity of 1.0 and success at 50%. I used these goals as my No Observable Adverse Effect Level (NOAEL) when determining effects of flow management on bald eagle reproduction.

For the AS, I analyzed among 5 periods, with only 3 periods for OS-02 and OS-03 nesting areas, related to flow regime. Period 1 and 2 were peaking flow periods and Periods 3, 4 and 5 were run-of-river. Mio Dam started run-of-river management in 1966 and there were only nesting data for 1 period prior to run-of-river; Period 2 was not included in the comparison to standardize the periods. Period 5 was also not included because of a bottleneck in the population from environmental contaminants during that period. Period 1, 1961-1965 for breeding areas OS-02 and OS-03 represented peaking discharge for comparison with Period 3, 1966-1970 and Period 4, 1971-1975 run-of-river. All others were classified as Period 1, 1984-1988 and Period 2, 1989-1993 under peaking discharge and Period 3, 1994-1998, Period 4, 1999-2003, and Period 5, 2004-2008 as run-of-river flow. Bald eagle breeding productivity and nesting success was averaged in 5 year periods to negate the yearly fluctuations from weather and other stochastic events (Weimeyer et al. 1993).

MA was separated by 5 periods, for all nests Period 1, 1979-1983, Period 2, 1984-1988, Period 3, 1989-1993, Period 4, 1994-1998 and Period 5, 1999-2003. Periods 1 and 2 occurred during peaking operations while Periods 3, 4, 5 and 6 were run-of-river. There were no recorded breeding attempts prior to Period 1.

MU bald eagle breeding areas were separated into 5 periods, Period 1, 1984-1988, Period 2, 1989-1993, Period 3, 1994-1998, Period 4, 1999-2003, and Period 5, 2004-2008. Periods 1, 2, 3 were during peaking operations. Periods 4 and 5 were during run-of-river operations.

Statistical Analysis

The objective of the statistical analysis was to determine differences between productivity and success rates before and after peaking operations. ANOVA tests followed by Fishers t Tests were used for testing mean differences between periods and locations. Chi-squared tests were used to determine differences in success rates. All calculations were performed using JMP 8 (JMP 1989-2007) using a simple least squares model.

RESULTS

Bald eagle reproduction did not change on the AS after hydroelectric project flow regimes changed from peaking to run-of-river (Table 3.1). Productivity did not vary among the 5 time periods ($F = 0.76$, d.f. = 4, $p < 0.55$). Period 1 was the only period where productivity was <1.0. Bald eagle nesting success also did not vary after the change in flow regime ($X^2 = 6.5$, d.f. = 4, $p < 0.16$). Period 1 was the only period where success was <50%.

Bald eagle reproduction did not change on the MA after hydroelectric flow regimes changed from peaking to run-of-river (Table 3.2). Productivity did not vary among the 5 time periods ($F = 1.36$,d.f. = 4, $p < 0.25$). Period 1 was the only period where productivity was <0.7, the level associated with a stable population. Bald eagle nesting success also did not vary after the change in flow regime ($X^2 = 4.21$, d.f. 4, $p < 0.38$). However, success for Periods 1 and 2 (during peaking) was less than Periods 3, 4, and 5 (run-of-river).

Bald eagle reproduction did increase on the MU after hydroelectric flow regimes changed from peaking to run-of-river (Table 3.3). Productivity increased after run-of-river management was implemented on the MU ($F = 4.08$, d.f. = 4, $p < 0.006$). Productivity along the MU was less in Period 1 then Periods 3 ($t = 2.00$, d.f. = 56, $p = 0.0009$), 4 ($t = 2.00$, d.f. = 56, $p = 0.0002$), and 5 ($t = 2.00$, d.f. = 56, $p = 0.03$). Productivity during Period 2 was less then Period 3 ($t = 2.00$, d.f. = 56, $p = 0.04$). MU productivity for Period 1 was less than 0.7, the level associated with a stable population. Productivity for Period 2 was greater than 0.7 but less than 1.0, the level associated with a healthy population. Success was greater after run-of-river management was implemented on the MU ($X^2 = 18.91$, d.f. = 4, $p < 0.0008$). Success during Period 2 was not less than run-of-river periods ($X^2 = 5.08$, d.f. = 3, $p < 0.17$) but success during Period 1 was less then run-of-river Period 3 ($X^2 = 12.05$, d.f. = 1, $p < 0.0005$), Period 4 ($X^2 = 15.03$, d.f. = 1, $p < .0001$), and Period 5 ($X^2 = 5.51$, d.f. = 1, $p < 0.02$). Success for Period 1 was below stable success rates.

