Assessment of Remnant Lake Sturgeon Populations in the Green Bay Basin,

2002-2003

Report to the Great Lakes Fishery Trust

Project Number 2001.113

Principal Investigators:

Robert Elliott and Brian Gunderman	920-866-1762 (voice)
U.S. Fish and Wildlife Service	920-866-1710 (fax)
2661 Scott Tower Drive	robert_f_elliott@fws.gov (email)
New Franken, WI 54229	brian_gunderman@fws.gov (email)
Rod Lange and Terry Lychwick (retired)	920-448-5127 (voice)
Wisconsin Department of Natural Resources	920-448-5129 (fax)
P.O. Box 10448	langer@dnr.state.wi.us (email)
Green Bay, WI 54307-0448	Lychwt@itol.com (email)
Tom Meronek and Greg Kornely	715-582-5052 (voice)
Wisconsin Department of Natural Resources	715-582-5005 (fax)
P.O. Box 208	Thomas.Meronek@dnr.state.wi.us (email)
Peshtigo, WI 54157	Gregory.Kornely@dnr.state.wi.us (email)

Report prepared by

Brian Gunderman and Robert Elliott

2004

Abstract

Habitat loss and overharvest during the late 1800s dramatically reduced lake sturgeon populations in Lake Michigan. There is currently widespread interest in rehabilitating sturgeon populations, but information regarding the abundance, distribution, and population dynamics of remaining populations is required for restoration efforts to be successful. The objectives of this study were to (1) estimate the abundance of adult lake sturgeon during the spawning run in four Green Bay tributaries, (2) describe and quantify reproductive success in these rivers, (3) describe spawner habitat availability and use in these systems, (4) determine the distribution and contribution of discrete spawning stocks to the mixed population of sturgeon inhabiting Green Bay, and (5) estimate the overall population size of lake sturgeon residing in Green Bay. From 1997-2003, over 450 sturgeon were captured using a variety of gear types. Run size estimates ranged from approximately 25 individuals in the Oconto River to ≥200 individuals in the Peshtigo and Menominee rivers. Larvae were produced in all four rivers, but relative abundance varied between systems. The amount of suitable spawning habitat ranged from 6-7 ha in the Fox and Peshtigo rivers to >18 ha in the Oconto and Menominee rivers. The mixed population in lower Green Bay is dominated by younger individuals (≤15 years), and preliminary estimates indicate a population size of approximately 2000 sturgeon (≥112 cm total length). Analysis of genetic samples collected during this study indicate that spawning populations are genetically structured. Specifics of the genetic analysis including preliminary results of mixed stock analysis and assignment tests are presented in the accompanying report by Scribner et al.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Page Number

Introduction

The lake sturgeon (*Acipenser fulvescens*) was historically abundant in Lake Michigan, with populations spawning in many of the major tributaries and on some shoal areas. Through the mid 1800s, they were a dominant component of the near-shore benthivore fish community. Although the exact size of the historic population is unknown, evidence from commercial catch records suggests that Lake Michigan may have supported a population of 11 million individuals (Hay-Chmielewski and Whelan 1997). Lake sturgeon were particularly abundant in the shallow productive waters of Green Bay and its surrounding tributaries, and the species held a special place in the culture of the local peoples.

The decline of lake sturgeon populations in the late 1800s was rapid and commensurate with habitat destruction, degraded water quality, and intensive fishing associated with settlement and development of the region. In a span of less than 50 years, beginning in the mid 1800s, their consideration as a species transitioned from a nuisance species of high abundance, to a highly desired commercial species, and then to a depleted species of little consequence. Lake sturgeon are now considered rare, endangered, threatened, or of watch or special concern status by the various fisheries management agencies, and their harvest from the lake and tributary waters is banned or highly limited. Currently, the most optimistic estimate of the lake-wide stock abundance is well below 1% of the most conservative estimates of historic abundance.

The lake sturgeon is the largest fish species native to the Great Lakes. The largest well-authenticated specimen, collected from Lake Michigan in 1943, measured 2.4 m and 140 kg, but commercial catch records suggest that even larger sturgeon may once have inhabited the Great Lakes (Harkness and Dymond 1961; Van Oosten 1956). The lake sturgeon is also the longest-lived freshwater fish in the world (Baker 1980). Individuals in excess of 50 years of age are commonly reported, and one individual from Lake of the Woods (Ontario) was estimated to be 152 years old (Van Oosten 1956).

Most lake sturgeon inhabiting the Lake Michigan basin are potamodromous, being born in rivers, spending most of their lives in the open waters of Lake Michigan, and returning to their native rivers to spawn in the spring (Hay-Chmielewski and Whelan 1997; Lyons and Kempinger 1992). Age at first spawning varies considerably for the species, but males usually spawn for the first time at age 12-22 and females at age 14-33 (Roussow 1957, Harkness and Dymond 1961). Spawning periodicity also varies, with males spawning once every 1-4 years and females every 3-7 years (Auer 1999, Lyons and Kempinger 1992). Their late age of maturity and infrequent spawning after maturity make lake sturgeon particularly vulnerable to overexploitation.

History

The Native American tribes surrounding Green Bay held lake sturgeon in high esteem, and relied upon them heavily for food and other products. Father Claude Allouez, an early missionary to the area, documented the construction of elaborate weirs for capturing lake sturgeon in the lower Fox River (Bieder 1995, Martin 1913). Missionaries to the Door Peninsula also referred to the area where the town of Sturgeon Bay now stands as "*La Portage des Eturgeons*", revealing the importance of lake sturgeon to the local peoples. Other sources indicate the importance of lake sturgeon to Native Americans. A Menominee fable, "The Battle of the Pierced Forehead", records the construction of a rock dam by one village to block sturgeon during their upstream spawning migration on the Menominee River (Kort 1984). According to the fable, the inhabitants of a village farther upstream, who were depending upon the sturgeon to prevent starvation after a long winter, asked the chief of the downstream village to let some sturgeon pass through the dam. When the chief refused, warriors from the upstream village attacked and destroyed the tribe that had constructed the dam.

Early European settlers of the region often did not share the native peoples' appreciation of lake sturgeon. In fact, most commercial fishers despised sturgeon because they ruined nets designed to catch more desireable species such as lake whitefish (*Coregonus clupeaformis*) and lake trout (S*alvelinus namaycush*). Lake sturgeon were clubbed to death, buried as fertilizer, and even used to fire steamboat boilers (Brousseau 1987). In many places, sturgeon carcasses were stacked like cordwood along the shore to dry before being burned (Tody 1974). By the 1860s, attitudes toward sturgeon had changed, and the production of caviar and smoked sturgeon flesh turned the lake sturgeon into one of the most commercially valuable fishes in Lake Michigan. As the market value of lake sturgeon increased, so did the number of fishermen targeting them. In 1879, the first year that records were kept, 3.8 million pounds of sturgeon were harvested from Lake Michigan (Baldwin et al. 1979; Figure 1). (It is believed that sturgeon populations had already begun to decline by this time, so harvest may have been even higher earlier in the decade.) In Marinette County (Wisconsin) alone, more than 51,000 lbs of lake sturgeon were harvested in 1884 (Smith and Snell 1891). Unfortunately, lake sturgeon populations were unable to support such intensive exploitation. Sturgeon populations around the lake crashed, and by 1928 the commercial harvest in Lake Michigan had declined to a mere 2,000 pounds (Baldwin et al. 1979).

Water pollution was another major factor in the decline of lake sturgeon. For example, the first saw mill was built on the Menominee River in 1832, and by 1867 numerous mills were operating on each side of the river (Emich 1987). The resulting deposition of large quantities of sawdust into the river, in concert with commercial overfishing, apparently ruined many of the local fisheries by 1870 (Thuemler and Schnicke 1992).

Dam construction on spawning tributaries also contributed to population declines. These dams originally were built to assist logging operations, but many eventually were converted to hydropower dams. Lake sturgeon require swift moving water and a rocky substrate for spawning. Such high gradient areas are where dams are typically constructed. On the Menominee River, over 70% of the high-gradient habitat once used by lake sturgeon is now impounded (Thuemler and Schnicke 1992). Even when suitable spawning habitat remains upstream, dams prevent sturgeon from reaching these areas. In addition, "peaking" flows from hydropower dams have been shown to be detrimental to lake sturgeon reproduction (Auer 1996).

<u>Current Status</u>

Despite closure of the commercial fishery for sturgeon and recent improvements in water quality, lake sturgeon populations throughout the Great Lakes remain severely depressed. The lake sturgeon is now listed as threatened or endangered in 19 of 20 states in its original range (Hill and McClain 1999) , is protected in seven of the eight states bordering the Great Lakes (Auer 1999a), and is considered a Federal species of concern by Region 3 of the U. S. Fish and Wildlife Service.

The largest remaining populations of lake sturgeon in Lake Michigan occur in tributaries entering southern Green Bay. The lower Menominee River is thought to support the largest population with free access to Green Bay. Two upstream populations also exist, isolated from Green Bay and each other by hydropower dams. A small number of lake sturgeon are observed every spring in the lower Fox River, and remnant populations of lake sturgeon are known to exist in the Peshtigo and Oconto Rivers. These four remnant populations were the focus of this study.

Project Objectives

Efforts to rehabilitate the lake sturgeon in the waters of Green Bay require accurate information on the characteristics and dynamics of the populations persisting in the basin. The objectives of this study were to (1) estimate the abundance of adult lake sturgeon during the spawning run in four Green Bay tributaries (Fox, Oconto, Peshtigo and Menominee rivers), (2) describe and quantify reproductive success in these rivers, (3) describe spawner habitat availability and use in these systems, (4) determine the distribution and contribution of discrete spawning stocks to the mixed population of lake sturgeon inhabiting Green Bay, and (5) estimate the overall population size of sturgeon residing in Green Bay.

Study Site

Green Bay

Green Bay is a long, narrow extension of northwestern Lake Michigan, with a length of 193 km and mean width of 22 km. Overall mean water depth is 20 m, however, the southern half of the bay is considerably shallower (generally <20 m) and more eutrophic than the northern half. The Green Bay watershed covers an area of 40,778 km^2, approximately one-third of the entire Lake Michigan basin. The southern end of the watershed is heavily industrialized, but the northern portion is more sparsely populated. There are eight tributaries that empty into southern Green Bay, four of which support remnant lake sturgeon populations.

Fox River

The Fox River is the largest tributary to Green Bay, with a mean discharge* of 138 m^3/s (4,889 cfs; Figure 2). The lower portion of the Fox River flows through the city of Green Bay (population = 102,000), and there is extensive industrial development throughout this section. Though much of the river is shallow (<3 m), a dredged shipping channel (>5 m) extends from the river mouth upstream to De Pere Dam. De Pere Dam (river kilometer [RKM] 11) serves as the current barrier to lake sturgeon migrating upstream from Green Bay. A large sturgeon population (~50,000 adults; Bruch 1999) exists upstream in Lake Winnebago, and the downstream movement of Lake Winnebago sturgeon into the lower Fox River has been observed.

Oconto River

The Oconto River (mean discharge = 14 m^3/s [489 cfs]; United States Geological Survey) is the smallest river examined during this project. From the 1890s to the late 1970s, pulp mill effluent severely degraded fish habitat in the lower Oconto River, but restoration efforts during the 1980s resulted in considerable improvements in water quality (Rost et al. 1989). Stiles Dam (RKM 22) is currently an upstream barrier to fish passage on the Oconto River. There is uncertainty as to what may have been the historic barrier to upstream migration (possibly Oconto Falls [RKM 32]), but no known populations of lake sturgeon now exist upstream of Stiles Dam.

Peshtigo River

The lower Peshtigo River (mean discharge = 26 m^3/s [912 cfs]) has the least residential and industrial development of the four study rivers. Unlike the other three rivers, whose estuaries have been largely sea-walled or riprapped, the Peshtigo River ends in a large natural marsh. Though lake sturgeon historically may have migrated upstream as far as Johnson Falls (RKM 96; FERC 1996), their migrations now are limited to the 12 km stretch of river below Peshtigo Dam.

* Discharge data for all four Green Bay tributaries was obtained from U. S. Geological Survey gaging stations.

Menominee River

The Menominee River forms the boundary between Wisconsin and the upper peninsula of Michigan. Only 3.9 km of the Menominee River (mean discharge = 91 m^3/s [3,214 cfs]) is accessible to lake sturgeon migrating from Green Bay. This portion of the river divides the towns of Marinette (Wisconsin) and Menominee (Michigan), and the lower 2 km of this section are dredged to allow shipping traffic. Menominee Dam now forms a barrier to upstream migrations, but lake sturgeon historically migrated as far upstream as Sturgeon Falls (RKM 125; Thuemler 1997). Reproducing populations of lake sturgeon still exist as far upstream as White Rapids Dam (RKM 81), and young sturgeon have been stocked into the further upstream river section below sturgeon falls for several years. Some downstream movement of sturgeon from these upper river sections into lower sections of the river has been documented (Thuemler 1997; Greg Kornely, personal communication).

Methods

Spawning Run Assessments

A variety of methods were used to collect and determine the abundance of adult lake sturgeon returning to spawn in these Green Bay tributaries. Surveys were first initiated in 1997 when electrofishing gear was used to collect adult lake sturgeon from below the first dams in the Fox, Oconto, Peshtigo and Menominee rivers during the spring spawning migration. In 1998-2001, dip nets were used to collect lake sturgeon below the first dam on the Fox and Peshtigo rivers during the peak of the spawning runs. In 2002-2003, large-mesh (20.3 cm to 35.6 cm stretch mesh) gill nets were set at the mouths of the Peshtigo and Oconto rivers and in deep pools within the Fox, Oconto, and Peshtigo rivers from late April through May. Setlines baited with 3 cm chunks of white sucker (*Catostomus commersoni*) and round goby (*Neogobius melanostomus*) flesh also were deployed at these locations. (The setlines used during this project were similar to those described by Thomas and Haas [1999], however, hooks of various sizes were used in an attempt to capture a wider size range of lake sturgeon.) Electrofishing surveys also were conducted below the lowermost dams on the Oconto and Peshtigo

Rivers during May of 2002-2003, and a single electrofishing survey was conducted below Menominee Dam in the Menominee River during June 2002. Visual observations of lake sturgeon on the spawning grounds below De Pere Dam on the Fox River were recorded from mid-April through May during all years, on the Peshtigo River during 2002-2003, and periodically on the Oconto and Menominee rivers.

Captured lake sturgeon were measured for total length, fork length, maximum girth, and weight. A tissue sample was taken from the caudal or dorsal fin for genetic analyses, and fish were examined for deformities, lamprey marks (classified according to King and Edsall [1979]), cut fins, and any other signs of injury. When possible, the sex of the fish was determined by massaging the area anterior to the vent (milt expressed = male). Each fish was tagged with PIT (passive integrated transponder) and Floy (T-bar anchor) tags prior to release.

Larval Sampling

Larval sturgeon were collected in each of the study rivers using D-frame drift nets (bottom width = 76 cm, height = 53 cm, length = 3.4 m, mesh size (net) = 16 mm, and mesh size (bucket) = 333 μm or 1000 μm). Whenever possible, the nets were set on the bottom in shallow water areas (<1 m water depth). Drift of larval sturgeon in the Wolf River was determined to be greatest between 21:00-04:00 (Kempinger 1988), so most sampling was conducted during these hours. Captured sturgeon were measured for total length prior to release, and a sub-sample of larval sturgeon was preserved in ethanol for subsequent genetic analyses.

When the dates of lake sturgeon spawning events were known, cumulative daily water temperature units (CTUs; Kempinger 1988) were used to predict larval emergence dates. CTUs also were used to link captured yolk-sac larvae to specific spawning events.

Fox River

Larval drift sampling on the Fox River was conducted in coordination with researchers from Stantec Consulting Services, Inc. In 2002, drift nets were set on three nights during the period when larvae from one of the larger spawning events were predicted to start drifting downstream. In 2003, drift nets were deployed nightly from 13 May through 01 June. All larval drift sampling on the Fox River was conducted within 300 m of the spawning grounds below De Pere Dam (Figure 3).

Oconto River

Drift net sampling also was conducted on the Oconto River from 04-21 June 2002. Most drift netting effort was concentrated at a site approximately 350 m below Stiles Dam, but on two occasions drift nets were deployed at another site approximately 8 km farther downstream (Figure 4). During the 2003 field season, drift netting was conducted only at the upstream site from 12 May through 08 June.

Peshtigo River

Drift net sampling for larval lake sturgeon on the Peshtigo River began on 21 May and continued through 20 June, 2002. Nets were set immediately below the spawning site and at various locations farther downstream in an effort to track the downstream movement of larval sturgeon (Figure 5). In 2003, drift net sampling began on 11 May and concluded on 12 June. One upstream and two downstream sites were monitored on a nightly basis during the 2003 larval drift sampling period.

Menominee River

Larval sampling on the Menominee River was conducted on four nights between 27 May and 04 June, 2003. All drift nets were deployed at a site approximately 700 m downstream of Menominee Dam (Figure 6).

<u>Spawning Habitat Assessment</u>

The Oconto, Peshtigo, and Menominee Rivers were surveyed for potential lake sturgeon spawning habitat during September-November, 2002-03. A section of river was classified as a potential sturgeon spawning site if it possessed the following two characteristics: predominantly rocky substrate (Wentworth scale categories = boulder, cobble, and pebble) and moderate to high current velocity. Depth, current velocity, and substrate type were recorded along transects throughout each site. The coordinates for the upstream and downstream boundaries of the sites were recorded, and area calculations were performed in Terrain Navigator®. Portions of sites that were unsuitable for lake sturgeon spawning (e.g. vegetated or silty areas) were not included in area calculations.

Researchers from Stantec Consulting Services, Inc. completed substrate mapping of the known spawning grounds below De Pere Dam on the Fox River during April-May, 2002-03 (Stantec Consulting Services, Inc. 2003). Data from these surveys were used to estimate the total area of potential spawning habitat in the lower Fox River.

Egg mats (furnace filter wrapped around a concrete block) were deployed at three suspected or potential spawning locations on the Oconto and Peshtigo Rivers beginning 30 April, 2003 (Figures 7 and 8). At each location, three strings of mats (ten mats per string, ten feet between mats; 30 mats total per site) were set across the river covering the suspected spawning area. In addition, a limited number of egg mats were placed at known spawning locations to evaluate the utility of the mats for collecting sturgeon eggs.

Non-spawning River Assessments

Adult and juvenile lake sturgeon also were collected and sampled during summer and fall in the study rivers using a variety of methods. During late July-early August 2002, setlines were deployed in the Menominee River and at the mouth of the Peshtigo River. Each setline included 10 to 20 hooks spaced 3 m apart. Four different styles of hooks and two different types of twine were used to construct the snews, and the hooks were baited with chunks of white sucker flesh.