Although rare, drawdowns to repair the hydroelectric projects have happened 3 times from 1992 to 2009. Tippy Dam has been drawn down twice, once in 1992 to remove a fish ladder that did not comply with the new FERC license agreement and again from 6 December 1999 to 24 March 2000 to wash away debris that had collected following removal of Stronach Dam on the Pine River. In 2009 Mio Pond was drawn down 2.44 m between 23 September 2009 to 25 November 2009 for concrete repair (Dawson unpublished data). Prior to 1992 there were no breeding attempts on Tippy Dam Pond. In 1992 there was 1 occupied nest with 2 young and from 1993 to 1995 there were 4 occupied nests with 3 young for a productivity of 0.8 young per occupied breeding area In 2000 Tippy Dam Pond had 2 nests with 3 young and a productivity of 1.5. From 1997 to 1999 those nests were occupied 6 times with 7 young and a productivity of 1.2. From 2001 to 2003 6 nests were occupied with 5 young and a productivity of 0.8. Mio Pond had 3 young on 2 nests with a productivity of 1.5 in 2010. From 2008 to 2009 it had 4 nests with 6 young and a productivity of 1.5. In 2011 Mio Pond had 1 nest with 3 young.

DISCUSSION

Many factors can impact bald eagle reproductive rates, which in turn could influence my results. OS-02 and OS-03 productivity may have been influenced by other factors that were not from changes of peaking to run-of-river flow regime. In the 1960's rotenone was used to poison Mio Pond to eradicate fish populations (Dawson unpublished data). Bowerman (1991) found productivity in nests within 3.2 km of lakes with fish removal had significantly less productivity for the year of removal and the following year.

Increased productivity could be correlated to a decrease in environmental contaminants in prey of bald eagles. Bald eagle productivity has increased since the ban of DDT and other organochlorines in the 1970s. Productivity in all areas increased at the same rate. Great Lakes' bald eagles had lower productivity because of the greater concentrations of environmental contaminants in the Great Lakes (Giesy et al. 1995; Bowerman et al. 1995; Bowerman et al. 1998). Bald eagles nesting above barrier dams had productivity of 1.24 young-per-occupied-breeding-territory on the Three Rivers compared to a productivity of 0.47 on nesting areas below the barrier dams and at nests surrounding river deltas on the Great Lakes from 1989-1993 (Datema in preparation). Productivity rates from 2004-2008 from the same nesting areas below the barrier dams increased to 1.02 (Datema in preparation). With only 3 nesting areas on the MU and 2 influenced by Great Lakes' anadromous fish runs, productivity was influenced more by decreased environmental contaminants in the Great Lakes on the MU than the AS and MA.

Bald eagles foraging on the Colorado River increased rates of foraging when water levels decreased. When water flows were elevated, bald eagles did not forage along the river but rather along adjacent, stable flowing steams (Brown et al. 1998). Flows on the Three Rivers did not fluctuate as greatly as the Colorado River when they were under peaking operations but drawdowns would have had similar effects. Bald eagles foraging on the South Fork Boise River, Idaho, concentrated foraging on pools and low turbulence runs. Runs that were slower and shallower were foraged more often than deeper, faster runs (Kaltenecker et al. 1999). Peaking flows at high water release, increase flow and water depth which may decrease foraging areas for bald eagles.

No relationships could be drawn from the minimal data collected during drawdowns but they may still have adverse effects. Although rare, drawdowns have been correlated to a decrease in osprey (*Pandion haliaeetus*) productivity (Sprandel et al. 2002). Drawdowns lead to an increase in prey abundance and availability because fish are confined to a decreased area and fish spawning areas are exposed to bald eagles in Northern California. With the decrease in reservoir surface area, competition between breeding bald eagles increases (Jackman and Hunt 2007). Water levels on Williston Reservoir, British Columbia had no or minimal impact on osprey nesting productivity (Booth and Corbould 2003). Although little can be said from only 1 drawdown during a breeding season in this study, increased prey abundance and competition may influence bald eagle productivity even when nestlings are not present.

Altered flow is detrimental to riverine habitat. Juvenile fish abundance was negatively correlated with peaking flow. Natural flow regimes had greater populations than regulated water flow on the Tallapoosa River, south east United States (Freeman et al. 2001). Salmon increased hatch rates when flows were not decreased during the day. High flows allowed for protection of fry on redds during the day time but low flow periods were detrimental on the Skagit River, Washington (Connor and Pflug 2004). A low rate of food delivery to nestling bald eagles was correlated with decreased productivity on Lake Superior shorelines (Dykstra et al. 1998). With peaking flow causing a decrease in fish populations and 90% of the Three Rivers nesting bald eagles diet composed of fish, a decrease in prey would cause adverse effects to bald eagles.

After hydroelectric projects in the study area changed from peaking to run-of-river flow regime, productivity and young increased on the MA and MU with the MU increasing dramatically. The increased productivity rates on GLI sections of the rivers coincide with the increased inland productivity from the decrease in environmental contaminants. However, based on this analysis of factors related to bald eagle reproduction, it remains uncertain that the change to run-of-river was the primary factor that increased productivity on the MA and MU. The AS had the least amount of nesting areas affected by GL contaminants and had the least change which would be expected with the analysis given.

WORKS CITED

Best DA, Bowerman WW, Kubiak TJ, Winterstein SR, Postupalsky S, Shieldcastle M. 1994 Reproductive impairment of bald eagles along the Great Lakes shorelines of Michigan and Ohio. Raptor Conservation Today 697-702.

Booth B.P. and F.B. Corbould. 2003. Abundance and Distribution of Osprey Nest Sites in the Williston Reservoir Area, North-Central British Columbia 2002. PWFWCP Report No. 277

Bowerman W. W. 1991. Factors influencing breeding success of bald eagles in upper Michigan. M.A. Thesis, Northern Michigan Univ., Marquette. 113pp.

Bowerman, W. W. 1993. Regulation of bald eagle *(Haliaeetus leucocephalus)* productivity in the Great Lakes Basin: An ecological and toxicological approach. PhD dissertation, Michigan State University, East Lansing, MI.

Bowerman, W. W., J. P. Giesy, D. Best and V. J. Kramer. 1995. A review of factors affecting productivity of bald eagles in the Great Lakes region: Implications for recovery. Environmental Health Perspectives 103: 51-59.

Bowerman, W. W., D. A. Best, T. G. Grubb, G. M. Zimmerman and J. P. Giesy 1998. Trends of Contaminants and Effects in Bald Eagles of the Great Lakes Basin. Environmental Monitoring and Assessment 53(1): 197-212.

Bowerman, D. W., A. S. Roe, M. J. Gilbertons, D. A. Best, J. G. Sikarskie, R. S. Mitchell and C. L. Summer. 2002. Using bald eagles to indicate the health of the Great Lakes' environment. Lakes & Reservoirs: Research and Management 7: 183-187.

Brown, B. T., L. E. Stevens, and T. A. Yates. 1998. Influences of fluctuating river flows on Bald Eagle foraging behavior. The Condor 100:745–748.

Connor, E. J. and D. E. Pflug. 2004. Changes in the Distribution and Density of Pink, Chum, and Chinook Salmon Spawning in the Upper Skagit River in Response to Flow Management Measures. North American Journal of Fisheries Management 24:835–852.

Cushman RM. 1985. Review of ecological effects of rapidly varying flows downstream from hydroelectric facilities. North American Journal of Fisheries Management 5: 330-339.

Datema, P. P. 2012. A Re-evaluation of Great Lakes Fish Passage and Effects on Bald Eagles Nesting along the Au Sable, Manistee and Muskegon Rivers. Thesis. Clemson University

Dawson G. 2012 Consumer Energy..

Dykstra, C.R., M. W. Meyer, D.K. Warnke, Karasov, D. E., Anerson, W. W. Bowerman and J. P. Giesy. 1998. Low reproductive rates of Lake Superior Bald Eagles: low food delivery rates or environmental contaminants? *J. Great Lakes Res.* 24:32–44.

Freeman, M. C., Z.H. Bowen, K. D. Bover and E. R. Irwin. 2001. Flow and habitat effects on juvenile fish abundance in natural and altered flow regimes. *Ecological Applications,* 11(1),:179–190.

Giesy, J. P., Bowerman, W. W., Mora, M. A., Verbrugge, D. A., Othoudt, R. A., Newsed, J. L., et al. (1995). Contaminants in fishes from Great Lakes-influenced sections and above dams of three Michigan rivers: III. Implications for health of bald eagles. Archives of Environmental Contamination and Toxicology, 29, 309–321.