From 10 October to 15 November 2002, setlines and monofilament gill nets (25.4 cm and 30.5 cm stretch mesh) were used to capture lake sturgeon at the mouth of the Peshtigo River. During this period, three different styles of hooks were used on the setlines. Two different types of cut bait were used on the setline hooks: round goby and white sucker. Each setline (61 m in length; 20 hooks) was attached to a gill net of the same length to facilitate evaluation of the effectiveness of the two gear types for capturing lake sturgeon. The position of the setline and gill net relative to shore (i.e. inshore or offshore) was alternated to reduce bias associated with gear location. Setlines also were deployed in deep pools in the Peshtigo River during fall 2002. During October-November 2003, monofilament gill nets (25.4-35.6 cm stretch mesh) again were used to collect lake sturgeon at the mouth of the Peshtigo River, but no setlines were deployed during this period.

During September-October 2001, biological data and samples from sturgeon harvested in the Menominee River during an open hook and line season were collected by the Wisconsin Department of Natural Resources (WDNR). Additional data and samples were collected in 1999-2001 by volunteer recreational anglers from sturgeon they caught and released during the open fishing season.

Processing of captured lake sturgeon was similar to that conducted during the spawning run assessments (see above). In addition, a 1-cm section of the leading ray of the right pectoral fin was removed from most of the lake sturgeon captured and/or processed by agency biologists for age determination.

Open Water Assessments

Targeted sampling of the mixed stock of lake sturgeon in the open waters of Green Bay was conducted using commercial trap nets, gill nets and set lines. With assistance from a local commercial fishing business, four (2002) and six (2003) large commercial trap nets (leads = 305 m, pot mesh = 11.4 cm, lead mesh = 35.6 cm; hood mesh = 17.8 cm for nylon nets and 35.6 cm for Marlex nets) were set and fished continuously from 14 May to 06 July, 2002 and from 03 May to 01 July, 2003. The nets typically were lifted every 3-6 days, and all lake sturgeon were removed from the pot, processed and released. A small skiff was used during every lift to check for and remove any sturgeon entangled in the hearts of each net.

In 2002 and 2003, gill nets (20.3 cm to 35.6 cm stretch mesh) were set near the trap net leads on several occasions, and in 2002, a setline (described by Thomas and Haas [1999]) also was set once near the Peshtigo Bank Net. During August 2001, gill nets and set lines targeting sturgeon were set at several sites in the open wates of southern Green Bay. Locations targeted during these open water surveys were selected based on results from prior telemetry surveys (Elliott 1998) while accomodating logistic constraints of how far survey vessels could travel in a day from their home port and the minimum depths in which the trap nets could be set without posing a navigation hazard.

With the assistance from another commercial fisher, bottom-set gill nets (11.6-cm stretch mesh) were set under the ice in southeastern Green Bay during early March 2003 (Figure 9). These nets were lifted every 2-3 days during the two-week sampling period.

For all open water collections, the date, time, location (latitude and longitude using a GPS) total length, fork length, maximum girth, weight and the presence and type of lamprey scars, fin cuts, deformities, and other abnormalities were recorded for each lake sturgeon captured. In addition, a tissue sample was taken from the caudal or dorsal fin for subsequent genetic analyses and a 1-cm section of the leading ray of the right pectoral fin was removed from representative sized individuals for age determination. Each fish also was checked for an existing tag and was then marked with a PIT and Floy tag. So as not to subject captured fish to the possibility of immediate recapture in fixed location gear, sturgeon were transported and released a suitable distance away from their location of capture.

<u>Incidental Captures</u>

To gain additional information regarding the abundance, distribution, and movements of sturgeon in Lake Michigan, data were opportunistically collected from lake sturgeon caught by commercial fishers and agency assessment crews while targeting other species. Fishing gear included gill nets, trap nets, pound nets and trawls targeting lake whitefish, lake trout, yellow perch (*Perca fulvescens)* and bloater chub (*Coregonus hoyi*).

Agency assessment crews and volunteer commercial fishers were provided a kit containing materials necessary to collect the desired biological information. The kits included a soft measuring tape, scissors, a pencil, a postage-paid return envelope, an instruction sheet and pre-printed data envelopes to record the necessary information and hold tissue samples. Disposable cameras were included in some of the kits given to fishers who encountered sturgeon more frequently. Kits were first distributed to commercial fishers and agency assessment crews in 2001, and continue to be distributed as additional volunteers are recruited.

Total length and maximum girth were recorded for most lake sturgeon, and fork length and weight were recorded for some individuals. If a fish had an external tag, the tag type, number, address, and placement were noted. Abiotic information collected included date, collector, general location, latitude and longitude, lake depth, and gear type. A small piece of the caudal fin was removed from most lake sturgeon for subsequent genetic analyses, and pectoral spine samples were taken from some individuals for age determination.

During 2002-2003, data also were collected from a number of dead sturgeon found by agency personnel and private citizens. Whenever possible, these fish were measured, checked for PIT and Floy tags, sampled for genetics, and examined to determine sex and maturity stage. Pectoral spine samples also were collected from several individuals for age determination. Fresh specimens were examined for obvious causes of mortality, and stomach, liver, and intestine samples from these fish were sent to Cornell University to be tested for botulism. Steaks (7.5 cm wide; removed from the middle of the body) also were collected from fresh specimens for contaminants analyses.

Age Determination

Pectoral fin ray samples were allowed to air dry for at least four weeks prior to analysis. Two or more cross-sections were obtained from each sample using an Isomet low-speed diamond-bladed saw (speed-setting = 7; about 200 rpm), and the cross-sections were examined on a microfiche reader at 42x magnification. Cross-sections used for age determination were approximately 300 μm in thickness. Age was assigned based on counts of annuli conducted by two independent readers. When results from each reader differed, the samples were re-aged until agreement was reached as to what the assigned age should be.

Size-at-age data for 102 lake sturgeon, captured in Green Bay and surrounding tributaries, was used to develop equations relating total length and weight to fish age. These equations were then used to estimate ages for lake sturgeon from which pectoral spine samples were not collected.

To evaluate the potential aging error associated with the location where the cross-section was taken from the fin ray, entire pectoral fin rays were removed from seven dead lake sturgeon encountered in Green Bay during 2001-2003. Four entire fin rays also were obtained from the Grand Traverse Band of Ottawa and Chippewa Indians Conservation Department. Cross-sections were taken from five different locations on each ray (locations reported as distance from fin joint): 5 mm (normal location), 10 mm, 15 mm, 25 mm, and 35 mm. Cross-sections were placed in randomly numbered envelopes to prevent the reader from knowing where the cross-section was taken. The number of annuli on each cross-section was counted, and the percent error was calculated using the formula

$$\text{Percent Error} = (\text{Age}_{5\text{ mm}} - \text{Age}_d)/\text{Age}_{5\text{ mm}} * 100$$

where d = distance from fin joint. A few cross-sections were taken <5 mm from the fin joint, but the presence of a large blood vessel in this area made age determination difficult.

Data Analysis and Statistical Tests

For river assessments, two sample t-tests were used to check for differences in total lengths of lake sturgeon between sampling years and Kruskal-Wallis One-way ANOVA tests were used to compare total lengths for lake sturgeon captured in the different rivers. When differences were detected, Mann-Whitney U-tests (with adjusted alpha) were used to determine which groups differed significantly from each other.

To evaluate body condition of lake sturgeon in each river, relative condition factors (K_n) were obtained using the equation

$K_n = W/W'$

where W is weight of the individual in kg, and W' is the length-specific mean weight for a fish in the Green Bay basin (Le Cren 1951). (W' was calculated using a weight-length equation derived from total length and weight data for 575 lake sturgeon captured in Green Bay and surrounding tributaries during 1996-2003.) To facilitate comparisons between Green Bay basin sturgeon populations and lake sturgeon from other waterbodies, Fulton-type condition factors also were calculated using the formula

$K = \text{weight}/(\text{total length})^3 \times 100{,}000$

where weight is in kg and total length is in cm (Murphy and Willis 1996; Power and McKinley 1997). Kruskal-Wallis One-way ANOVAs and Mann-Whitney U-tests were used to determine if condition factors varied between rivers or between seasons (for fish captured at the mouth of the Peshtigo River).

For open water assessments, Mann-Whitney U-tests were used to compare total lengths and ages of sturgeon observed between years, between net types (nylon and Marlex) and between locations for the 2002-2003 trap net assessments. Mann-Whitney U-tests also were used to compare the CPUE for lake sturgeon captured in gill nets and setlines and in nylon and Marlex trap nets. A Kruskal-Wallis One-way ANOVA was used to compare total lengths of lake sturgeon captured in gill nets of different mesh sizes (during spring and fall), and Mann-Whitney U-tests (with adjusted alpha) were used to determine which mesh sizes differed significantly from each other. Graphical comparisons also were made between the length-frequency distributions for lake sturgeon collected using gill nets, trap nets, dip nets, and electrofishing gear.

To facilitate comparison of lake sturgeon growth rates, von Bertalanffy growth functions were calculated from mean length-at-age data for sturgeon from Green Bay, the Manistee River (Gunderman 2001), Lake St. Clair (Thomas and Haas 2000), and the upper Menominee River (Priegel 1973). The values derived from the von Bertalanffy equation for Green Bay lake sturgeon then were used to estimate the exponential coefficient of natural mortality (M) according to the following formula

$$\log M = -0.0066 - 0.279 \log L_{\infty} + 0.6543 \log K + 0.4634 \log T$$

where L_{∞} equals the asymptotic length from the von Bertalanffy equation, K is the Brody growth coefficient, and T equals the mean environmental temperature in Celsius degrees (Pauly 1980). Mean environmental temperature was calculated from water temperature data collected during the Green Bay Mass Balance Study in 1989-1990 (USEPA [United States Environmental Protection Agency] and WDNR 1996). Annual mortality for sturgeon from 9 to 30 years of age also was estimated using a catch curve constructed from the open water trap net data (Ricker 1975).

Estimation of Spawning Run Abundance and Population Size

The size of the 2003 spawning run in the Peshtigo River was estimated from recapture data using the Schnabel method (Schnabel 1938). Lake sturgeon captured at the mouth of the Peshtigo River were assumed to be fish migrating to (or returning from) the spawning grounds below Peshtigo Dam. But because this assumption may not have been valid for all individuals, four different Schnabel estimates were derived from the recapture data. (1) The first estimate included fish captured during the fall 2002 river mouth sampling and the 2003 spring spawning assessment and 100% of the fish captured at the mouth were assumed to be part of the 2003 spawning run. (2) The second estimate only included sturgeon captured during 2003 spring spawning assessment. As in the first estimate, 100% of the fish captured at the mouth were assumed to be part of the 2003 spawning run. (3) The third estimate included fish captured during both fall 2002 and spring 2003, but only 50% of the fish collected at the river mouth were assumed to be part of the 2003 spawning run. (4) The fourth estimate only included fish captured during the spring 2003 spawning assessments, and 50% of the fish captured at the mouth were assumed to be part of the 2003 spawning run. Confidence intervals for each estimate were calculated from the

Poisson distribution. Schnabel estimates could not be calculated for the other three tributaries due to the limited number of recaptures in those systems.

Two different methods were used to estimate population size for the mixed stock of lake sturgeon residing in Green Bay. The first method used was the Jolly-Seber open population model in program MARK. Two Jolly-Seber estimates were calculated. For the first estimate, mark-recapture data from the trap net assessments and dead fish collections were used in the calculation. In the second estimate, mark-recapture data from the fall river mouth assessments also were included in the calculation. For both of the Jolly-Seber estimates, only fish $\geq$112 cm in total length were included in the calculation. This length was chosen for two reasons. (1) The smallest ripe male captured during the spawning run assessments was 112 cm, so fish over this size could potentially be adults. (2) Based on the length-frequency distributions for the trap net and gill net samples, it appeared that sturgeon smaller than 112 cm were not vulnerable to most of the sampling gear used during this study.

The other method used to estimate the size of the mixed population was extrapolation from the spawning run estimates for Green Bay tributaries. For the extrapolations, average spawning periodicity was assumed to be 1.5 years for males and five years for females. Based on data from other unexploited sturgeon populations (Threader and Brousseau 1986, Dumont et al. 1987, Nowak and Jessop 1987), the sex ratio for the entire population was assumed to be 1:1.

Results

Spawning Run Assessments

A total of 144 lake sturgeon were captured during spawning run assessments in the Fox, Oconto, and Peshtigo Rivers, and genetic samples were collected from 126 individuals for spawning stock characterization. Total lengths for all fish captured in the three rivers were found to differ significantly (Figure 10; Kruskal-Wallis One-way ANOVA; $p < 0.001$). Mann-Whitney U-tests ($\alpha = 0.017$) indicated that lake sturgeon in Fox River were significantly larger than fish in the Oconto and Peshtigo Rivers ($p < 0.001$), but that total lengths of sturgeon in Oconto and Peshtigo Rivers were not significantly different (p

= 0.930). When gill net captures were excluded in order to reduce bias from gear size selectivity (see *Fall Sampling and Gear Evaluation* below), the resulting length-frequency distributions still differed significantly (Kruskal-Wallis One-way ANOVA; $p < 0.001$). Fox River fish again were determined to be significantly larger than sturgeon in the Oconto and Peshtigo Rivers ($p < 0.001$), and no difference was found between Oconto and Peshtigo River lake sturgeon ($p = 0.098$). No between-year differences in lake sturgeon total lengths were detected ($p = 0.185$-0.665).

Seventy percent of the lake sturgeon captured in the Fox, Oconto, and Peshtigo Rivers were determined to be males (Table 1). Only 4% of the sturgeon collected were identified as females, and the sex of the remaining individuals could not be determined. The most complete sex ratio information collected was for the Fox River in 2000 and 2001. If individuals of unknown sex were assumed to be females (thus giving the minimum ratio of males to females), the estimated sex ratios were approximately 3:1 (males:females) in 2000 and 5:1 in 2001.

Relative condition factors were found to differ significantly between rivers (Kruskal-Wallis One-way ANOVA; $p = 0.004$; Table 2). Mann-Whitney U-tests ($\alpha = 0.017$) indicated that Fox River fish had significantly higher relative condition factors than lake sturgeon in the Oconto ($p = 0.010$) and Peshtigo ($p = 0.002$) Rivers, but no difference was found between Oconto and Peshtigo River sturgeon ($p = 0.461$). Relative condition factors for males also differed between rivers (Kruskal-Wallis One-way ANOVA; $p = 0.015$), but Mann-Whitney U-tests ($\alpha = 0.017$) only detected significant differences between the Fox and Peshtigo Rivers ($p = 0.008$). When only males between 131 cm to 150 cm were included to eliminate any possible bias associated with differences in mean total length of fish in the different rivers, sturgeon from the Peshtigo River still were determined to have significantly lower relative condition factors than fish from the Fox River (Mann-Whitney U-test; $p = 0.016$). Fulton-type condition factors followed the same pattern as the relative condition factors, with values ranging from 0.570 in the Oconto River to 0.640 in the Fox River.

An additional 88 lake sturgeon were captured during spring river mouth sampling. Tissue samples were collected from 81 of these individuals and analyzed to determine river of origin. The total lengths of sturgeon captured during spring and fall sampling at the mouth of the Peshtigo River did not differ significantly (Mann-Whitney U-test; $p = 0.688$), however, relative condition factors were significantly higher (Mann-Whitney U-test; $p = 0.001$) for sturgeon captured in the spring. Fulton-type condition factors also were higher in the spring.

Because spawning run assessments were not conducted on the Menominee River, body condition of Menominee River spawners cannot be compared to spawning sturgeon in the other three rivers. However, relative condition factors for sturgeon captured in the Menominee River during the fall were significantly lower than those for fish captured during fall sampling at the mouth of the Peshtigo River (Mann-Whitney U-test; $p = 0.004$).

Fox River

During 1997-2001, a total of 50 lake sturgeon were captured below De Pere Dam (total length = 126 cm to 197 cm), including three sturgeon originally tagged in the Lake Winnebago/Wolf River system (Figure 10; Table 3). Three males tagged during the 2000 spawning run assessment were recaptured in 2001.

Unseasonably warm weather during mid-April 2002 caused a rapid increase in water temperature (18 ^{o}C by 17 April). This rise in temperature coincided with the arrival of sturgeon on the spawning grounds, and spawning behavior was first observed on 17 April (Figure 11; Table 4). With the return of cold weather, the water cooled rapidly to 12 ^{o}C by 22 April and remained at approximately this temperature for the next month. This unusual temperature regime apparently prevented the synchronous arrival of sturgeon at the spawning grounds and resulted in a very protracted spawning period. Small numbers ($\leq$ 15 individuals) of lake sturgeon were observed below De Pere Dam from 17 April to 24 May, and spawning behavior was observed intermittently throughout this period. The large spawning aggregations (30-75 fish) present in past years never arrived, making capture of sturgeon difficult. The wide dispersal of fish, coupled with poor visibility and high flows, made an attempt to collect lake sturgeon on 06 May unsuccessful.

One lake sturgeon (TL = 132 cm) was captured in a gill net set below De Pere Dam on 14 May, 2002. A tissue sample was taken from this fish for genetic analyses and added to the 45 samples collected at this location during 2000-2001.

Visual observations below De Pere Dam in 2003 began on 17 April and continued through 05 May. Sturgeon first appeared on the spawning grounds on 21 April (water temperature = 9 ^{o}C) when two fish were observed. Although water temperatures were rising rapidly (up to 14.5 ^{o}C on 26 April), there continued to be only two to three individuals on the spawning grounds for several days, and no spawning behavior was observed during this time. Most spawning activity apparently occurred during a three-day period from 29 April through 01 May, when congregations of up to 24 lake sturgeon were observed below De Pere Dam. Water temperatures during this period ranged from 13-15 ^{o}C. By 02 May, only two lake sturgeon were left below the dam, and no sturgeon were observed after 03 May.

Oconto River

Electrofishing surveys below Stiles Dam in 2002 and 2003 resulted in the capture of nine (CPUE = 3.75 fish/h) and two (CPUE = 15.4 fish/h) lake sturgeon, respectively. In 2003, eleven lake sturgeon were captured during four gill net sets below Stiles Dam (0.174 fish/100 m/h), and one individual was captured twice. No sturgeon were captured during three gill net sets at other deep pools within the Oconto River in 2003.

Total lengths of lake sturgeon collected in the Oconto River ranged from 113 cm to 177 cm. Fifteen (68%) of the sturgeon captured below Stiles Dam were identified as males, and the sex of the remaining seven individuals could not be determined.

Five lake sturgeon were captured in 15 gill net sets (0.031 fish/100 m/h) at the mouth of the Oconto River during spring 2002. Total lengths of these fish ranged from 107 cm to 137 cm. No lake sturgeon were captured on the setlines.

Peshtigo River

From 1996-2001, a total of 17 lake sturgeon were collected below Peshtigo Dam. Fourteen of these individuals were captured with dip nets, and three were collected during electrofishing surveys.

In 2002, 12 lake sturgeon were captured in 37 gill net sets (CPUE = 0.018 fish/100 m/h) in a pool (Peshtigo Island Pool) approximately 500 m downstream of Peshtigo Dam. An additional 13 sturgeon were collected during 7.3 h of electrofishing effort below Peshtigo Dam (CPUE = 1.78 fish/h), raising the total number of lake sturgeon captures in the Peshtigo River in that year to 25. No sturgeon were captured during 12 setline lifts in 2002.