Grier , J. W., J. B. Elder, F. J. Gramlich, N.F. Green, J. V. Kussman, J. E. Mathison, and J. P Mattson. 1983. Northern states bald eagle recovery plan. U.S. Fish Wildl. Serv. Reference Serv., Denver, Colo. 147pp.

Hansen, A. J. 1984. Behavioral ecology of Bald Eagles along the Pacific Northwest Coast: a landscape perspective. Dis-sertation. University of Tennessee, Knoxville, Tennessee, USA.

International Joint Commission. 1991. Proceedings of the Expert Consultation Meeting on Bald Eagles in the Great Lakes Basin (ed. M. Gilbertson). International Joint Commission, Windsor, Ontario, Canada.

Jackmanm, R. W., W. G. Hunt and N. L Hutchins 2007. Bald Eagle foraging and reservoir management in northern California. J. Raptor Res. 41:202–211.

Sprandel et al. 2002.

JMP (1989–2007) Version 8. SAS Institute Inc., Cary

Kaltenecker G. S., K.Steenhof, M. J. Bechard and J. C. Munger. 1998. Winter foraging ecology of bald eagles on a regulated river in Southwest Idaho. Journal Raptor Res. 32(3):215-220

Kurta, A., and Teramina, J. A. 1994. A novel hibernaculum and noteworthy records or the Indiana bat and Eastern pipistrelle (Chiroptera: Vespertilionidae). American Midland Naturalist 132(2):410-413.

O’Neal, R. P. 1997. Muskegon River Watershed Assessment. Michigan Department of Natural Resources, Fisheries Division. Special Report Number 19. Ann Arbor, Michigan.

Ray, D. K., Duckles, J. M. and Pijanowski, B. C. (2010) “The impact of future land use scenarios on runoff volumes in the Muskegon River watershed.” Environmental Management 46:351-366.

Rozich, T. J. 1998. Manistee River Assessment. Michigan Department of Natural Resources, Fisheries Division, Special Report Number 21. Ann Arbor, Michigan.

Shapiro, A. E., F. Montalbanoii and D. Mager. 1982. Implications of construction of a flood control project upon bald eagle nesting activity. Wilson Bull. 94:55-63.

Sprunt A IV, Robertson WB Jr, Postupalsky S, Hensel RJ, Knoder CE, Ligas FJ. 1973. Comparative productivity of six bald eagle populations. Transactions North America Wildlife Natural Recourses Conference 38:96-106.

Sprandel, G., R. Caileux, D. Cobb. 2002. Influence of a reservoir drawdown on bird use of Lake Talquin, Florida. Lake and Reservoir Management 18(2):164-176.

Stalmaster M. V. 1987. The Bald Eagle. New York, New York. Universe Books.

Wiemeyer S. N., Bunck, C. M., Stafford, C. J. 1993. Environmental contaminants in bald eagle eggs-1980-84-and further interpetations of relationships to productivity and shell thickness. Arch Environmental Contaminant Toxicology 24:213-227.

Zorn, T. G., and Sendek, S. P. 2001. Au Sable River Assessment. Michigan Department of Natural Resources, Fisheries Division, Special Report 26, Ann Arbor, Michigan.

CHAPTER FOUR

CONCLUSION

CONCLUSION

Hazard quotients (HQs) of environmental contaminants indicate that Great Lakes' fishes still have concentrations at levels that can negatively affect breeding bald eagles. TCDD-EQ HQs, extrapolated from 1990, in 2006 for all Great Lakes influenced sections on the Three Rivers were above the level for adverse effects at the population level. HQs for PCBs below barrier dams were at great enough concentrations to negatively affect individual bald eagle reproduction of those nesting on the Three Rivers and HQs for DDE were at great enough concentrations to negatively affect individual bald eagles nesting on the Manistee and Muskegon rivers. Using the bald eagle as a biomonitor, the risk assessment concludes that wildlife exposure would be significantly greater to environmental contaminants, transported by Great Lakes' fishes, if fish passage is allowed past the barrier dams on the Au Sable, Manistee and Muskegon Rivers. Therefore fish passage should not be allowed past Foote, Tippy and Croton dams. Concentrations of environmental contaminants in nestling bald eagle blood plasma confirm these results.