In 2003, three lake sturgeon were collected during 21 gill net sets (0.012 fish/100 m/h) in the Peshtigo Island Pool and 228 lake sturgeon were collected during 2.6 h of electrofishing effort below Peshtigo Dam (CPUE = 10.8 fish/h). No setlines were deployed in 2003.

Total lengths of lake sturgeon captured in the Peshtigo River ranged from 105 cm to 213 cm. Overall, forty-nine (69%) of the sturgeon collected in the Peshtigo River were identified as males, two were considered females, and the sex of the remaining 20 individuals could not be determined. The ratio of males to "unknowns" was approximately 3:2 for the 2002-2003 spawning run assessments.

In 2002, a total of 36 gill net sets at the mouth of the Peshtigo River resulted in the capture of 46 lake sturgeon (CPUE = 0.092 fish/100 m/h). In 2003, 39 lake sturgeon were captured in 18 gill net sets at the mouth (CPUE = 0.162 fish/100m/h). Total lengths of fish collected at the mouth of the Peshtigo River ranged from 104 cm to 175 cm (Figure 12). Eleven (13%) of theese fish were identified as males, and the sex of the remaining 74 individuals could not be determined.

Fourteen lake sturgeon were recaptured during spawning run assessments in the Peshtigo River. Seven of these fish were tagged at the mouth of the Peshtigo River and recaptured near Peshtigo Dam. (Four of these fish were tagged earlier that spring, and three fish had been tagged during the previous fall). Two lake sturgeon captured below Peshtigo Dam during May 2002 had been captured at the same location in 1998. Another sturgeon recaptured below Peshtigo Dam in 2002 had been tagged in the Menominee River six years earlier, at which time it was not found to be in ripe spawning condition (Ed

Baker, Michigan Department of Natural Resources, personal communication). The four remaining individuals were recaptured at the mouth of the Peshtigo River. Two of these individuals had been tagged at the Peshtigo River mouth, one had been tagged at the mouth of the Oconto River, and the other fish had been tagged below Stiles Dam in the Oconto River. None of these fish recaptured at the mouth of the Peshtigo River were in ripe spawning condition.

Schnabel estimates for the 2003 spawning run ranged from 199 to 577 individuals (Table 5). Confidence intervals for all of the estimates were wide due to the limited number of recaptures in the sample. Inclusion or exclusion of the fall river mouth samples appeared to have little effect on the observed population estimates, however, the confidence intervals were slightly smaller when the fall river mouth samples were included in the calculation.

Menominee River

From 1999-2001, volunteer recreational anglers provided information on nine lake sturgeon captures in the lower Menominee River, one sturgeon was found dead by USFWS personnel, and ten fish were collected during electrofishing surveys. Data also were collected for 75 sturgeon harvested during the 2001 fishing season. In addition, three hours of electrofishing effort below Menominee Dam resulted in the capture of 23 lake sturgeon on 07 June 2002 (CPUE = 7.67 fish/h). One other lake sturgeon was collected during setline sampling in August 2002 (see *Fall Sampling and Gear Evaluation* below). Both juvenile and adult lake sturgeon were collected in the Menominee River, and total lengths of captured individuals ranged from 53 cm to 160 cm (Figure 13; harvest data excluded). Three fish captured during the 2002 electrofishing survey had been Floy-tagged previous, but only one of the tags was still legible and indicated that the fish was originally captured in the same location by Michigan DNR personnel on 21 May 1996. Another fish tagged at the mouth of the Peshtigo River during the 2001 spring assessment was harvested by an angler in the Menominee River 5 months later.

The length-frequency distribution of lake sturgeon collected in the lower Menominee River differed substantially from that of fish collected in the upper Menominee River by WDNR (Figure 13). Many of the fish collected in both sections of the river were juveniles, and very few large individuals were captured in this system. Out of 522 sturgeon collected in the Menominee River, only three fish were larger than 150 cm.

Larval Sampling

Larval lake sturgeon were collected in all four rivers. The numbers of sturgeon larvae captured varied greatly between systems, with the largest numbers of larvae collected in the Peshtigo River. The timing of larval drift also varied between rivers, with peak drift in the Peshtigo River occurring 9 days later than peak drift in the Fox River in 2003 (Table 6).

Fox River

No larval sturgeon were captured during the limited sampling efforts in 2002 (Appendix 1). A total of 48 larval sturgeon were collected during 255 net hours of effort (CPUE = 0.19 fish/net h) below De Pere Dam in 2003 (Appendix 2). Larval drift began on 17 May, when two yolk-sac larvae were captured, and continued through 28 May. One peak (18 individuals) was observed on 22 May. Fifteen sturgeon larvae were preserved for genetic analyses.

Calculated egg deposition dates for the yolk-sac larvae captured on 17-18 May were 11-12 May. This suggests that some spawning did occur after the observed spawning events on 30 April and 01 May.

Oconto River

No larval sturgeon were collected in 149.25 net hours of effort in 2002 (Appendix 3). In 2003, 227 net hours of effort resulted in the capture of six lake sturgeon larvae (CPUE = 0.026 fish/net h; Appendix 4). The period of larval drift lasted from 22 May through 01 June, with no distinguishable peaks. Total lengths of captured individuals ranged from 15-20 mm. Five larvae were preserved for genetic analyses.

Peshtigo River

In 2002, a total of 262 hours of drift net sampling effort was expended immediately downstream of the spawning grounds, with an additional 429 hours of drift net sampling effort directed farther downstream (Appendix 5). (Only the results of the upstream sampling are reported here. See the final report for GLFT project 109 for more information on larval lake sturgeon sampling in the Peshtigo River). This effort resulted in the collection of 147 larval sturgeon (0.561 fish/net h) at the upstream site. Larval drift began on 01 June and peaked on 02 June when 78 fish were collected. The primary drift period lasted from 01 June to 08 June. Total lengths of captured larvae ranged from 16 mm to 23 mm. A sub-sample of 20 individuals was preserved in ethanol for subsequent genetic analyses.

In 2003, a total of 614 larval sturgeon were collected in 410 net hours of effort (CPUE = 1.50 fish/net h) at the upstream sampling site (Appendix 6). Larval drift began on 12 May, when four yolk-sac larvae were captured, and ended on 07 June. Four peaks were observed on 25 May, 29 May, 31 May, and 05 June, with the largest peak occurring on 31 May. Total lengths of captured larvae ranged from 14 mm to 23 mm and averaged 18 mm. A sub-sample of 120 individuals was preserved for subsequent genetic analyses.

Menominee River

Twenty-one larval sturgeon were collected on the Menominee River in 27 net-hours of effort conducted in 2003 (CPUE = 0.78 fish/net h; Appendix 7). At least one larval sturgeon was captured each night, with the highest catch of 17 individuals occurring on 27 May. Total lengths of larvae collected ranged from 16 mm to 22 mm. None of the larvae captured in the Menominee River were preserved for genetic analyses.

Spawning Habitat and Egg Deposition Assessment

The amount of potential lake sturgeon spawning habitat available in each river ranged from 6.03 ha for the Fox River to 18.46 ha for the Oconto River (Table 7). Multiple patches of potential spawning habitat were found in the Oconto and Peshtigo Rivers, but spawner habitat in the Fox and Menominee Rivers was limited to the sections immediately below the lowermost dams (Figures 14-17).

Areas of marginal spawner habitat also were found in the Fox, Oconto, and Peshtigo Rivers. In the Fox River, the marginal area was the site of a former railroad trestle (Stantec Consulting Services, Inc. 2003).

Mariginal areas in the Oconto River consisted of sections of riprap shoreline (i.e. suitable substrate) with low current velocity. The marginal site in the Peshtigo River contained some larger substrate (e.g. pebbles and cobble) mixed with a large amount of gravel.

Egg mats were found to be successful in documenting egg deposition. In the Fox River, a mat placed on the known spawning grounds below De Pere Dam during the evening of 01 May was covered with sturgeon eggs the next morning. In the Oconto River, 120-150 sturgeon eggs were collected on one of the 30 egg mats set below Stiles Dam from 30 April to 05 May. Approximately 30 of these eggs were preserved for genetic analyses. No sturgeon eggs were collected at the Suzies Rapids and Peshtigo Riffle sites.

Spawning behavior was observed below the lowermost dams on the Fox and Peshtigo Rivers. (Sturgeon were observed below Stiles Dam in the Oconto River, but water depths prevented observations of spawning behavior.) In the Fox River, virtually all of the spawning activity was concentrated on the eastern side of the river between De Pere Dam and the Hwy 32 bridge (Figure 14). Spawning activity in the Peshtigo River appears to be limited to the stretch of river between Peshtigo Dam and the covered bridge (Figure 16).

Open Water Assessments

In 2002, 198 net days of trap net effort resulted in the capture of 50 lake sturgeon (CPUE = 0.258 fish/net d). In 2003, 154 lake sturgeon captures were made during 318 net days of trap net effort, resulting in a CPUE of 0.470 fish/net d. Only one lake sturgeon was collected during the overnight gill net sets in 2001-2003 (CPUE = 0.002 fish/100 m/h), and no sturgeon were captured on setlines during the open water assessments.

Overall, 203 lake sturgeon were captured during the 2002-2003 trap net assessments. Total lengths of captured lake sturgeon ranged from 60 cm to 208 cm (Figure 18), and no significant differences were found between the length-frequency distributions for 2002 and 2003 (Mann-Whitney U-test; $p = 0.956$). Ages determined from pectoral fin rays ($N = 88$) ranged from 4 to 61 years, and calculated ages (see *Age Determination* section below for equations) for the remaining individuals (N = 114) ranged from 4 to 51 years (Figure 19). Sixty-three percent of the fish collected were younger than 15 years, whereas individuals older than 30 years made up only 5% of the total catch. No significant differences were found between the age-frequency distributions observed in 2002 and 2003.

Eight sturgeon were recaptured during the open water trap net assessments. One fish was captured twice in the same net in 2002, and another fish was captured twice during the 2003 assessment - once on the west shore and once on the east shore of Green Bay. Six of the sturgeon recaptured during the 2003 trap net assessment had been tagged in previous years. Two of these fish had been tagged during spawning surveys (one on the Peshtigo River and one on the Fox River) and were in ripe spawning condition at the time. Three other fish were tagged at the mouth of the Peshtigo River, and one fish was tagged during the 2002 open water assessment.

Sea lamprey marks were found on 34% of the sturgeon captured during the 2003 open water trap net assessment, whereas marks were found on 53% of the sturgeon collected during the 2003 spawning run assessments (Table 8). The average number of marks per fish also was lower for sturgeon collected during the open water assessment. During both types of assessments, B marks were more common than A marks, and the majority of the marks appeared relatively old (type 4 marks).

Eight lake sturgeon were captured during the 2003 winter gill net sampling in southeastern Green Bay (CPUE = 0.003 fish/100 m/h). Total lengths of captured sturgeon ranged from 43.2 cm to 81.9 cm, with most individuals falling in the 70-80 cm size class. Ages determined from pectoral fin rays (N = 4) ranged from 6 to 7 years, and calculated ages for the other four individuals ranged from 3 to 6 years.

Both techniques used to derive Jolly-Seber estimates for the overall population size in Green Bay yielded similar results. When just the trap net and dead fish (see *Incidental Captures* below) data were included in the Jolly-Seber model, the number of sturgeon $\geq$112 cm residing in Green Bay was estimated to be 2266 (95% confidence interval [CI] = 929-5535). When the fall river mouth data also were included in the calculation, the estimate was 2022 fish (CI = 920-4455). Confidence intervals for both estimates were wide due to the limited numbers of recaptures in the samples.

Extrapolation estimates for the Fox, Oconto, and Peshtigo River populations were 117, 59, and 461 fish, respectively (Table 9), providing a total estimate of 637 adults contributing to the lower Green Bay population from these three rivers. The Menominee River population was not included in the extrapolation estimate because spawning run estimates are not yet available for this system.

Lake sturgeon in Green Bay generally had the highest mean length-at-age of the four populations examined, especially for fish >20 years of age. The von Bertalanffy plot revealed that Green Bay lake sturgeon have the largest asymptotic length, but they also have the lowest Brody growth coefficient (Figure 20; Table 10). Confidence intervals for the von Bertalanffy growth parameters were wider for the Green Bay and Manistee River samples. These wider confidence intervals likely were caused by smaller sample sizes, because some of the age classes from these systems were represented by only one or two individuals.

The catch curve for sturgeon captured during the open water trap net assessments in Green Bay indicated an instantaneous rate of total mortality (Z) of 0.063 (Figure 21). The exponential coefficient of natural mortality (M) calculated from the von Bertalanffy growth parameters and mean environmental temperature was 0.073. Annual mortality estimates derived from Z and M were 6.1% and 7.0%, respectively.

Incidental Captures

Sixteen commercial fishers, three tribal resource agencies, the United States Fish and Wildlife Service, the Wisconsin Department of Natural Resources, and one recreational angler provided data on 84 lake sturgeon (86 total captures) encountered in Lake Michigan from 1996-2003 (Table 11). Approximately 37% of the fish came from Green Bay (Figure 22). Most of the other captures occurred in one of four locations: Grand Traverse Bay (MI), Little Traverse Bay (MI), along the Door County (WI) shoreline of Lake Michigan, and along the east-central Lake Michigan shoreline (near Ludington and Manistee, MI).

Total lengths of sturgeon encountered ranged from 28.1 cm to 213.4 cm (Figure 23), and pectoral fin ray samples (N = 26) revealed ages between 5 to 58 years. Depths at capture locations ranged from 1.8 to 115.8 m, however, 74% of incidental sturgeon captures occurred at water depths ≤20 m (Figure 24). The number of incidental captures also varied by season, with the largest number of captures occurring in the month of October (Figure 25).

Five lake sturgeon were captured multiple times. One fish tagged in the Menominee River was recaptured in North Bay (on the eastern side of the Door Peninsula) seven years later. Another fish that was tagged at the mouth of the Sturgeon Bay ship canal was recaptured near Naubinway (MI) almost ten years later. The longest movement observed was for a fish that originally was tagged in southern Lake Huron in 1996, and was recaptured near Baileys Harbor (Door County, WI) in 1999.

During 2001-2003, 29 dead lake sturgeon were found in Green Bay by biologists and private citizens. Twenty-four (83%) of these sturgeon were found during late July through September, including 17 fish found during the summer of 2003. Most of the fish were found in the greater Sturgeon Bay area, and only two dead fish were found along the western shoreline of Green Bay (Figure 26). Three dead sturgeon that washed ashore near Sturgeon Bay had previously been captured during spawning run assessments (two fish from the Peshtigo River and one fish from the Fox River). The cause of mortality was apparent for only one sturgeon. This fish (found near the mouth of Sturgeon Bay during late August 2002) had contusions on the top of its head, indicating that it may have been hit by a boat. All seven of the samples tested for botulism revealed high levels of the toxin, however, only one specimen was fresh enough to establish botulism as the probable cause of death (Rod Getchell, Cornell University, personal communication).

Fall Sampling and Gear Evaluation

Setline sampling in the Menominee River resulted in the capture of only one lake sturgeon (TL = 78.7 cm; CPUE = 0.005 fish/25 hooks/h), and no sturgeon were captured during eight setline lifts at the mouth of the Peshtigo River during August 2002. Similarly, attempts to capture lake sturgeon with setlines (5 lifts) at various deep pools in the Peshtigo River also resulted in zero captures, and no sturgeon were captured during limited sampling efforts (2 setline lifts and 2 gill net lifts) at the mouth of the Oconto River during November 2002.

Four sturgeon were captured on setlines (CPUE = 0.022 fish/25 hooks/h) during fall sampling at the mouth of the Peshtigo River. Twenty-nine sturgeon (CPUE = 0.202 fish/100 m/h) were collected in gill nets during this same period, and an additional 28 lake sturgeon (CPUE = 0.147 fish/100m/h) were captured during fall gill net sampling in 2003. Statistical analysis of CPUE data from 2002 revealed that CPUE was significantly higher for gill nets than for setlines (Mann-Whitney U-test; $p = 0.001$).

Total lengths of fish collected during fall sampling at the mouth of the Peshtigo River ranged from 111 cm to 170 cm (Figure 12), and pectoral spine samples from five lake sturgeon captured in 2002 revealed ages of 9 to 18 years.

Four of the fish collected at the mouth of the Peshtigo River were recaptures. Three of these fish had been tagged at the mouth of the Peshtigo River 5 to 17 months earlier. The other fish (recaptured in October 2002) had been captured on the spawning grounds below Peshtigo Dam during May 2001.

No significant differences were found between total lengths of lake sturgeon captured in gill nets of the same mesh size, regardless of location or season (Table 12). Total lengths of sturgeon captured in gill nets of different mesh sizes did differ significantly, with larger mesh sizes collecting larger lake sturgeon on average (Figure 27). Modal size classes observed for the three mesh sizes were as follows: 115-135 cm for 25.4 cm mesh, 135-155 cm for 30.5 cm mesh, and $\geq$ 155 cm for 35.6 cm mesh. Graphical comparisons of length-frequency distributions for lake sturgeon captured using various gear types suggest that gill nets are more size-selective than trap nets, dip nets, and electrofishing gear (Figures 27 and 28).

Lake sturgeon CPUE was significantly higher in nylon trap nets than in Marlex trap nets (Mann-Whitney U-test; $p < 0.001$; Table 13). Mann-Whitney U-tests indicated that CPUE was significantly higher in both the pots ($p = 0.001$) and hearts ($p < 0.001$) of nylon nets than in Marlex nets. No significant differences were detected between total lengths of lake sturgeon captured in nylon and Marlex trap nets (Mann-Whitney U-test; $p = 0.700$; Figure 29). For the nylon trap nets, lake sturgeon captured in the hearts were significantly smaller than sturgeon collected in the pots (Mann-Whitney U-test; $p = 0.026$).

Age Determination

Two different equations were used to estimate the ages of captured sturgeon. The first equation incorporates both total length and weight as follows:

$$\text{Age} = (e\text{^}((\text{total length} + 7.3816)/52.354) + ((\text{weight} + 5.073)/1.4302))/2 \quad (R^2 = 0.902)$$

where age is in years, total length is in cm, and weight is in kg. When only total length was known for an individual, age was estimated using the equation

$$\text{Age} = e\text{^}((\text{total length} + 7.3816)/52.354) \quad (R^2 = 0.844)$$

where age is in years and total length is in cm.

For ages determined from cross-sections taken at different locations from entire pectoral fin rays, the observed age for a fish varied depending on where the cross-section was taken along the ray. Cross-sections taken farther from the base of the ray often were missing annuli, thus, causing the reader to underestimate the age of the fish (Figure 30). This effect was most obvious at 35 mm, but one or more annuli already had disappeared by 10 mm in 45% of the samples examined. Annuli in the center of the ray (e.g. the first annulus or "central star") appeared to be the first annuli to disappear on cross-sections taken farther from the base. Annuli also were crowded and less distinct on cross-sections taken at 25 mm and 35 mm, making estimation of age from these cross-sections difficult.