Throughout the study area bald eagle population nesting along the Au Sable, Manistee and Muskegon Rivers in northern Michigan has increased throughout the study area. Nesting populations along the Great Lakes and Great Lakes influenced sections of river have increased more than inland Michigan nesting areas. Productivity and success results indicate that inland nesting bald eagles are not limited by environmental contaminants and that suitable nesting areas are now the limiting factor. Inland areas have no HQs at levels detrimental to bald eagle populations. Inland populations have expanded to open nesting areas. Because the Great Lakes' nesting bald eagle population is still recovering from environmental contaminants, the shorelines are not saturated with nesting areas. Inland nesting eagles are being forced into these open territories. The inland bald eagles that have moved to the Great Lakes have less contaminants, allowing for the increased productivity and success rates recorded.

After hydroelectric projects in the study area changed from peaking to run-of-river flow regime, productivity and young increased on the MA and MU with the MU increasing dramatically. The higher productivity rates on GLI sections of the rivers coincide with the higher inland productivity associated with the decline in environmental contaminants. However, based on this analysis of factors related to bald eagle reproduction, it remains uncertain that the change to run-of-river was the primary factor led to increased productivity on the MA and MU. The AS had the fewest nesting areas affected by GL contaminants and had the least change which would be expected with the analysis given.

APPENDICES

APPENDIX A

CHAPTER TWO TABLES

Table 2.1. Environmental contaminants in whole fish samples from the Au Sable, Manistee and Muskegon Rivers. Samples from 1990 (Giesy et al., 1994). 2000 and 2006 samples (Consumers Energy, 2008). All contaminants in ug/kg ww (wet weight).

River	Location	Year	Species	Mercury	Total PCB	DDT/DDE	Dieldrin
Au Sable (AS)	IN	1990	pike	0.28	0.07	0.01	0.01
			walleye	0.42	0.26	0.02	0.01
			w. sucker	0.05	0.06	0.01	0.01
			b. trout	0.45	0.06	0.02	0.01
			walleye	0.41	0.07	0.02	0.01
			w. sucker	0.13	0.05	0.01	0.01
		2000	w. sucker	0.37	0.06	0.01	0.00
			walleye	1.14	0.11	0.02	0.00
		2006	w. sucker	0.08	0.06	0.01	0.00
			walleye	0.43	0.20	0.02	0.00
Manistee (MA)		1990	b. trout	0.27	0.02	0.01	0.00
			pike	0.19	0.02	0.02	0.00
			w. sucker	0.08	0.01	0.00	0.00
		2000	w. sucker	0.32	0.02	0.00	0.00
			walleye	0.78	0.08	0.03	0.00
		2006	w. sucker	0.10	0.00	0.01	0.00
			walleye	0.29	0.04	0.00	0.00
Muskegon (MU)		1990	carp	0.05	0.16	0.06	0.00
			perch	0.05	0.07	0.19	0.02
			walleye	0.72	0.37	0.08	0.02
		2000	w. sucker	0.43	0.12	0.03	0.00
			walleye	1.11	0.10	0.02	0.00
		2006	w. sucker	0.20	0.06	0.02	0.00
			walleye	0.40	0.16	0.04	0.00
Au Sable (AS)	GLI	1990	chinook	0.20	1.70	0.36	0.21
			pike	0.11	0.72	0.09	0.04
			walleye	0.05	2.20	0.18	0.07
			w. sucker	0.05	0.37	0.08	0.05
			w. sucker	0.05	0.46	0.12	0.07
		2000	steelhead	0.26	0.35	0.10	0.01
			w. sucker	0.30	0.40	0.09	0.01
			walleye	0.25	0.66	0.08	0.01
		2006	steelhead	0.07	0.17	0.03	0.00

		w. sucker	0.13	0.25	0.04	0.00
		walleye	0.24	1.07	0.19	0.00
Manistee (MA)	1990	pike	0.27	1.30	0.28	0.11
		steelhead	0.26	3.90	0.98	1.06
		w. sucker	0.09	0.66	0.19	0.20
	2000	steelhead	0.17	0.78	0.22	0.03
		w. sucker	0.35	0.62	0.18	0.01
		walleye	0.46	0.35	0.96	0.00
	2006	steelhead	0.03	0.39	0.11	0.01
		w. sucker	0.13	1.08	0.32	0.01
		walleye	0.27	2.29	0.48	0.01
Muskegon (MU)	1990	carp	0.23	6.00	0.77	0.60
		perch	0.73	0.77	0.03	0.30
		walleye	0.39	3.50	0.72	0.45
	2000	steelhead	0.17	1.17	0.44	0.02
		walleye	0.38	1.25	0.33	0.02
		w. sucker	0.44	0.44	0.12	0.01
	2006	walleye	0.26	1.64	0.38	0.02
		w. sucker	0.19	0.54	0.14	0.00
		steelhead	0.05	0.65	0.17	0.02

Table 2.2. Sum PCBs in nestling bald eagle plasma in Michigan from Great Lakes and Inland collected from 1999-2008. All samples ug/kg ww.

Location	Period	Sum PCBs averages
Inland	1 (1999-2003)	7.0 ± 4.1
	2 (2004-2008)	2.8 ± 5.9
Great Lakes	1 (1999-2003)	40.3 ± 4.7
	2 (2004-2008)	44.6 ± 4.0

Table 2.3. Total DDE in nestling bald eagle plasma in Michigan from Great Lakes and Inland collected from 1999-2008. All samples ug/kg ww.

Location	Period	Total DDE averages
Inland	1 (1999-2003)	4.5 ± 2.1
	2 (2004-2008)	2.9 ± 3.0
Great Lakes	1 (1999-2003)	28.1 ± 2.4
	2 (2004-2008)	24.2 ± 2.1

Table 2.4. Dieldrin in nestling bald eagle plasma in Michigan from Great Lakes and Inland collected from 1999-2008. All samples ug/kg ww.

Location	**Period**	**Dieldrin averages**
Inland	1 (1999-2003)	.00001 ± 0.4
	2 (2004-2008)	0.3 ± 0.6
Great Lakes	1 (1999-2003)	0.8 ± 0.5
	2 (2004-2008)	2.7 ± 0.4

Table 2.5. Bald eagle productivity, nesting success, occupied nest and young for the study area for Period 1(1989-1993), Period 2 (1994-1998), Period 3 (1999-2003) and Period 4 (2004-2008) in Michigan for 4 Locations, Anadromous fish run sections of the Three Rives, Inland sections of the Three Rivers not effected by anadromous fish runs, Great Lake Influenced section including Great Lakes shorelines and Anadromous section of the Three Rivers, and Great Lakes area which include all nesting areas within 8 km of the Great Lakes shoreline. Productivity = young/ occupied nest. Success = nests with at least 1 fledged young/ occupied nesting areas

Location		**P1 1989-1993**	**P2 1994-1998**	**P3 1999-2003**	**P4 2004-2008**
Anadromous(AN)	Productivity[1]	0.56	1.38	1.20	1.08
	Success[2]	44%	79%	76%	68%
	Occupied Nests	9	24	25	25
	Young	5	33	30	27
Inland (IN)	Productivity[1]	1.24	1.11	1.24	1.00
	Success[2]	78%	64%	69%	70%
	Occupied Nests	51	56	67	74
	Young	63	61	83	74
Great Lakes	Productivity[1]	0.47	1.33	1.04	1.02
Influenced (GLI)	Success[2]	35%	78%	66%	65%
	Occupied Nests	17	40	68	110
	Young	8	53	71	112
Great Lakes (GLA)	Productivity[1]	0.38	1.25	0.95	1.00
	Success[2]	25%	75%	60%	65%
	Occupied Nests	8	16	43	85

Young	3	20	41	85

[1]Number of Fledged Young/Occupied Breeding Area

[2]Proportion of occupied nests producing at least 1 fledged young.

Table 2.6. Hazard Quotients (HQs) Fish samples acquired from 1990 (Geisy et al.,1994) 2000 and 2006 (Consumers Energy, 2008). Toxic Reference Values on Table 4.Hazard quotient (HQ = [Fish Contaminant Concentration*Bio Magnification Factor(BMF)] / [Dietary No Observable Adverse Effect Concentration (NOAEC)])