A few cross-sections from <5 mm from the base were examined, however, the presence of a large blood vessel in these samples made the annuli crowded and difficult to count. In addition, cutting a fin ray at this location on a live sturgeon would cause severe bleeding.

Genetic Characterization and Assignment Tests

During 1999-2003, 767 lake sturgeon genetic samples were collected in Green Bay and surrounding tributaries (Figure 31). The numbers of genetic samples collected during spawning run assessments were 46, 22, and 58 for the Fox, Oconto, and Peshtigo Rivers, respectively. One hundred thirty-one genetic samples have been collected in the lower Menominee River during June through October and an additional 86 samples were collected from river resident fish in the upper Menominee River.

A total of 524 tissue samples for genetic assignment tests were collected through the open water assessments, river mouth sampling, incidental captures by volunteers and agency crews, and dead fish collections. Seventy-one percent of these samples came from central Green Bay, but a few samples were collected at the southern and northern ends of the bay. An additional 34 genetic samples for assignment testing were collected in northeastern Lake Michigan through incidental captures by volunteers.

A number of lake sturgeon eggs and larvae also were collected for parentage analysis during 2002-2003. The numbers of sturgeon larvae collected from each river were 9, 5, and 136 for the Fox, Oconto, and Peshtigo Rivers, respectively. Sixty-two sturgeon eggs were collected in the Fox River during the larval drift assessments, and 35 sturgeon eggs were collected from a single egg mat in the Oconto River. An additional 93 genetic samples were collected from young-of-year lake sturgeon in the Peshtigo River by researchers from Purdue University (see report for GLFT project 109). Results and current status of the genetic analysis of these samples are presented in the accompanying Lake Michigan Basin Genetics Sub-project: 2004 Progress Final Report (Scribner et al.).

Discussion

Spawning Run Assessments

Fox River

Annual spawning runs in the Fox River generally included 25 to 75 individuals. The Fox River spawning runs included a higher percentage of larger, and presumably older, fish than those in the Oconto and Peshtigo Rivers, with 53% of the fish captured in the Fox River estimated to be >20 years of age. This age structure is more similar to that observed in Lake Winnebago, where the mean age for sturgeon harvested during the winter spear fishery in 1991-1996 was 23 years (Bruch 1999). Immigration of Wolf River/Lake Winnebago sturgeon into the lower Fox River was observed during this study, but the relative contributions of immigration and local reproduction to overall recruitment have not been determined (see *Larval Assessments* below for more information on larval recruitment in the Fox River).

Fox River lake sturgeon had higher condition factors than sturgeon in the Oconto and Peshtigo Rivers. For the Fox and Peshtigo Rivers, these differences were significant even when confounding variables (such as differences in sex ratios or length-frequency distributions) were eliminated. One explanation for differences in sturgeon body condition between the Fox and Peshtigo Rivers may be latitude. Fortin et al. (1996) found that condition factors for lake sturgeon generally decreased with increasing latitude in the eastern part of their range. However, this pattern was not observed for sturgeon in the western part of their range (including Wisconsin), where condition factors did not appear to vary with latitude. In addition, Fox and Peshtigo River sturgeon spend most of their lives in the same environment (i.e. Green Bay), so latitude does not appear to be a plausible explanation for the observed pattern. Another possible explanation is that the observed differences in body condition are genetically determined. Fox River lake sturgeon are genetically distinct from Peshtigo and Oconto River sturgeon, but the effect of these genetic differences on growth rates and body morphology have not been elucidated. One final possibility is that many of the fish captured in the lower Fox River were recent immigrants from the Lake Winnebago system. If this hypothesis were true, then the observed differences in body condition may have been related to past environmental factors (e.g. food availability and water temperature). The capture of three Lake Winnebago fish below De Pere Dam, coupled with the genetic similarities between the lower Fox River and Wolf River populations, indicates that some (perhaps all) of the adult sturgeon in the lower Fox River are immigrants from the Lake Winnebago system.

Although the reasons for the small population size in the Fox River are unknown, it is likely that recruitment problems have limited population size in this system. One environmental factor that may have limited past (and possibly present) reproductive success in the Fox River is PCB (polychlorinated biphenyl) contamination from paper recycling mills. High concentrations of PCBs have been found in the Fox River (up to 190 ng/L in the water column) and lower Green Bay, and this region has been classified as an Area of Concern by the International Joint Commission (Velleux et al. 1995; Velleux and Endicott 1994). High levels of PCBs were associated with elevated occurrences of lesions and tumors in adult walleyes (Barron et al. 2000) and immunosuppression in juvenile chinook salmon (Jacobson et al. 2003); however, the effects of PCBs on early life stages of fishes are unclear. Although a number of researchers have attempted to determine the effects of PCBs on fish eggs and larvae, the results of these studies have been conflicting and inconclusive (Mac et al. 1993; Smith et al. 1994; Smith 1998).

Another factor that may be limiting reproductive success (and, thus, population size) in this system is egg predation by common carp (*Cyprinus carpio*). Large numbers of carp are present below De Pere Dam during and after lake sturgeon spawning. In this study, no attempt was made to determine if carp were preying on sturgeon eggs, but carp have been found to consume white sturgeon eggs in the Columbia River (Miller and Beckman 1996).

Oconto River

The annual spawning runs in the Oconto River appear to be very small (approximately 25 fish). Only a small percentage of the lake sturgeon in this system were estimated to be over 20 years of age. Although the age structure (and low population levels) observed in the Oconto River could be caused by high adult mortality, historical information suggests that the relative abundance of younger fish in this system is the result of a long period of minimal recruitment followed by increasing recruitment in recent years.

One factor that probably has affected recruitment in the Oconto River is changes in water quality. A pulp mill was operated on the Oconto River in Oconto Falls since the 1890s, and this mill began to cause water quality problems soon after its construction. Fish kills occurred periodically from 1941 through 1977, and by 1975 the Oconto River had become the single largest source of ammonia nitrogen on the Wisconsin side of Lake Michigan (Rost et al. 1989). Shortly after the pulp mill was closed in 1978, water quality in the Oconto River improved dramatically (Rost et al. 1989).

Flow conditions in the Oconto River also have changed markedly in recent years. Prior to June 1986, Stiles dam was operated in peaking mode, and reservoir levels fluctuated 0.6-0.9 m per day, while discharge from the dam often varied "twice daily, from as low as 125 cubic feet per second (cfs) to as high as 1,000 cfs" (FERC 1991). These flow fluctuations likely would have disrupted spawning activity (Auer 1996), and desiccation of much of the stream channel during low flows would have resulted in substantial mortality of sturgeon eggs. Flow conditions improved slightly in 1987 when reservoir fluctuations were limited to 0.46 m per day, and minimum flows of 200 cfs (5.6 m^3/s) were instituted. Beginning in 1992, minimum flows during May-June were increased to 572 cfs (16.2 m^3/s), and reservoir fluctuations were decreased slightly. These changes in dam operations probably provided improved conditions for spawning and incubation. This hypothesis is supported by the age structure data; fifteen (68%) of the fish captured in the Oconto River had calculated ages of ≤15 years and, thus, likely were born after the minimum flow requirements were instituted.

The current license for Stiles Dam (issued in February 2003) requires run-of-river (ROR) flows and reservoir fluctuations of ≤0.06 m. The combination of ROR flows and improved water quality should provide favorable conditions for lake sturgeon recovery in this system.

Peshtigo River

The Peshtigo River had the largest spawning runs of the three rivers examined during this study. Based on the length-frequency distribution of sturgeon captured in the Peshtigo River, and length-at-age data from fish captured in Green Bay, it appears that the vast majority of the sturgeon in this river are <20 years of age. One factor that may have contributed to this youthful age structure is high adult mortality.

Prior to 1989, there was guard to prevent fish from swimming upstream into one of the turbines on Peshtigo Dam. Six sturgeon were found dead in the turbine in 1989, but an unknown number of sturgeon may have been killed in the turbine before the problem was discovered. Another possible cause of the observed age structure could be increasing recruitment. Peshtigo Dam has been a ROR operation for many years, but peaking flows from the upstream dams prevented natural flows in the lower section of the river. During 1997-1999, new licenses were issued to the upstream dams that require ROR flows from 15 April through 30 June. These new requirements probably began producing improved flow conditions in the lower Peshtigo River in spring 1998. These changes may be affecting current levels of recruitment, but they occurred too late to be responsible for the observed age structure. A third possible explanation is that the observed age structure was caused by a temporary increase in recruitment consisting of a few good year classes during 1985-1990.

Menominee River

Spawning run assessments were not conducted in the Menominee River during this study. Some sturgeon remain in the Menominee River year-round, and the presence of these resident fish complicates estimation of spawning run size. The best information available suggests that annual spawning runs in this river consist of more (perhaps substantially more) than 200 individuals (Elliott 2003).

Larval Assessments

The largest numbers of larval sturgeon were captured in the Peshtigo River. The Peshtigo River had much larger spawning runs than the Fox and Oconto Rivers, so the high relative abundance of larvae in this system was not surprising. Recruitment of lake sturgeon to the juvenile stage also has been documented in the Peshtigo River. Approximately 230 YOY sturgeon were collected during 2002-2003 by researchers from Purdue University, and the estimated size of the 2003 YOY population in this river was 205 individuals (95% confidence interval = 133-294; see report for GLFT project 109 for more information).

The lowest numbers of lake sturgeon larvae were collected in the Oconto River, where CPUE of larvae was 98% lower than in the Peshtigo River in 2003. If one assumes that CPUE reflects actual abundance of larvae produced, and that mortality between the larval and juvenile stage is the same in both rivers, then the expected number of YOY sturgeon produced in 2003 would be only four individuals. The absence of measurable larval production in 2002, coupled with the very limited amount of observed larval production in 2003, suggests that the lake sturgeon population in the Oconto River may not be self-sustaining. It is important to note, however, that the failure of one or two year classes may have little effect on populations of long-lived species such as lake sturgeon. Several years of larval assessments would be needed to definitively demonstrate that the population is not self-sustaining.

Larval CPUE was slightly higher in the Fox River than in the Oconto River in 2003. Given the assumptions mentioned in the above paragraph, the estimated number of YOY sturgeon produced would be 15. This level of recruitment may or may not be sufficient to maintain the population at current levels, however, the lower Fox River population has another means of recruitment. Immigration of fish from the Wolf River/Lake Winnebago system may be sufficient to maintain a sturgeon population in the lower Fox River, even in the absence of natural reproduction in this section of the river.

The limited data available indicate that there is some larval recruitment in the Menominee River, however, the data is too sparse to draw any conclusions as to the relative abundance of larvae in this system. Considering the large size of the adult population in the Menominee River, it seems likely that substantial numbers of larvae are being produced in this system. The larval drift assessments in spring 2004 will provide additional information on the relative abundance of larval sturgeon in this river.

Overall, timing of larval drift varied in a predictable manner, with peak drift occurring slightly later in the more northern Peshtigo River than in the Fox River. The observed durations of larval drift periods likely were related to the spacing of spawning events in each river. The 2003 larval drift period was twice as long for the Peshtigo River as for the Fox River (16 days compared to 8 days), so it appears that spawning activity was spread out over a longer period in the Peshtigo River.

Spawning Habitat Assessments

In all three of the rivers examined, spawning lake sturgeon appeared to be using only a small percentage of the available habitat. (Although spawner habitat availability was determined for the Menominee River, we did not attempt to evaluate use of this site by spawning lake sturgeon.) A number of factors may be responsible for this observed pattern. For example, lake sturgeon may have a tendency to migrate as far upstream as possible before spawning. This hypothesis has been advanced by so many authors, that Harkness and Dymond (1961) made the following statement.

> All accounts agree in suggesting that sturgeon pass through minor rapids in the course of a spawning river and only spawn in rapids at the foot of falls which bar their farther progress upstream.

At current population levels, there may be sufficient spawning habitat available immediately below the dams, so there is no need to utilize other potential spawning areas.

Another complicating factor is that some of the areas classified as potential lake sturgeon spawning habitat during this study may not actually be suitable for spawning (or at least are low quality habitat). Although the general characteristics of lake sturgeon spawning sites have been described by many authors (e.g. rocky substrate and moderate-to-high current velocity), the microhabitat features that influence spawning site selection by lake sturgeon are poorly understood. For example, much of the area designated as "potential spawning habitat" below De Pere Dam appears, to the human eye, to be relatively homogeneous. However, nearly all of the observed spawning activity at this location occurred just below the eastern edge of the dam, and sturgeon were only rarely observed in the central or western portions of the river.

Despite uncertainties about the microhabitat requirements of spawning lake sturgeon, the large disparity between the amount of potential spawning habitat identified and the amount of habitat that is currently being used suggests that spawning habitat availability is not limiting population size in the Fox, Oconto, and Peshtigo Rivers. This may not have been true in the past, however, as power peaking operations and pollution may have hindered reproduction for many years (see discussion for Spawning Run Assessments above).

Open Water Assessments

The two methods used to estimate population size for the mixed stock of lake sturgeon residing in Green Bay gave substantially different results (2022 and 2266 for the Jolly-Seber estimates and 637 for the extrapolation estimates). There are two probable reasons for the observed discrepancy. The first reason is that Menominee River fish were not included in the extrapolation estimate. Because the Menominee River is thought to have the largest spawning runs of the four tributaries examined, addition of Menominee River spawners to the calculation would probably increase the extrapolated population estimate by well over 100%. The other reason that the two methods yielded different results is that they were providing estimates for different portions of the overall population. The extrapolation estimate only included adult fish, whereas some of the fish (though they were larger than 112 cm) included in the Jolly-Seber estimates were not sexually mature. Both of these factors would cause the extrapolation estimates to be lower than the Jolly-Seber estimates.

The Jolly-Seber model, like most mark-recapture techniques, is not valid unless three assumptions are met. The first assumption is that every fish in the population has an equal probability of capture. Telemetry data from a previous study suggest that sturgeon from all four tributaries utilize the area where the trap nets were deployed (Elliott, unpublished data). A substantial percentage of the lake sturgeon in the Menominee River do not appear to stray far from the river, however, so the observed contribution of the Menominee River stock to mixed population in Green Bay probably is disproportionately small. The second assumption is that there is no difference in survival of marked and unmarked fish. Although it is difficult to determine if this assumption has been violated, there is no evidence to suggest that this assumption was not valid. A number of dead fish were found in Green Bay in late summer 2003, however, the ratio of marked vs. unmarked fish in the dead fish sample was similar to the ratio observed for live sturgeon captured during the fall river mouth assessments in that year. The third assumption is that tags are not overlooked or lost. All of the fish captured were checked for PIT and Floy tags. In addition, most of the fish collected in Green Bay were double-tagged, and it seems highly unlikely that many fish would lose both their tags during the course of this study (Clugston 1996).

The abundance estimates for the mixed stock of lake sturgeon in Green Bay are preliminary, and the wide confidence intervals reflect the scarcity of recaptures in the sample. Continued trap net sampling in northern and central Green Bay (scheduled for 2004) will help to refine these abundance estimates and, coupled with the results of the genetic assignment tests, should provide estimates of the contribution of each of the discrete spawning stocks to the overall population in Green Bay.

The age structure observed for lake sturgeon in Green Bay cannot be compared to a healthy, unexploited population because no such population exists. When compared to other well-known lake sturgeon populations (Lake St. Clair – Thomas and Haas 2000; Lake Winnebago – Probst and Cooper 1954; Black Lake – Baker and Borgeson 1999), the mixed stock of sturgeon in Green Bay appears to have a relatively small percentage of individuals >30 years of age. However, differences in the sampling designs employed during these studies complicate interpretation of these results.

Based on the limited information available, the relative scarcity of older individuals in Green Bay does not appear to have resulted from high adult mortality (at least between the ages of 9 to 30 years). The annual mortality estimate of 6.1% obtained during this study was lower than the total annual mortality estimates for the exploited lake sturgeon populations in Black Lake (9.7%; Baker 1980) and Lake Winnebago (18.6% [1991-1996 value]; Bruch 1999). Annual mortality of Green Bay lake sturgeon also appears to be slightly lower than the annual natural mortality observed for white sturgeon in the lower Columbia River (9.5%; DeVore et al. 1995).

An age structure dominated by young individuals often is the result of increasing recruitment. To determine if recruitment to the mixed lake sturgeon stock in Green Bay was increasing, the number of YOY sturgeon needed to produce the observed number of age 9 fish was calculated. Age 9 fish made up 10.5% of the catch, so the Jolly-Seber population estimate (N = 2266) was multiplied by 0.105 to give 237 age 9 individuals. The number of YOY sturgeon needed to produce 237 age 9 fish was then back-calculated using two different scenarios. In the first scenario, annual survival from age 1 to age 9 was assumed to be 93.9% (based on catch curve for adults), and survival from YOY to age 1 also was assumed to be 93.9%. Using these assumptions, the back-calculated number of YOYs was 418. In the second scenario, annual survival from age 1 to age 9 was assumed to be 93.9%, but survival from YOY to age 1 was assumed to be 60%. (This number was based on survival of hatchery raised white sturgeon [age 1+] through their first winter in the Kootenai River, Idaho and British Columbia [Ireland et al., In Press]). Given these assumptions, the back-calculated number of YOYs was 654. It is likely that wild fish would have better survival over their first winter than hatchery fish (but still not as high as adults), so the real number of YOYs needed to produce 237 age 9 sturgeon is probably between 418 and 654.

The estimated total number of YOY sturgeon produced in the Fox, Oconto, and Peshtigo Rivers during 2003 was 224. Considering the large size of the spawning runs in the Menominee River, it seems likely that a substantial number (>200) of YOYs also were produced in this system. In addition, an unknown percentage of YOY sturgeon may move into Green Bay at an early age and, thus, would not have been included in the YOY population estimate obtained for the Peshtigo River. Based on the available information, it appears that the level of recruitment observed in 2003 was at least sufficient to maintain lake sturgeon abundance in Green Bay at its current level. The 2004 larval drift surveys in the Menominee River should provide additional information on recruitment trends in Green Bay.

The major difference between the von Bertalanffy growth equation for Green Bay sturgeon and the equations for the other three populations was that the L_{∞} parameter was larger for Green Bay fish. Three of the sturgeon captured during the open water trap net assessments had total lengths $\geq$200 cm, so the calculated asymptotic length of 204 cm does not appear to be artificially high. The von Bertalanffy growth curves derived during this study primarily reflected growth of fish >5 years of age for two reasons. The first reason is that a relatively small number of sturgeon $\leq$5 years of age were captured. (This was especially true for the Green Bay and Manistee River populations). The second reason is that growth in early life stages usually does not follow the von Bertalanffy model (Quinn and Deriso 1999).

Green Bay lake sturgeon were generally longer at a given age than sturgeon from the three other populations. For fish in the Peshtigo River, this rapid growth is already evident at the YOY stage. By the age of 5 months, lake sturgeon in the Peshtigo River had grown to 26-30 cm (see report for GLFT project 109 for more information). In contrast, the mean length of sturgeon (age = 152 d) in the Lake Winnebago system was 22 cm (Kempinger 1996), and the mean length of age 1 fish in the upper Menominee River was only 15 cm (Priegel 1973).

The reasons behind the apparent rapid growth of Green Bay sturgeon are not known. It is possible that the observed differences in lake sturgeon growth rates were due to environmental factors. Compared to the open waters of Lake Michigan, Green Bay is relatively warm and shallow and, thus, probably provides better feeding and growing conditions than Lake Michigan (where Manistee River fish presumably spend most of their time). Green Bay sturgeon also do not have to expend energy swimming against current all their lives, as do fish from the slowly growing population in the upper Menominee River. In addition, lake sturgeon from Green Bay tributaries are genetically distinct from sturgeon in eastern Lake Michigan and Lake St. Clair (De Haan 2003), and these genetic differences may be partially responsible for the observed differences in growth rates.

The mean Fulton-type condition factor for lake sturgeon captured in Green Bay was 0.630, which falls in the middle of the range reported by Power and McKinley (1997) for other sturgeon populations. Relative condition factors were higher for sturgeon captured during the open water assessments than for sturgeon captured in Green Bay tributaries. The exertion associated with migration and spawning, coupled with reduced food intake during the spawning period, probably caused spawning sturgeon to be in poorer condition than fish captured in the open waters of Green Bay (many of which would not have spawned in that year).

Sea lamprey marking rates were higher for lake sturgeon captured during spawning run assessments than for fish captured in the open waters of Green Bay. Two factors may have been responsible for the observed pattern. (1) Most of the fish examined for lamprey marks during the spawning run assessments were captured in the Peshtigo River or at the mouth of the Peshtigo River.

Large sea lamprey spawning runs occur in this river (Klar and Young 2003), so the population density of sea lampreys is likely higher in the vicinity of the Peshtigo River than in the open waters of Green Bay. (2) Based on mark-recapture data, it appears that at least some adult lake sturgeon preparing to spawn in the Peshtigo River arrive at the river mouth during the previous fall. Sea lampreys move into shallow water during the fall (Becker 1983), so lake sturgeon staging at river mouths would probably experience higher lamprey predation rates than fish that remained farther offshore.

Overall, a large percentage of the lake sturgeon captured during this study had at least one visible lamprey wound. It is obvious that sea lampreys do prey upon sturgeon, however, the ratio of B marks to A marks suggests that the majority of sea lampreys detach or are brushed off before they can penetrate the skin. In addition, lamprey marks on sturgeon apparently heal rapidly. For example, one sturgeon captured during October 2003 had no lamprey scars, but when it was recaptured in April 2004 it had two lamprey scars that already were mostly healed (1A3 and 1B3).

Incidental Captures

Most lake sturgeon captures occurred in just five locations. Although the observed spatial distribution of captures may be partially explained by differences in fishing effort and reporting rates, it is likely that high capture rates in some areas are the result of proximity to one or more spawning sites. The high capture rates of lake sturgeon in Green Bay and around Door County (WI) were not surprising, since four Green Bay tributaries are known spawning locations, and two of these rivers (Peshtigo and Menominee rivers) have relatively large annual spawning runs. At present, it is unclear if other areas where sturgeon were encountered also are associated with localized spawning populations, or if they represent a typical occurrence of sturgeon that disperse throughout the lake from known spawning areas. The Manistee and Muskegon Rivers located on the eastern side of Lake Michigan are known spawning locations, however, the annual spawning runs in these rivers are fairly small (<50 individuals in Manistee River [Peterson et al. 2002]; <50 individuals in Muskegon River [see report for Muskegon River sub-project]). Remnant lake sturgeon populations also are thought to persist in the Grand, Kalamazoo, and St.

Joseph Rivers in southwestern Michigan (Elliott 2003). All of these rivers are south of Grand Traverse Bay and Little Traverse Bay, so the relatively high number of reported sturgeon captures in these areas remains an enigma. A possible spawning location near these bays is the Bear River (Emmet County, MI). Although spawning has not been confirmed in this system, an adult lake sturgeon has been observed in the short (~200 m) portion of the river below the lowermost dam during the spring (Randy Claramunt and Steve Lenart, Little Traverse Bay Band of Odawa Indians, personal communication).

Another possible explanation for the observed distribution of incidental lake sturgeon captures in eastern Lake Michigan is that shoal spawning is occurring. Lake sturgeon historically spawned on wave-swept shoals in Lake Michigan, and one such shoal, the Ludington Shoal, is close to one of the locations where incidental lake sturgeon captures have been reported (Elliott 2003; Hay-Chmielewski and Whelan 1997). At the present time, it is not known if successful reproduction is occurring on any of the historic spawning shoals in Lake Michigan (Elliott 2003).

Genetic analyses should allow determination of river of origin for most lake sturgeon captured in the open waters of Green Bay and Lake Michigan. Tissue samples were collected from 75 incidentally caught sturgeon during this project. Analysis of these samples will provide information on lake sturgeon movements in Green Bay and Lake Michigan, and may indicate the presence of additional spawning populations that have not been discovered.

Although a few sturgeon were encountered in surprisingly deep water, the majority of incidental captures occurred $\leq$ 20 m of water, supporting the hypothesis of Harkness and Dymond (1961) that lake sturgeon spend most of their time in shallow water. The predominantly shallow water distribution of lake sturgeon probably is responsible for the higher capture frequencies in October, because fishers targeting lake whitefish move their nets into shallower water during the fall.

Recaptures of tagged fish have shown that lake sturgeon are capable of long-range movements (hundreds of kilometers), however, the frequency of long-range movements and the reasons behind these movements have not been determined. The genetic assignment tests should provide additional information of the frequency of long-range movements of sturgeon in Lake Michigan.

Fall Sampling and Gear Evaluation

The mouth of the Peshtigo River appears to be a staging area for lake sturgeon preparing to spawn. Three sturgeon captured at the mouth of the Peshtigo River during fall 2002 were recaptured near the spawning grounds in the Peshtigo River during spring 2003, suggesting that some sturgeon may arrive at the river mouth early and spend the winter at that location. Whether most sturgeon arrive at the Peshtigo River mouth during the previous fall or in the spring has not been determined, but several lines of evidence suggest that the Peshtigo River mouth would be an excellent staging area. (1) Large numbers of sturgeon have been captured in this area during both spring and fall. (2) The distance between the mouth and the spawning grounds is relatively short (~12 km), so sturgeon could reach the spawning grounds quickly when the water reaches the proper temperature. (3) There is no current, so sturgeon that stage at the mouth would expend much less energy than fish that staged farther upstream. (4) River mouths often are very productive, therefore sturgeon staging at the mouth would have excellent feeding conditions. (This would be especially important if the fish arrived during the previous fall.)

Gill nets were much more effective than setlines for capturing sturgeon at the mouth of the Peshtigo River. Gill nets are more size-selective than other gear types (e.g. dip nets and electrofishing), however, so it is important to account for this size-selectivity when drawing conclusions about the size (or age) structure of a population. For sturgeon research studies targeting adult lake sturgeon, we recommend using equal amounts of 25.4 cm, 30.5 cm, and 35.6 cm mesh nets to reduce bias resulting from gill net size selectivity. The use of other, less size-selective, gear types in conjunction with gill nets would also help to ensure a more representative sample of the entire population.

Trap nets appear to be the most effective gear for sampling lake sturgeon in the open waters of Green Bay. Nylon trap nets had higher CPUEs than Marlex trap nets, but it is likely that the observed difference in catch rates was related to mesh size rather than the twine material. The mesh sizes in the hoods (tops of the hearts) of the nylon and Marlex nets were 17.8 cm and 35.6 cm, respectively. The larger mesh in the Marlex nets may have allowed many sturgeon to swim through the hoods. In the nylon nets, most fish trying to escape through the top of the hearts would either become tangled (based on the length-frequency distribution for the nylon hearts, this was more likely to happen with fish 110-130 cm in length) or turn back toward the pot. Because the trap nets were set in different locations, it is also possible that the Marlex nets simply were set in areas with lower densities of lake sturgeon. Given the marked difference in catch rates, coupled with the fact that both types of nets were deployed at similar depths in the same general region, it seems unlikely that locational differences were entirely responsible for the lower CPUE observed for Marlex trap nets.

Age Determination

It appears that the present practice of making the proximal cut 5 mm from the pectoral fin joint is the best method for collecting samples for age determination. Making the first cut any closer to the joint is not feasible because this would result in severe bleeding (and the presence of the blood vessel causes crowding of annuli). Making the proximal cut farther from the joint also does not appear to be a valid option because this would cause the reader to underestimate the age of the fish. Making the first cut at 5 mm from the fin joint rarely resulted in substantial bleeding, and all of the annuli generally were present on cross-sections obtained using this method.

Future Research Needs

Spawning run estimates have been obtained for the Fox, Oconto, and Peshtigo Rivers. For the Oconto and Peshtigo Rivers, however, these estimates are only preliminary, and even less information is currently available for the Menominee River population. Now that the most productive gear types and upstream sampling locations for capturing adult sturgeon in the Peshtigo River have been identified, an additional two field seasons of spawning run assessments will likely result in enough recaptures to calculate absolute abundance estimates for this system. This information, coupled with absolute abundance data for the Fox River and relative catch rates of fish from each stock during the open water assessments, will make it possible to calculate absolute abundance estimates for the Oconto and Menominee rivers.

Larval drift assessments have provided information on lake sturgeon reproductive success in the Fox, Oconto, and Peshtigo Rivers, but limited data are available for the Menominee River. Comprehensive drift net sampling encompassing the entire drift period in the lower Menominee River, similar to that conducted on the Fox, Oconto, and Peshtigo Rivers in 2003, will reveal the abundance of larvae and timing of drift in this system. This sampling also will allow the collection of additional tissue samples for genetic characterization and parentage assignments.

Spawning has been verified immediately below the lowermost dams in each of the four study rivers. Additional suspected spawning locations have been identified farther downstream on the Oconto and Peshtigo rivers, but spawning has not been verified at these sites. In 2003, it was found that egg mats were effective at documenting spawning on the Fox, Oconto (Stiles Dam), and Manistee Rivers (see report for Manistee River sub-project). Now that the utility of egg mats has been demonstrated, deployment of mats at suspected spawning locations can be employed to evaluate use of these sites by spawning lake sturgeon.

Rough estimates of lake sturgeon abundance in Green Bay have been obtained, but the wide confidence intervals associated with these estimates limit their usefulness for developing rehabilitation strategies. In addition, preliminary results from the genetic assignment tests suggest that Menominee River fish were underrepresented in the trap net samples. Continued trap net sampling, with effort focused primarily in northern Green Bay should ensure that Menominee River sturgeon are adequately represented in the open water samples. This additional trap net sampling should result in a better understanding of the contribution of each sturgeon stock to the mixed population inhabiting Green Bay, and will allow refinement of our estimate of the absolute abundance of sturgeon in Green Bay. Continued sampling and tagging of fish at the mouth of the Peshtigo River will provide additional mark-recapture data for calculating absolute abundance.

Although much information has been gathered regarding the status and population dynamics of lake sturgeon in the Green Bay basin during this study, the spawning periodicity of lake sturgeon, coupled with the large size of the study area and the ability of sturgeon to travel long distances, have made it difficult to accurately assess the status of these sturgeon populations in just two field seasons. Completion of the additional fieldwork described in this section will provide valuable information needed to devise an effective rehabilitation strategy for lake sturgeon in the Green Bay basin.

Acknowledgements

Funding for this project was provided by the Great Lakes Fishery Trust, the Giovanni Auletta Armenise Harvard Foundation, and the National Fish and Wildlife Foundation's Great Lakes Conservation Fund. We thank and acknowledge the significant contributions of all the co-principal investigators involved in this study and in addition, the contributions of Dan Schroeder, Kris Konyn, and Steve Kuchenberg from the WDNR, Nick Legler from the USFWS, and Angela Benson from Purdue University as well as other staff from the WDNR Sturgeon Bay Service Center and from the USFWS Green Bay Field Office for their assistance with data collection during this project. We also thank the following commercial fishers for providing information on incidental lake sturgeon captures: Bob Benson, Val Drzewiecki, Dennis Hickey, Jeff Hickey, Rick Johnson, Ken Koyen, Mark Maricque, Doug Tahlman, Neil Teskie, Jeff Weborg, Greg Ruleau, Monte Carew, George Duhamel, William Fowler, Stuart Schwander, John Keshick, Darren Mitchell, and Theron King. Special thanks are extended to the following tribal biologists: Steve Lenart (Little Traverse Bay Band of Odawa Indians), Erik Olsen (Grand Traverse Band of Ottawa and Chippewa Indians), Marty Holtgren (Little River Band of Ottawa Indians), and Mark Ebener (Chippewa/Ottawa Resource Authority) for collecting and organizing information on incidental sturgeon captures. In addition, we would like to thank Consumers Energy and their consultants for providing information on lake sturgeon captures near their Ludington Pumped Storage Facility, and we thanks all of the private citizens that reported lake sturgeon that had washed up on shore.

References

Auer, N. A. 1996. Response of spawning lake sturgeons to change in hydroelectric facility operation. Transactions of the American Fisheries Society 125:66-77.

Auer, N. A. 1999a. Lake sturgeon: a unique and imperiled species in the Great Lakes. Pages 515-536 in W. W. Taylor and C. P. Ferreri eds. Great Lakes Fisheries Policy and Management: A Binational Perspective. Michigan State University Press, East Lansing, Michigan.

Auer, N. A. 1999b. Population characteristics and movements of lake sturgeon in the Sturgeon River and Lake Superior. Journal of Great Lakes Research 25:282-293.

Baker, E. A. and D. J. Borgeson. 1999. Lake sturgeon abundance and harvest in Black Lake, Michigan, 1975-1999. North American Journal of Fisheries Management 19:1080-1088.

Baker, J. P. 1980. The distribution, ecology, and management of the lake sturgeon (*Acipenser fulvescens* Rafinesque) in Michigan. Michigan Department of Natural Resources, Fisheries Research Report No. 1883, Ann Arbor, Michigan.

Baldwin, N. S., R. W. Saalfeld, M. A. Ross, and H. J. Buettner. 1979. Commercial fish production in the Great Lakes 1867-1977. Technical Report No. 3, Great Lakes Fishery Commission, Ann Arbor, Michigan.

Barron, M. G., M. J. Anderson, D. Cacela, J. Lipton, S. J. Teh, D. E. Hinton, J. T. Zelikoff, A. L. Dikkeboom, D. E. Tillitt, M. Holey, and N. Denslow. 2000. PCBs, liver lesions, and biomarker responses in adult walley (*Stizostedium vitreum vitreum*) collected from Green Bay, Wisconsin. Journal of Great Lakes Research 26:250-271.

Becker, G. C. 1983. Fishes of Wisconsin. University of Wisconsin Press, Madison, Wisconsin.

Bieder, R. E. 1995. Native American communities in Wisconsin 1600- 1960. A study of tradition and change. University of Wisconsin Press, Madison, Wisconsin.

Brousseau, C. S. 1987. The lake sturgeon (*Acipenser fulvescens*) in Ontario. Pages 2-9 *in* Proceedings of a workshop on the lake sturgeon (*Acipenser fulvescens*). Ontario Ministry of Natural Resources Fisheries Technical Report Series No. 23, Toronto, Ontario.

Bruch, R. 1999. Management of lake sturgeon on the Winnebago System – long term impacts of harvest and regulations on population structure. Journal of Applied Ichthyology 15:142-152.

Clugston, J. P. 1996. Retention of T-bar anchor tags and passive integrated transponder tags by Gulf sturgeons. North American Journal of Fisheries Management 16:682-685.

DeHaan, P. W. 2003. Demographic and life history characteristics of remnant lake sturgeon populations in the upper Great Lakes basin: inferences based on genetic analyses. M. S. Thesis, Michigan State University, East Lansing, Michigan.

Dumont, P., R. Fortin, G. Desjardins, and M. Bernard. 1987. Biology and exploitation of lake sturgeon (*Acipenser fulvescens*) in the Quebec waters of the Saint-Laurent River. Pages 57-76 *in*

Proceedings of a workshop on the lake sturgeon (*Acipenser fulvescens*). Ontario Ministry of Natural Resources Fisheries Technical Report Series No. 23, Toronto, Ontario.

Elliott, R. F. 1998. Great Lakes native fish restoration – lake sturgeon *Acipenser fulvescens*. Fisheries stewardship progress report, U.S. Fish and Wildlife Service – Green Bay Fishery Resources Office, Green Bay, Wisconsin.

Elliott, R. F. 2003. Lake sturgeon update for Lake Michigan. Minutes of the March 19-20, 2003 Lake Michigan Committee meeting, Great Lakes Fishery Commission, Upper Lakes meetings, Milwaukee, Wisconsin.

Emich, H. L. 1987. City of Marinette Centennial Program and History 1887-1987. Marinette, Wisconsin.

FERC (Federal Energy Regulatory Commission). 1996. Draft environmental impact statement for relicensing six existing hydroelectric projects in the Peshtigo River basin. Caldron Falls Hydroelectric Project (FERC No. 2525), High Falls Hydroelectric Project (FERC No. 2595), Johnson Falls Hydroelectric Project (FERC No. 2522), Sandstone Rapids Hydroelectric Project (FERC No. 2546), Potato Rapids Hydroelectric Project (FERC No. 2560), and Peshtigo Hydroelectric Project (FERC No. 2581). Issued June 28, 1996. Federal Energy Regulatory Commission, Office of Hydropower Licensing, Washington, D.C.

FERC (Federal Energy Regulatory Commission). 1991. Order amending license for Stiles Hydroelectric Project (FERC No. 1981). Issued July 26, 1991. Federal Energy Regulatory Commission, Office of Hydropower Licensing, Washington, D.C.

Gunderman, B. J. 2001. Population dynamics of lake sturgeon (*Acipenser fulvescens* Rafinesque) in the Manistee River. M. S. Thesis, Central Michigan University, Mt. Pleasant, Michigan.

Harkness, W. J. K. and J. R. Dymond. 1961. The lake sturgeon. Ontario Department of Lands and Forests, Fish and Wildlife Branch, Toronto, Ontario.

Hay-Chmielewski, E. M. and G. E. Whelan, editors. 1997. Lake Sturgeon Rehabilitation Strategy. Management report of the lake sturgeon committee, Fisheries Division, Michigan Department of Natural Resources, Ann Arbor, Michigan.

Hill, T. D. and J. R. McClain. 1999. Activities of the central Great Lakes bi-national lake sturgeon group in 1997 and 1998. United States Fish and Wildlife Service, Alpena, Michigan.

Ireland, S. C., J. T. Siple, V. L. Paragamian, V. D. Wakkinen, R. C. P. Beamesderfer. In Press. Spawning locations and movement of Kootenai River White Sturgeon. Submitted to Proceedings of the Fourth International Sturgeon Symposium. Journal of Applied Ichthyology.

Jacobson, K. C., M. R. Arkoosh, A. N. Kagley, E. R. Clemons, T. K. Collier, and E. Casillas. 2003. Cumulative effects of natural and anthropogenic stress on immune function and disease resistance in juvenile chinook salmon. Journal of Aquatic Animal Health 15:1-12.