	IN			GLI		
Contaminant/River	1990	2000	2006	1990	2000	2006
HQ Total PCB						
Au Sable	0.4	0.6	0.9	7.6	3.3	3.5
Manistee	0.1	0.4	0.2	13.5	4.1	8.8
Muskegon	1.4	0.8	0.8	23.9	6.7	6.6
HQ DDT/DDE						
Au Sable	0.1	0.1	0.1	0.8	0.6	0.5
Manistee	0.1	0.1	0	2.4	2.8	1.9
Muskegon	0.5	0.2	0.2	2.5	1.9	1.4
HQ Dieldrin						
Au Sable	0.1	0.1	0	2.4	0.5	0
Manistee	0	0	0	3.3	0.8	0.7
Muskegon	0.1	0.1	0	3.2	1.2	0.8
HQ TCDD-EQ						
Au Sable	2	2.3	2.4	26.8	24	22.3
Manistee	2	2.3	2.4	59.5	55.9	53.7
Muskegon	1.9	1.5	1.2	75.7	64.2	57.3
HQ Mercury						
Au Sable	0.7	1.5	0.5	0.2	0.5	0.3
Manistee	0.4	1.1	0.4	0.4	0.7	0.3
Muskegon	1	1.5	0.6	0.4	0.7	0.3

Table 2.7. Toxic Reference Values (TRV) for environmental contaminants.

Toxin	TRV mg/kg	End Point	Location	Reference
Total PCBs	4.0 egg	Egg lethality	US(15states)	Wiemeyer 1990
Total PCBs	0.14 Dietary	Egg lethality	3 rivers	Giesy et al. 1995
p'p'DDE	3.5 egg	productivity	14 states	Wiemeyer et al.1984
p'p'DDE	0.16 Dietary	productivity	3 rivers	Giesy et al 1995
Dieldrin	0.1 egg	Egg lethality	14 states	Wiemeyer et al 1984
Dieldrin	$1.4*10^{-2}$ Dietary	Egg lethality	3 rivers	Giesy et al 1995
TCDD-EQ	$7*10^{-6}$ egg	Egg lethality	Arkansas	White and Seginik 1994
TCDD-EQ	$3.7*10^{-7}$ Dietary	Egg lethality	3 Rivers	Giesy et al 1995

APPENDIX B

CHAPTER THREE TABLES

Table 3.1. Bald eagle productivity, success, number of occupied breeding areas, and number of fledged young for nests located along the Au Sable River, Michigan for 5 periods[3].

	Productivity[1]	Success[2]	Occupied Breeding Areas	Fledged Young
Period 1	0.71	43%	21	15
Period 2	1.09	70%	23	25
Period 3	1.04	57%	28	29
Period 4	1.11	65%	37	41
Period 5	1.13	75%	32	36

[1]Number of Fledged Young/Occupied Breeding Area

[2]Proportion of occupied nests producing at least 1 fledged young.

[3]Breeding areas OS-02, OS-03 Period 1, 1961-1965, Period 3, 1966-1970, Period 4, 1971-1975 all other nesting area periods were Period 1, 1984-1988, Period 2, 1989-1994, Period 3, 1994-1998, Period 4, 1999-2003 and Period 5, 2004-2008.

Table 3.2. Bald eagle productivity, success, number of occupied breeding areas, and number of fledged young for nests located along the Manistee River, Michigan for 5 periods[3].

	Productivity[1]	Success[2]	Occupied Breeding Areas	Fledged Young
Period 1	0.33	33%	6	2
Period 2	1.00	50%	10	10
Period 3	1.06	59%	17	18
Period 4	1.30	70%	30	39
Period 5	1.06	69%	32	34

[1]Number of Fledged Young/Occupied Breeding Area

[2]Proportion of occupied nests producing at least 1 fledged young.

[3]Period 1, 1979-1983, Period 2, 1984-1988, Period 3, 1989-1994, Period 4, 1994-1998 and Period 5, 1999-2003.

Table 3.3. Bald eagle productivity, success, number of occupied breeding areas, and number of fledged young for nests located along the Muskegon River, Michigan for 5 periods[3].

	Productivity[1]	Success[2]	Occupied Breeding Areas	Fledged Young
Period 1	0.25	13%	8	2
Period 2	0.78	67%	9	7
Period 3	1.53	87%	15	23
Period 4	1.47	93%	15	22
Period 5	1.07	64%	14	15

[1]Number of Fledged Young/Occupied Breeding Area

[2]Proportion of occupied nests producing at least 1 fledged young.

[3]Period 1, 1984-1988, Period 2, 1989-1994, Period 3, 1994-1998, Period 4, 1999-2003 and Period 5, 2004-2008.

APPENDIX C

STUDY AREA

Figure 1. The location of the Au Sable, Manistee, and Muskegon Rivers in the northern Lower Peninsula of Michigan, where Consumers Energy hydroelectric projects are located.