Kempinger, J. J. 1996. Habitat, growth, and food of young lake sturgeons in the Lake Winnebago system, Wisconsin. North American Journal of Fisheries Management 16:102-114.

Kempinger, J. J. 1988. Spawning and early life history of lake sturgeon in the Lake Winnebago system, Wisconsin. American Fisheries Society Symposium 5:110-122.

King, E. L. and T. A. Edsall. 1979. Illustrated field guide for the classification of sea lamprey attack marks on Great Lakes lake trout. Great Lakes Fishery Commission Special Publication 79-1, Ann Arbor, Michigan.

Klar, G. T. and R. J. Young. 2003. Integrated management of sea lampreys in Lake Michigan 2002. Minutes of the March 19-20, 2003 Lake Michigan Committee meeting, Great Lakes Fishery Commission, Upper Lakes meetings, Milwaukee, Wisconsin.

Kort, E. 1984. A history of Wisconsin's Fox Cities. Windsor Publications Inc., Woodland Hills, California.

Le Cren, E. D. 1951. The length-weight relationship and seasonal cycle in gonad weight and condition in the perch *Perca fluviatilis*. Journal of Animal Ecology 20:201-219.

Lyons, J. and J. J. Kempinger. 1992. Movements of adult lake sturgeon in the Lake Winnebago system. Wisconsin Department of Natural Resources Research Report 156, Madison, Wisconsin.

Mac, M. J., T. R. Schwartz, C. C. Edsall, and A. M. Frank. 1993. Polychlorinated biphenyls in Great Lakes lake trout and their eggs: relations to survival and congener composition 1979-1988. Journal of Great Lakes Research 19:752-765.

Martin, D. B. 1913. History of Brown County, Wisconsin: past and present. Vol. I. S. J. Clarke Publishing Company, Chicago, Illinois.

Miller, A. I. and L. G. Beckman. 1996. First record of predation on white sturgeon eggs by sympatric fishes. Transactions of the American Fisheries Society 125:338-340.

Murphy, B. R. and D. W. Willis. 1996. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Nowak, A. M. and C. S. Jessop. 1987. Biology and management of the lake sturgeon (*Acipenser fulvescens*) in the Groundhog and Mattagami Rivers, Ontario. Pages 20-32 *in* Proceedings of a workshop on the lake sturgeon (*Acipenser fulvescens*). Ontario Ministry of Natural Resources Fisheries Technical Report Series No. 23, Toronto, Ontario.

Pauly, D. 1980. On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. Journal of the International Council for the Exploration of the Sea 39:175-192.

Peterson, D. L., B. Gunderman, and P. Vecsei. 2002. Lake sturgeon of the Manistee River: a current assessment of spawning stock size, age, and growth. Pages 175-182 *in* W. Van Winkle, P. Anders, D. H. Secor, and D. Dixon, editors. Biology, management, and protection of North American sturgeon. American Fisheries Society Symposium 28, American Fisheries Society, Bethesda, Maryland.

Power, M. and R. S. McKinley. 1997. Latitudinal variation in lake sturgeon size as related to the thermal opportunity for growth. Transactions of the American Fisheries Society 126:549-558.

Probst, R. T. and E. L. Cooper. 1954. Age, growth, and production of the lake sturgeon (*Acipenser fulvescens*) in the Lake Winnebago region, Wisconsin. Transactions of the American Fisheries Society 84:207-227.

Quinn, T. J. and R. B. Deriso. 1999. Quantitative fish dynamics. Oxford University Press, New York, New York.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Bulletin of the Fisheries Research Board of Canada No. 191, Ottawa, Quebec.

Rost, R. A., J. C. Brand, R. M. Bruch, D. H. Crehore, S. I. Dodson, R. L. Fassbender, L. J. Herman, T. F. Rasman, and A. M. Stranz. 1989. Water quality and restoration of the lower Oconto River, Oconto County, Wisconsin. Wisconsin Department of Natural Resources Technical Bulletin No. 164, Madison, Wisconsin.

Roussow, G. 1957. Some considerations concerning sturgeon spawning periodicity. Journal of the Fisheries Research Board of Canada 14:553-572.

Schnabel, Z. E. 1938. The estimation of the total fish population of a lake. American Mathematical Monthly 45:348-352.

Smith, D. 1998. Evidence of strong lake trout recruitment despite high PCB (total aroclors) concentrations. Journal of Great Lakes Research 24:974-979.

Smith, H. M. and M. M. Snell. 1891. Review of the fisheries of the Great Lakes in 1885, with introduction and description of fishing vessels and boats by J. W. Collins. U. S. Fish and Fisheries Commission Report for 1887, Washington, D.C.

Smith, I. R., B. Marchant, M. R. van den Heuvel, J. H. Clemons, and J. Frimeth. 1994. Embryonic mortality, bioassay derived 2,3,7,8-tetrachlorodibenzo-*p*-dioxin equivalents, and organochlorine contaminants in Pacific salmon from lake Ontario. Journal of Great Lakes Research 20:497-509.

Stantec Consulting Services, Inc. 2003. Lake sturgeon spawning studies on the Fox River below the De Pere Dam 2002-2003. Federal Energy Regulatory Commission Report No. 4914.

Thomas, M. V. and R. C. Haas. 1999. Capture of lake sturgeon with setlines in the St. Clair River, Michigan. North American Journal of Fisheries Management 19:610-612.

Thomas, M. V. and R. C. Haas. 2000. Evaluation of lake sturgeon, *Acipenser fulvescens*, populations in the St. Clair River and Lake St. Clair. Federal Aid Performance Report, Michigan Department of Natural Resources, Mt. Clemens, Michigan.

Threader, R. W. and C. S. Brousseau. 1986. Biology and management of the lake sturgeon in the Moose River, Ontario. North American Journal of Fisheries Management 6:383-390.

Thuemler, T. F. 1997. Lake sturgeon management in the Menominee River, a Wisconsin-Michigan boundary water. Environmental Biology of Fishes 48:311-317.

Thuemler, T. F. and G. Schnicke. 1992. Menominee River Fisheries Plan. Wisconsin and Michigan Departments of Natural Resources, Marinette, Wisconsin.

Tody, W. H. 1974. Whitefish, sturgeon, and the early Michigan commercial fishery. Pages 45-60 *in* Michigan fisheries centennial report 1873-1973. Michigan Department of Natural Resources, Lansing, Michigan.

United States Environmental Protection Agency and Wisconsin Department of Natural Resources. 1996. Green Bay Mass Balance Data. United States Environmental Protection Agency – Great Lakes National Program Office. Available: www.epa.gov/glnpo/gbdata. (March 2004)

Van Oosten, J. 1956. The lake sturgeon. Pages 9-10 *in* Our endangered wildlife. National Wildlife Federation, Washington, D.C.

Velleux, M. and D. Endicott. 1994. Development of a mass balance model for estimating PCB export from the Lower Fox River to Green Bay. Journal of Great Lakes Research 20:416-434.

Velleux, M., D. Endicott, J. Steuer, S. Jaeger, and D. Patterson. 1995. Long-term simulation of PCB export from the Fox River to Green Bay. Journal of Great Lakes Research 21:359-372.

Table 1. Sex ratio data for lake sturgeon captured during spawning run assessments in the Fox, Oconto, and Peshtigo Rivers, 1997-2003.

River	Year	# Males	# Females	# Unknowns	Males:Females & Unknowns
Fox	1997	1	0	0	1:0
Fox	1998	1	0	2	1:2
Fox	1999	0	0	1	0:1
Fox	2000	22	5	2	22:7
Fox	2001	16	1	2	16:3
Fox	2002	0	0	1	0:1
Oconto	2002	5	0	4	5:4
Oconto	2003	10	0	3	10:3
Peshtigo	1996	3	0	0	3:0
Peshtigo	1998	5	0	0	5:0
Peshtigo	2001	9	0	0	9:0
Peshtigo	2002	16	0	9	16:9
Peshtigo	2003	18	0	13	18:13

Table 2. Condition factors for lake sturgeon captured in Green Bay and surrounding tributaries, 1996-2003.

Group	Number of Fish*	Mean Relative Condition Factor (K_n)	Mean Fulton-type Condition Factor (K)
Spawning Stocks			
Fox River	31	1.037	0.640
Oconto River	20	0.938	0.570
Peshtigo River	67	0.955	0.580
Mixed Stocks			
Peshtigo River Mouth (spring)	84	1.084	0.658
Peshtigo River Mouth (fall)	58	0.993	0.603
Menominee River (fall)	105	0.922	0.563
Menominee River (total)	138	0.958	0.580
Green Bay (open water captures)	189	1.051	0.630

* Only includes fish for which both total length and weight were recorded.

Table 3. Summary of lake sturgeon recapture information for 1998-2003.

Fish ID #	Date Tagged	Date Recaptured	Tagging Location	Recapture Location
Fox River (1999-2001)				
89-06-12-01	6/12/1989	4/30/1999	Lake Winnebago	Fox River
86-04-20-01	4/20/1986	4/27/2000	Wolf River	Fox River
95-04-27-01	4/27/1995	4/27/2000	Upper Fox River	Fox River
00-04-27-03	4/27/2000	5/1/2001	Fox River	Fox River
00-04-27-05	4/27/2000	5/1/2001	Fox River	Fox River
00-04-27-11	4/27/2000	5/1/2001	Fox River	Fox River
Oconto River (2003)				
03-05-02-07	5/2/2003	5/9/2003	Oconto River	Oconto River
Peshtigo River (Spring 2002)				
98-05-05-01	5/5/1998	5/10/2002	Peshtigo River	Peshtigo River
02-04-25-03	4/25/2002	5/14/2002	Oconto River Mouth	Peshtigo River Mouth
98-05-05-05	5/5/1998	5/16/2002	Peshtigo River	Peshtigo River
02-05-17-02	5/17/2002	5/22/2002	Peshtigo River Mouth	Peshtigo River
02-05-30-08	5/29/1996	5/30/2002	Menominee River	Peshtigo River
Peshtigo River (Spring 2003)				
02-10-25-03	10/25/2002	4/24/2003	Peshtigo River Mouth	Peshtigo River Mouth
03-04-24-01	4/24/2003	4/29/2003	Peshtigo River Mouth	Peshtigo River Mouth
03-05-02-03	5/2/2003	5/8/2003	Oconto River	Peshtigo River Mouth
02-10-17-03	10/17/2002	5/19/2003	Peshtigo River Mouth	Peshtigo River
03-04-29-04	4/29/2003	5/19/2003	Peshtigo River Mouth	Peshtigo River
03-05-08-03	5/8/2003	5/19/2003	Peshtigo River Mouth	Peshtigo River
03-04-24-12	4/24/2003	5/20/2003	Peshtigo River Mouth	Peshtigo River
02-10-17-04	10/17/2002	5/21/2003	Peshtigo River Mouth	Peshtigo River
02-11-14-07	11/14/2002	5/21/2003	Peshtigo River Mouth	Peshtigo River
Menominee River (2002-2003)				
96-05-21-01	5/21/1996	6/7/2002	Menominee River	Menominee River
03-04-24-03	4/24/2003	9/11/2003	Peshtigo River Mouth	Menominee River
Open Water Assessment (2002)				
02-05-19-102	5/19/2002	7/6/2002	Marinette Net	Marinette Net
Open Water Assessment (2003)				
02-05-29-02	5/29/2002	6/2/2003	Peshtigo River Mouth	Oconto Net
02-06-13-105	6/13/2002	6/7/2003	N. Peshtigo Reef Net	S. Little Sturgeon Net
02-05-28-03	5/28/2002	6/17/2003	Peshtigo River	Peshtigo River Net
02-10-17-04	10/17/2002	6/20/2003	Peshtigo River Mouth	S. Little Sturgeon Net
01-05-01-06	5/1/2001	6/23/2003	Fox River	S. Little Sturgeon Net
02-10-10-09	10/10/2002	6/23/2003	Peshtigo River Mouth	S. Little Sturgeon Net
03-05-27-103	5/27/2003	6/28/2003	Peshtigo River Net	S. Little Sturgeon Net
Dead Fish (2002-2003)				
00-04-27-16	4/27/2000	8/5/2002	Fox River	East-central Green Bay
02-10-17-04	10/17/2002	8/14/2003	Peshtigo River Mouth	Sturgeon Bay

Table 3 continued.

Fish ID #	Date Tagged	Date Recaptured	Tagging Location	Recapture Location
Dead Fish (2002-2003) continued				
01-05-03-02	5/3/2001	8/19/2003	Peshtigo River	East-central Green Bay
Peshtigo River (Fall 2002)				
01-05-02-06	5/2/2001	10/10/2002	Peshtigo River	Peshtigo River Mouth
02-05-29-08	5/29/2002	10/10/2002	Peshtigo River Mouth	Peshtigo River Mouth
Peshtigo River (Fall 2003)				
03-05-07-06	5/7/2003	10/16/2003	Peshtigo River Mouth	Peshtigo River Mouth
02-05-21-04	5/21/2002	10/17/2003	Peshtigo River Mouth	Peshtigo River Mouth
Incidental Captures (1998-2003)				
91-07-17-01	7/17/1991	7/2/1998	Menominee River	North Bay (Door Co.)
96-10-22-01	10/22/1996	4/6/1999	Southern Lake Huron	Baileys Harbor (Door Co.)
98-10-14-01	10/14/1998	8/22/1999	Grand Traverse Bay	Grand Traverse Bay
00-06-08-01	6/8/2000	5/16/2001	Grand Traverse Bay	Little Traverse Bay
94-05-23-01	5/23/1994	10/17/2003	Sturgeon Bay Canal	Naubinway (Lake Mich.)

Table 4. Summary of visual observations of lake sturgeon in the Fox River below De Pere Dam, 1997-2003. An asterisk indicates that spawning was observed on that date.

	NUMBER OF FISH OBSERVED						
Date	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
17 April	--	--	--	--	--	0	0
18	--	--	--	--	--	2*	0
19	--	--	--	--	--	12	--
20	--	--	--	--	--	6	--
21	--	--	--	--	--	--	2
22	--	--	--	--	--	8	2
23	--	--	--	--	--	2-3	3
24	--	--	--	--	2	1	--
25	--	--	--	--	0	4	3
26	--	--	--	--	2-3	8-12*	2
27	--	--	--	50-60*	0	0	--
28	--	--	--	50-60*	0	--	--
29	--	--	>30*	--	2	--	15
30	--	--	30*	--	20*	--	24*
01 May	--	≥1	--	1	30-35*	--	20-21*
02	--	--	--	--	2-3	--	2
03	--	--	--	20*	2	--	1
04	--	≥2	--	--	1-2	≥2	--
05	--	--	--	7	--	4*	0
06	--	≥1	--	--	--	6	--
07	6-12*	12*	--	--	0	0	--
08	6-10	<12	--	--	1	8-12*	--
09	0	--	--	--	0	9-10	--
10	--	--	--	1	--	3	--
11	--	--	--	--	1	--	--
12	1	--	--	--	--	--	--
13	--	--	--	--	--	--	--
14	--	--	--	--	1	--	--
15	--	--	--	--	--	2-3	--
16	--	--	--	--	0	3-4	--
17	--	--	--	--	0	2	--
18	--	--	--	--	0	--	--
19	--	--	--	--	--	--	--
20	--	--	--	--	--	6*	--
21	--	--	--	--	--	2-3	--
22	--	--	--	--	--	2	--
23	--	--	--	--	--	≥15*	--
24	--	--	--	--	--	1	--
25	--	--	--	--	0	--	--
26	--	--	--	--	--	--	--
27	--	--	--	--	--	0	--
28	--	--	--	--	--	0	--
29	--	--	--	--	--	--	--
30	--	--	--	--	--	--	--
31	--	--	--	--	--	0	--

Table 5. Schnabel population estimates for the 2003 lake sturgeon spawning run in the Peshtigo River. The numbers in parentheses are the 95% confidence intervals for each estimate.

Estimate #	**Sampling Periods Included in Estimate**	**% Assumed To Be Part of 2003 Spawning Run**	**Estimated Run Size**
1	Fall 2002 and Spring 2003	100	577 (309-1,404)
2	Spring 2003	100	489 (204-1,431)
3	Fall 2002 and Spring 2003	50	240 (129-585)
4	Spring 2003	50	199 (104-729)

Table 6. Number of larval lake sturgeon caught by date in each of the four major tributaries to Green Bay. The Peshtigo River data is for the upstream site only, and thus is comparable to the data collected on the other three rivers. (WDNR = Wisconsin Department of Natural Resources, GB = Green Bay Office, USFWS = United States Fish and Wildlife Service, and P = Peshtigo Office)

Date	Fox River (Stantec, WDNR-GB, USFWS)	Oconto River (USFWS)	Peshtigo River (Purdue University)	Menominee River (WDNR-P)
11 May	---	---	0	---
12 May	---	0	4*	---
13 May	0	---	0	---
14 May	---	0	1*	---
15 May	0	---	1*	---
16 May	---	0	0	---
17 May	2*	---	0	---
18 May	2*	0	0	---
19 May	0	---	0	---
20 May	---	0	0	---
21 May	10	---	0	---
22 May	18	2	3 (1*)	---
23 May	8	---	8	---
24 May	5	---	12	---
25 May	2	--	24	---
26 May	0	0	34	---
27 May	0	---	12	2
28 May	1	2	3	---
29 May	0	---	63	1
30 May	0	1	35	---
31 May	0	---	160	---
01 June	0	1	148	---
02 June	---	---	54	17
03 June	---	0	16	---
04 June	---	---	11	1
05 June	---	0	22	---
06 June	---	---	3	---
07 June	---	---	0	---
08 June	---	0	0	---
09 June	---	---	0	---
10 June	---	---	0	---
11 June	---	---	0	---
12 June	---	---	0	---
# Larvae	48	6	614	21
Effort (net h)	438	227	410	27
CPUE	0.11	0.026	1.5	0.78

* Yolk-sac larvae

Table 7. Summary of potential lake sturgeon spawning habitat and marginal spawning habitat in four Green Bay tributaries.

River	# Potential Spawning Sites	Total Area of Potential Spawning Habitat (ha)	# Marginal Spawning Sites	Total Area of Marginal Spawning Habitat (ha)
Fox	1	6.03	1	0.52
Oconto	6	18.46	3	0.84
Peshtigo	8	7.59	1	1.52
Menominee	1	18.18	0	0.00

Table 8. Summary of sea lamprey wounding data for lake sturgeon captured during spring spawning run assessments in the Oconto and Peshtigo Rivers and the open water assessment in Green Bay in 2003.

	# Fish	# Fish	% Fish	Number of Marks								# Marks/
Assessment	Examined	Marked	Marked	A1	A2	A3	A4	B1	B2	B3	B4	Fish
Spring	57	30	53	2	2	1	8	2	4	6	26	0.96
Open Water	155	52	34	0	3	5	7	11	9	4	38	0.50
Total	212	82	39	2	5	6	15	13	13	10	64	0.60

Table 9. Extrapolated population estimates for the discrete lake sturgeon spawning stocks from the Fox, Oconto, and Peshtigo Rivers. Average spawning periodicity was assumed to be 1.5 years for males and 5 years for females. The sex ratio in the entire population was assumed to be 1:1.

River	Spawning Run Estimate	# Males in Spawning Run	# Females in Spawning Run	Total # Males in Population	Total # Females in Population	Total # Adults in Population
Fox	50	38	12	57	60	117
Oconto	25	19	6	29	30	59
Peshtigo	200	154	46	231	230	461

Table 10. Von Bertalanffy growth parameters, calculated from mean length-at-age data, for lake sturgeon from Green Bay (present study; 2002-2003), the Manistee River (Gunderman 2001), Lake St. Clair (Thomas & Haas 2000), and the upper Menominee River (Priegel 1973). The numbers in parentheses are the 95% confidence intervals.

Waterbody	L_∞ (cm)	K	t_0
Green Bay	204 (184-225)	0.055 (0.036-0.073)	-3.94 (-6.91--0.97)
Manistee River	176 (168-184)	0.075 (0.057-0.092)	-2.214 (-4.32--0.20)
Lake St. Clair	159 (155-163)	0.077 (0.068-0.085)	-2.558 (-3.261--1.86)
Upper Menominee River	168 (162-174)	0.063 (0.056-0.070)	-0.408 (-1.01--0.19)

Table 11. Commercial fishers, agencies, and other volunteers that provided data on incidental lake sturgeon captures in Lake Michigan, 1996-2003. (GTB = Grand Traverse Band of Ottawa and Chippewa Indians, LTBB = Little Traverse Bay Band of Odawa Indians, LRB = Little River Band of Ottawa Indians, SST = Sault Ste. Marie Tribe of Chippewa Indians, USFWS = United States Fish and Wildlife Service, WDNR = Wisconsin Department of Natural Resources, IDNR = Indiana Department of Natural Resources, LWF = lake whitefish, YEP = yellow perch, LAT = lake trout, CHS = chinook salmon, BLO = bloater, and RUE = ruffe)

Collector	Gear (Target Species)	Years Data Collected
Bob Benson (WI commercial fisher)	Gill Net (LWF)	2001
Val Drzewiecki (WI commercial fisher)	Gill Net (YEP)	2001
Hickey Brothers (WI commercial fisher)	Pound Net (LWF)	1998-1999
Hickey Brothers (WI commercial fisher)	Trap Net (LWF)	1999-2001
Rick Johnson (WI commercial fisher)	Gill Net (LWF)	1999
Rick Johnson (WI commercial fisher)	Trap Net (LWF)	2002
Ken Koyen (WI commercial fisher)	Gill Net (LWF)	2003
Mark Maricque (WI commercial fisher)	Gill Net (YEP)	2003
Mark Maricque (WI commercial fisher)	Gill Net (LWF)	2003
Doug Tahlman (WI commercial fisher)	Gill Net (LWF)	2003
Neil Teskie (WI commercial fisher)	Trap Net (LWF)	2001-2002
Jeff Weborg (WI commercial fisher)	Trap Net (LWF)	2001
Greg Ruleau (MI commercial fisher)	Trap Net (LWF)	1999-2003
GTB Natural Resources Department	Gill Net (LAT)	1996
GTB Natural Resources Department	Gill Net (LWF)	1998
GTB Natural Resources Department	Unknown	2002
Monte Carew (GTB commercial fisher)	Gill Net (LWF)	1996
George Duhamel (GTB commercial fisher)	Gill Net (LAT)	1998-1999
William Fowler (GTB commercial fisher)	Gill Net (LAT)	2000
William Fowler (GTB commercial fisher)	Gill Net (LWF)	2002
Stuart Schwander (GTB commercial fisher)	Trap Net (LWF)	2001
LTBB Natural Resources Department	Gill Net (CHS)	2000-2002
John Keshick (LTBB commercial fisher)	Gill Net (LWF)	2000-2003
Chippewa/Ottawa Resource Authority	Gill Net (LWF)	2003
Darren Mitchell (LRB commercial fisher)	Gill Net (BLO)	2002
Darren Mitchell (LRB commercial fisher)	Trap Net (LWF)	2001
Theron King (SST commercial fisher)	Trap Net (LWF)	2003
Corey Kroesing (sport fisher)	Hook & Line (CHS)	1999
Private citizens and agency personnel	Found Dead	2001-2003[1]
Consumers Energy	Graded-mesh Gill Net	2000-2002[2]
USFWS	Trawl (RUE)	2002
USFWS	Gill Net (LAT)	2003
WDNR	Trawl (YEP)	2001
IDNR	Gill Net (LAT)	2003

[1] Dead fish found along the shore of Lake Michigan (including Green Bay)
[2] Fish captured in assessment gill nets near Ludington Pumped Storage Facility

Table 12. Statistical comparisons of total length data for lake sturgeon captured in gill nets (monofilament if not otherwise indicated) of various mesh sizes during spawning run assessments in the Oconto and Peshtigo Rivers, 2002-2003. Asterisks indicate significant differences.

Mesh Size (cm)	Groups Compared	Statistical Test	p-value
Within Mesh Size Comparisons			
25.4	Peshtigo River - multifilament Peshtigo River Mouth (spring) Peshtigo River Mouth (fall) Oconto River Oconto River Mouth	Kruskal-Wallis One-way ANOVA	0.475
30.5	Peshtigo River – multifilament Peshtigo River Mouth (spring) Peshtigo River Mouth (fall) Oconto River	One-way ANOVA	0.635
35.6	Peshtigo River Mouth (spring) Peshtigo River Mouth (fall)	Mann-Whitney U-test	0.816
Between Mesh Size Comparisons			
Various	Combined 25.4 cm mesh Combined 30.5 cm mesh Combined 35.6 cm mesh	Kruskal-Wallis One-way ANOVA	<0.001*
Various	Combined 25.4 cm mesh Combined 30.5 cm mesh	Mann-Whitney U-test (post-hoc)†	<0.001*
Various	Combined 25.4 cm mesh Combined 35.6 cm mesh	Mann-Whitney U-test (post-hoc)	<0.001*
Various	Combined 30.5 cm mesh Combined 35.6 cm mesh	Mann-Whitney U-test (post-hoc)	0.002*

† The value of alpha was adjusted to 0.017 for the post-hoc tests to avoid increasing the likelihood of a type I error.

Table 13. Catch-per-unit-effort (CPUE) of lake sturgeon during the open water trap net assessments in Green Bay, 2002-2003.

Net Material	Net Section(s)	Catch	Net Days[1]	CPUE[2]
Nylon	Pot	79	300	0.263
Nylon	Hearts	102	315	0.324
Nylon	All	184	315	0.584
Marlex	Pot	15	193	0.078
Marlex	Hearts	4	202	0.020
Marlex	All	21	202	0.104
Total		205	517	0.397

[1] The pots were tied shut a few days before the nets were removed, but some sturgeon were captured in the hearts and leads during this time.
[2] Number of lake sturgeon captured per net day.

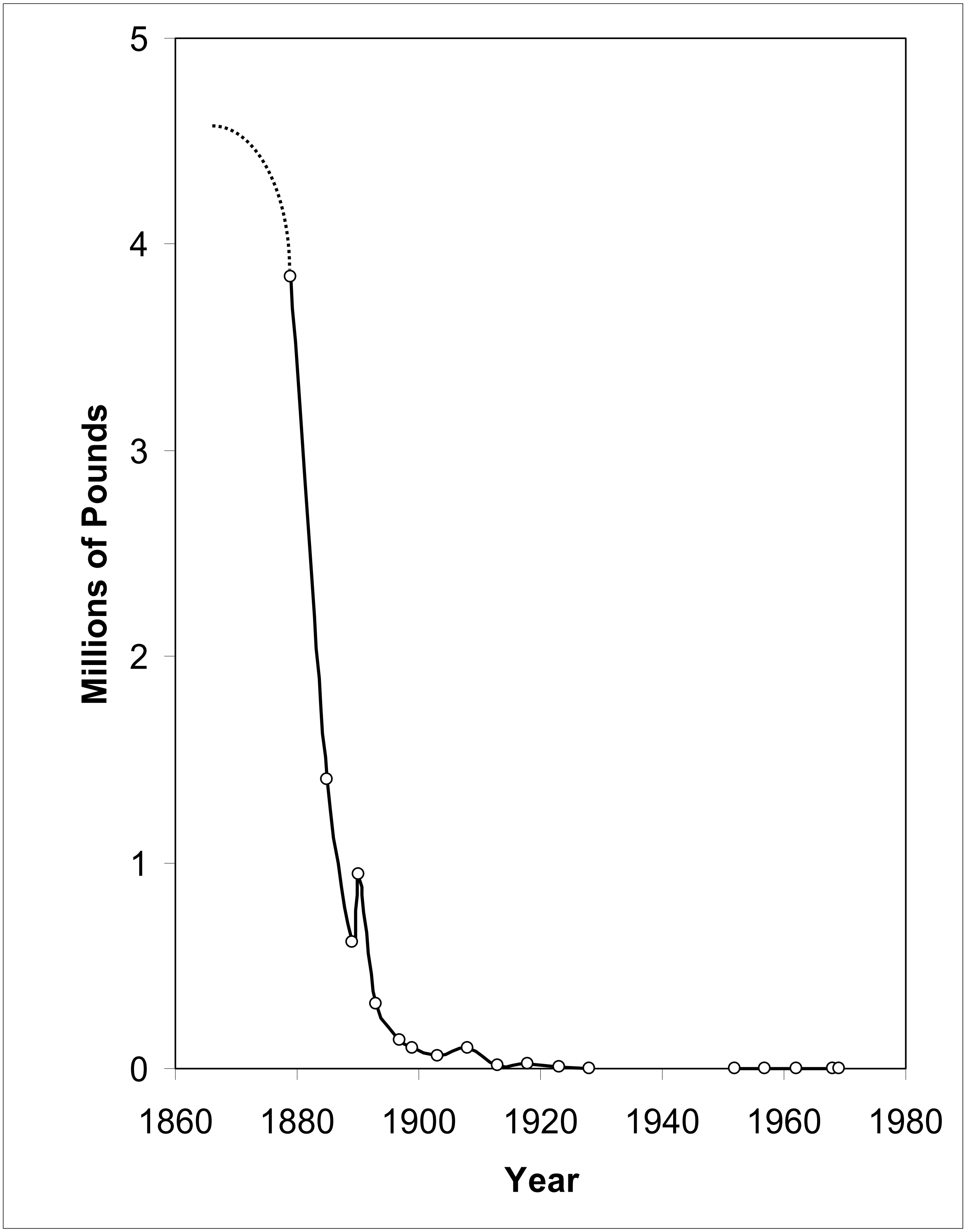


Figure 1. Commercial harvest of lake sturgeon from Lake Michigan (data from Baldwin et al. 1979). Populations had begun declining before commercial harvest records were instituted in 1879, so it is likely that annual lake sturgeon harvests were even higher during the 1860s and 1870s (dashed line).

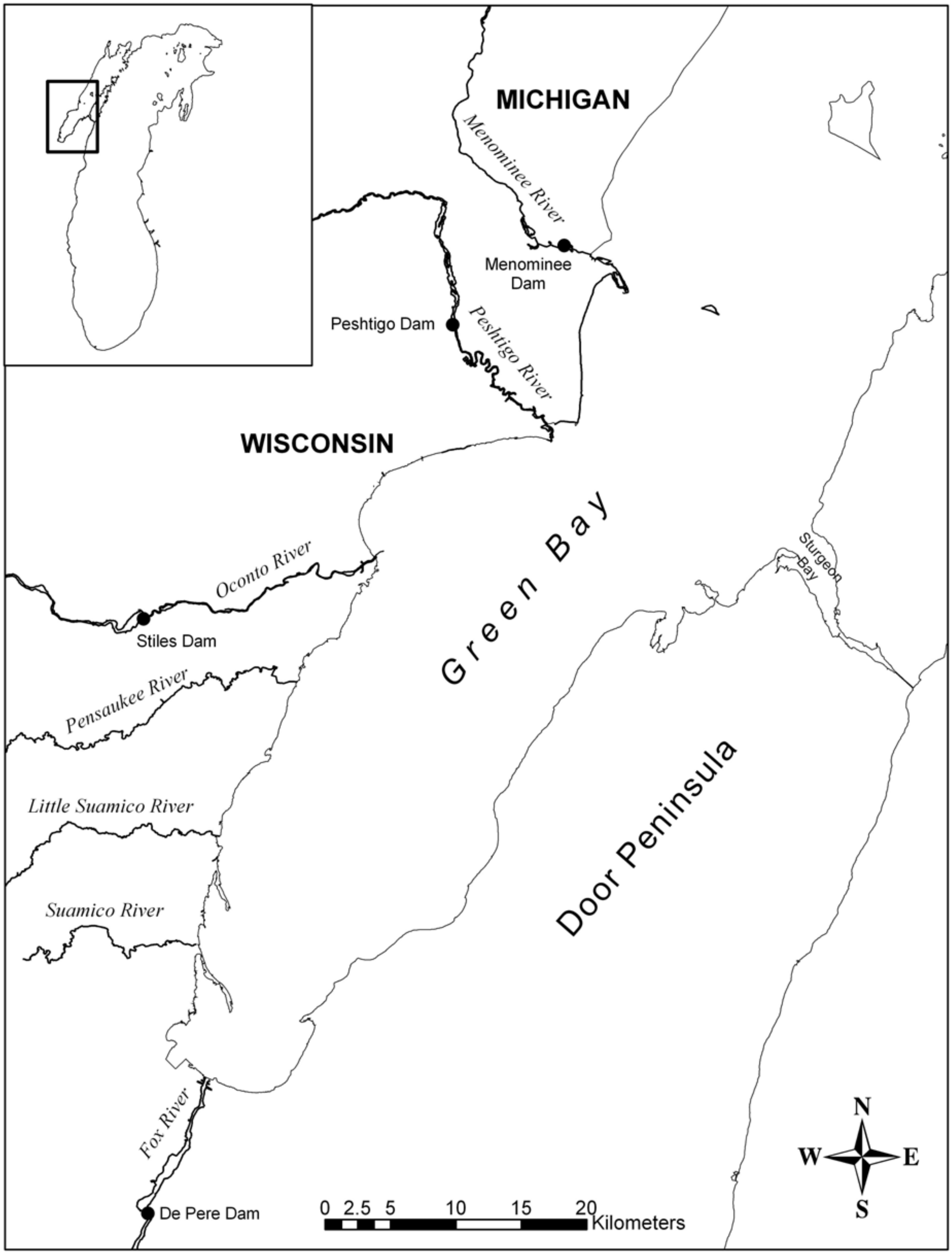


Figure 2. Locations of major Green Bay tributaries and lowermost dams on the four rivers sampled during this project (Fox, Oconto, Peshtigo, and Menominee Rivers).

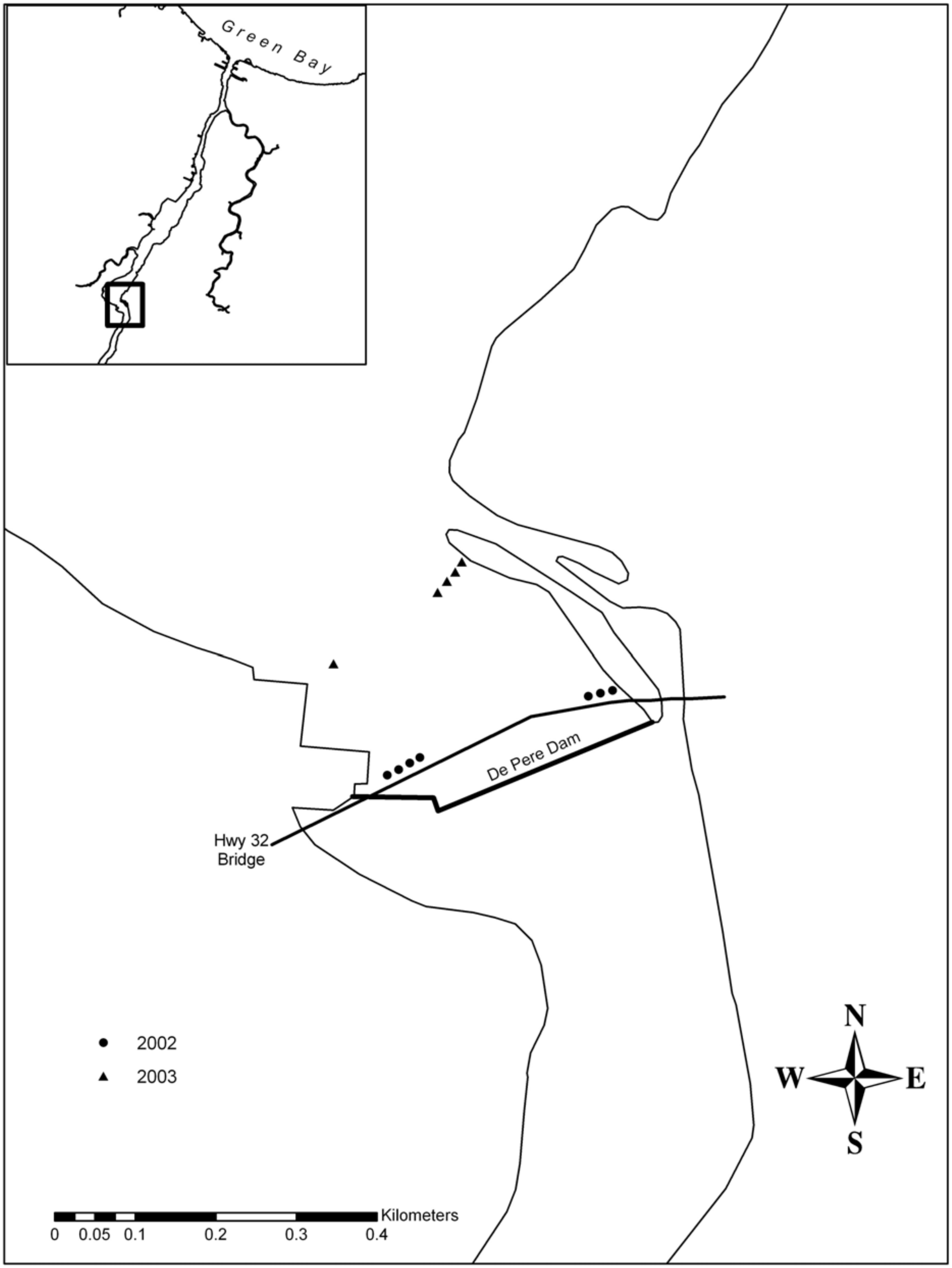


Figure 3. Larval drift sampling locations in the Fox River, 2002-2003.

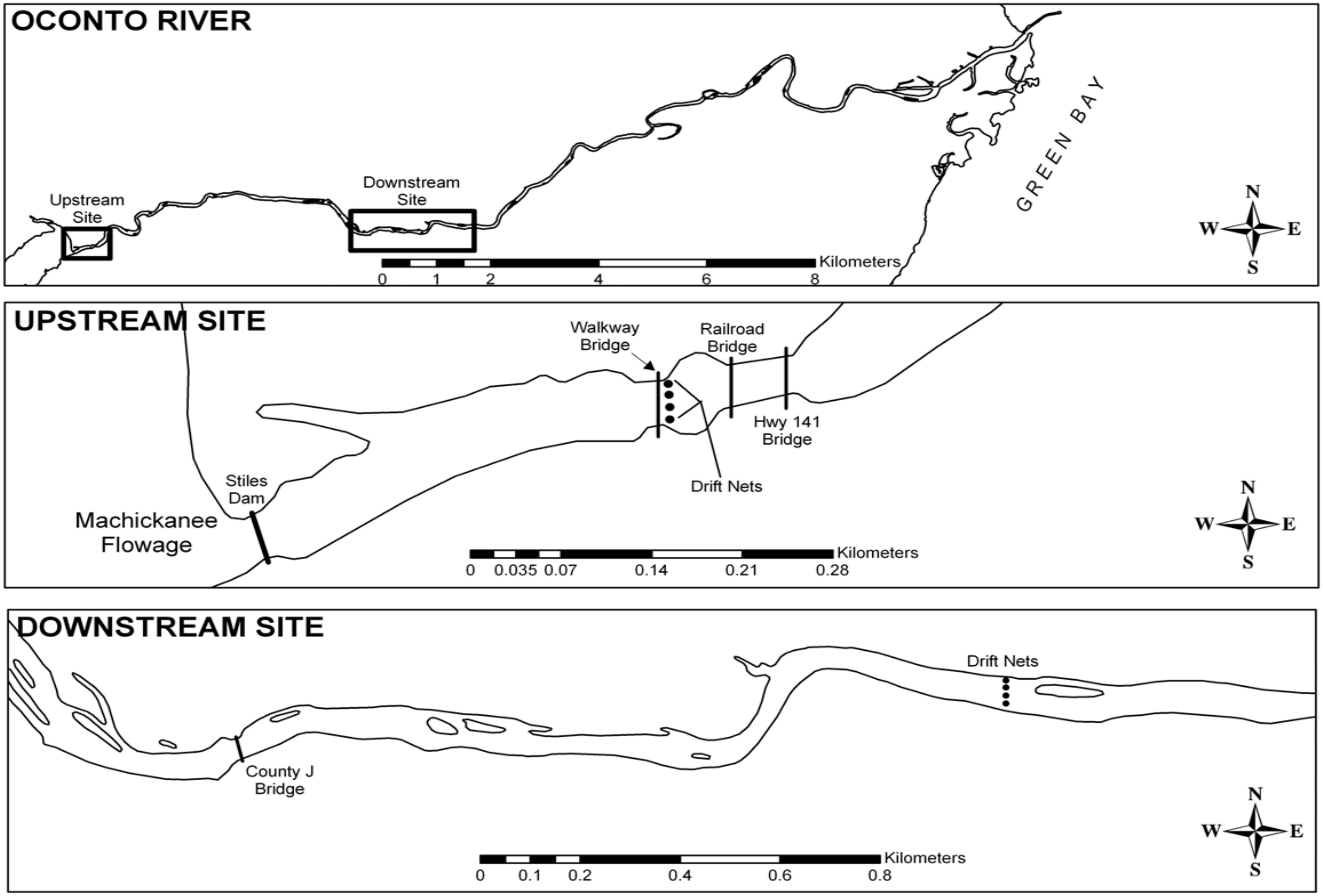


Figure 4. Larval drift sampling locations in the Oconto River. Drift nets were fished at the upstream location during 2002 and 2003. Drift nets were fished at the downstream location during June 2002.

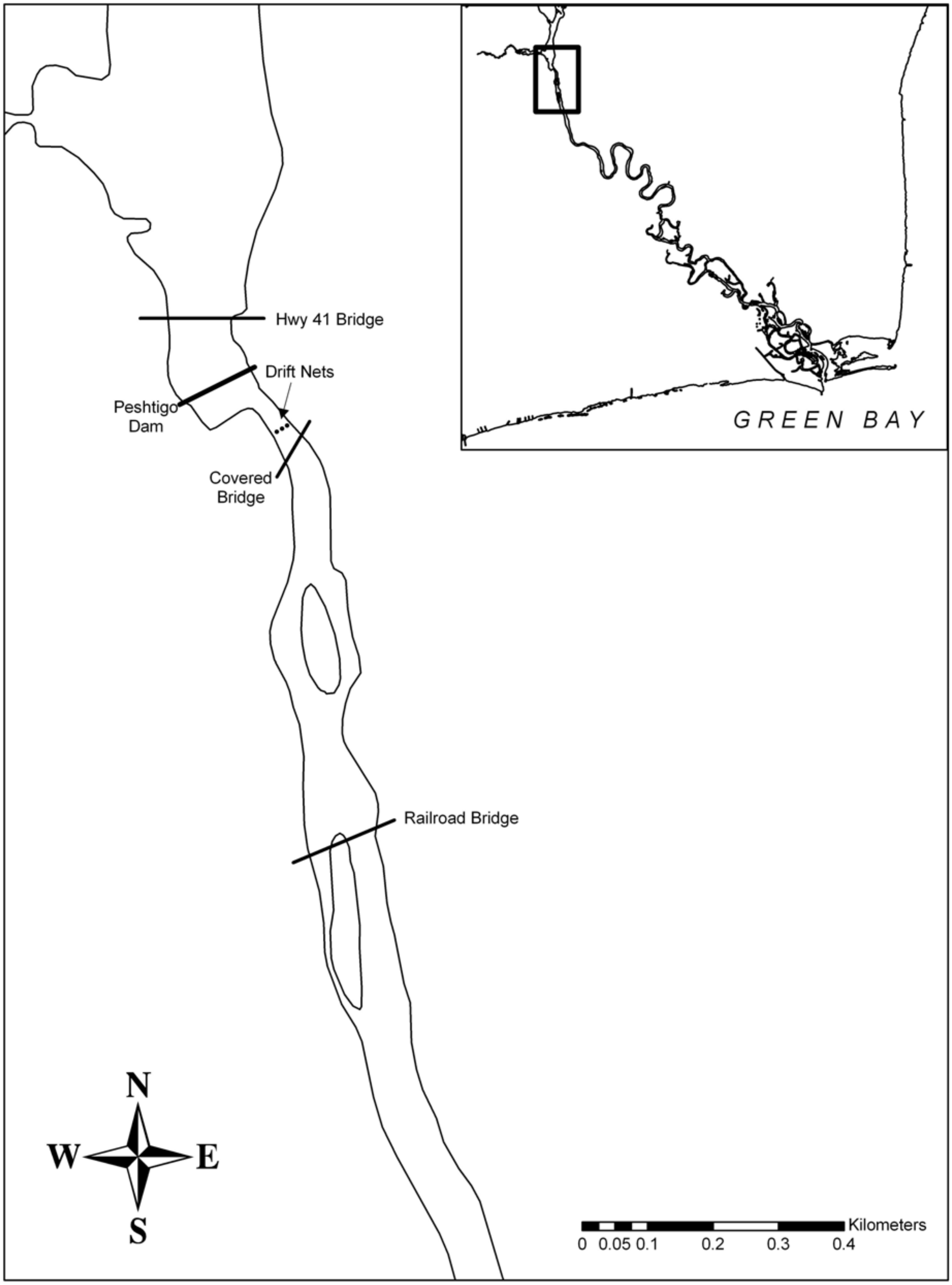


Figure 5. Location of the upstream larval drift sampling site on the Peshtigo River, 2002-2003. (For downstream sampling locations in the Peshtigo River, see report for GLFT project 109).

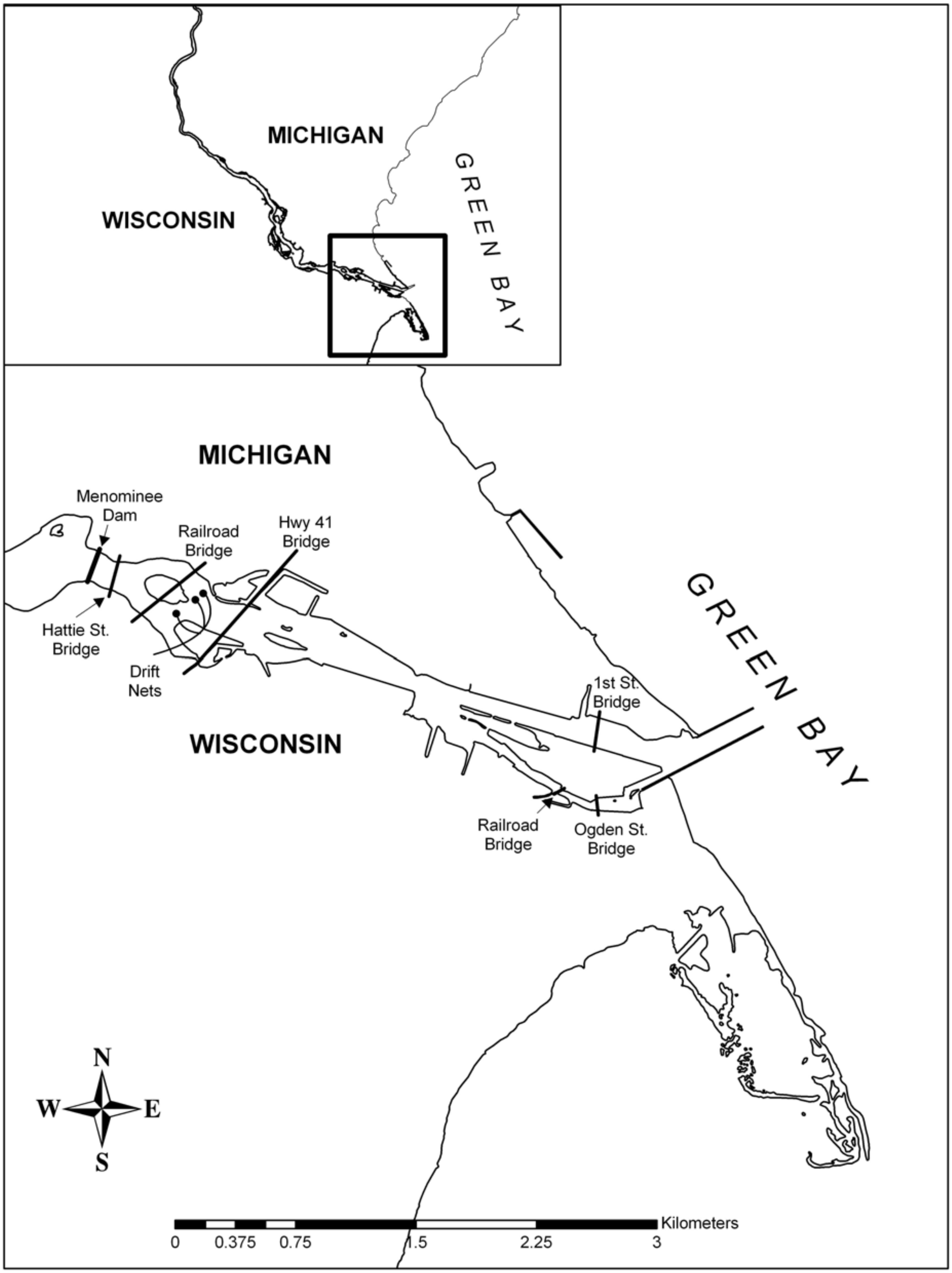


Figure 6. Larval drift sampling locations in the Menominee River, May-June 2003.

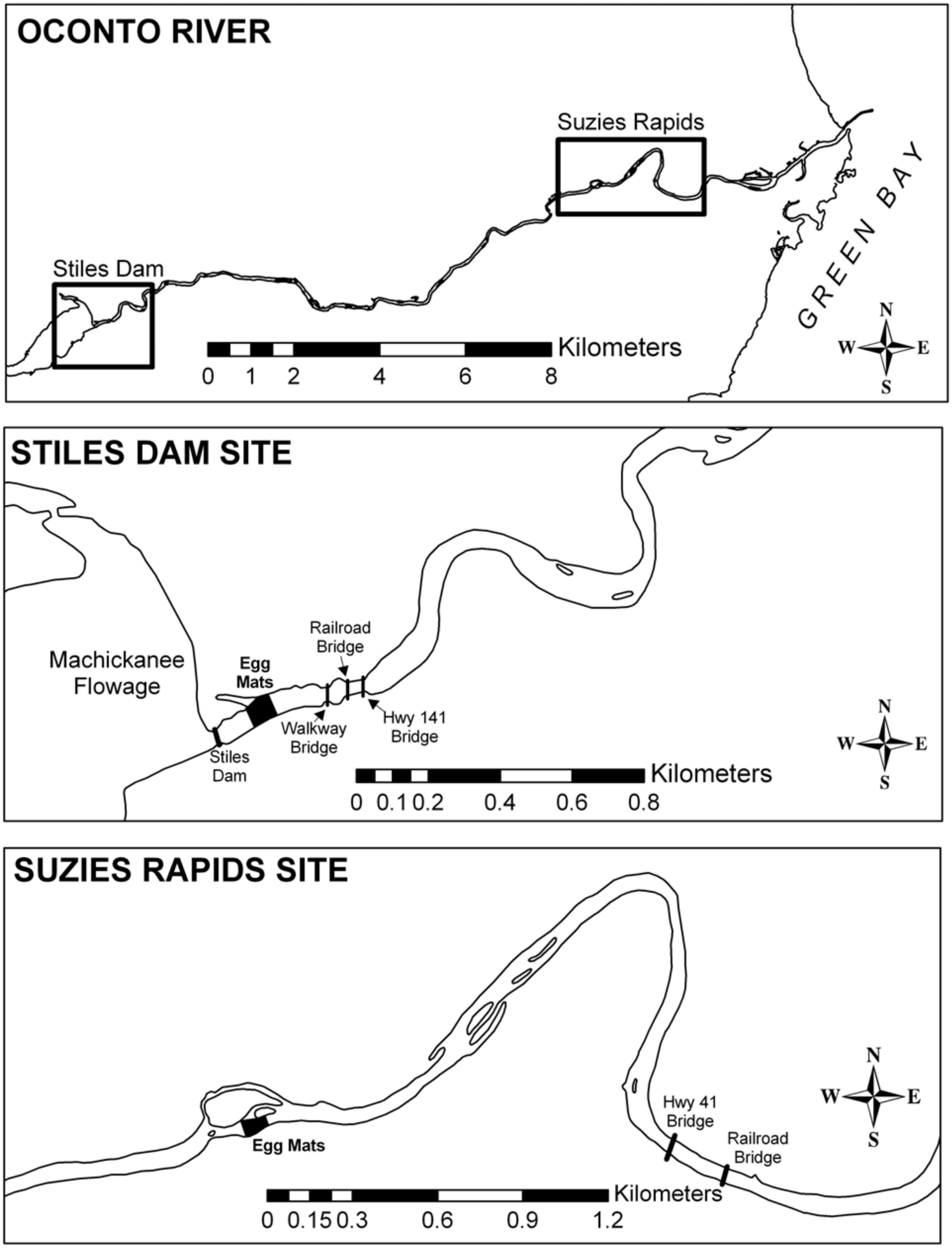


Figure 7. Egg mat sampling locations in the Oconto River, April-June 2003.

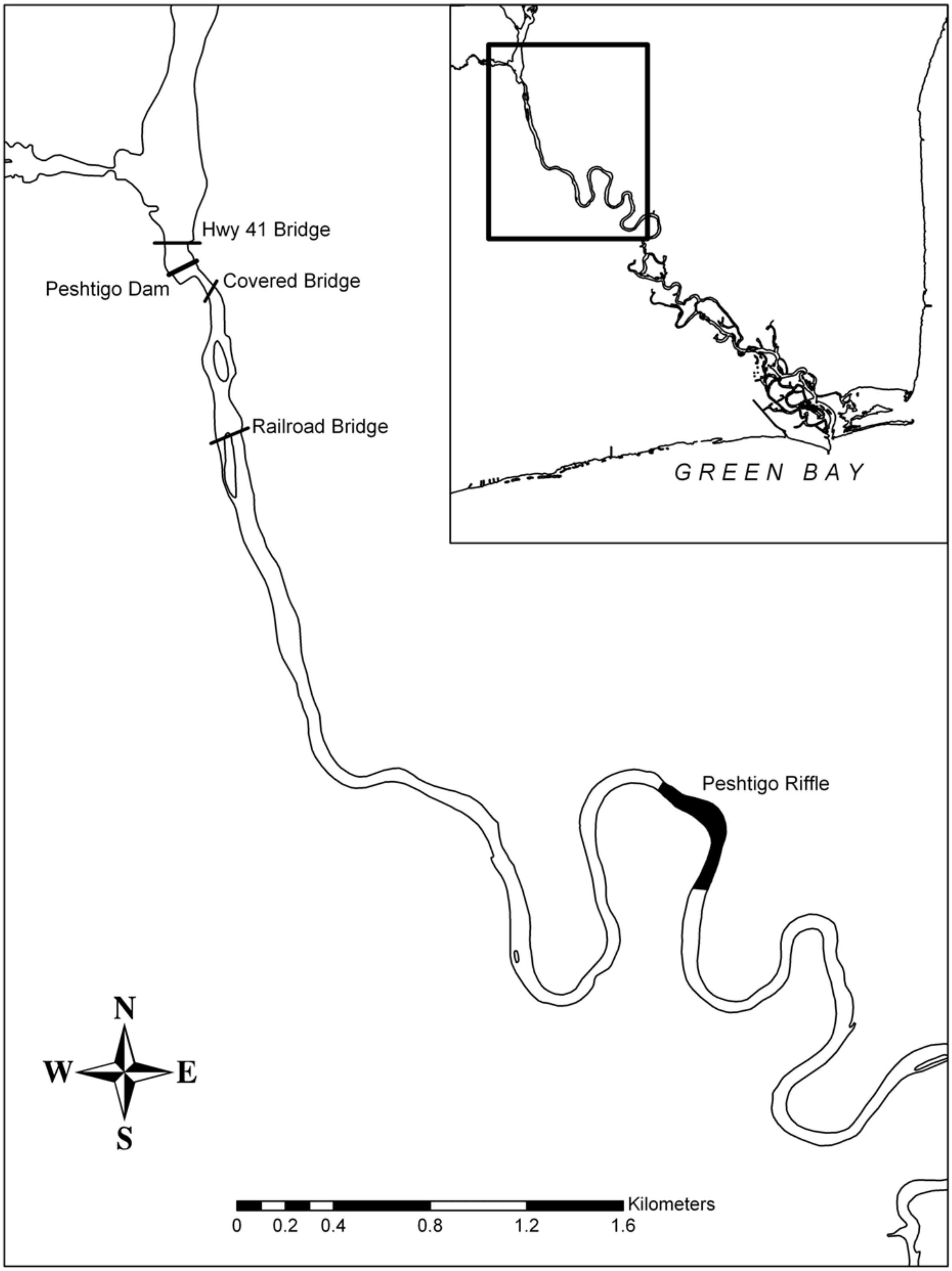


Figure 8. Egg mat sampling location in the Peshtigo River, May-June 2003.

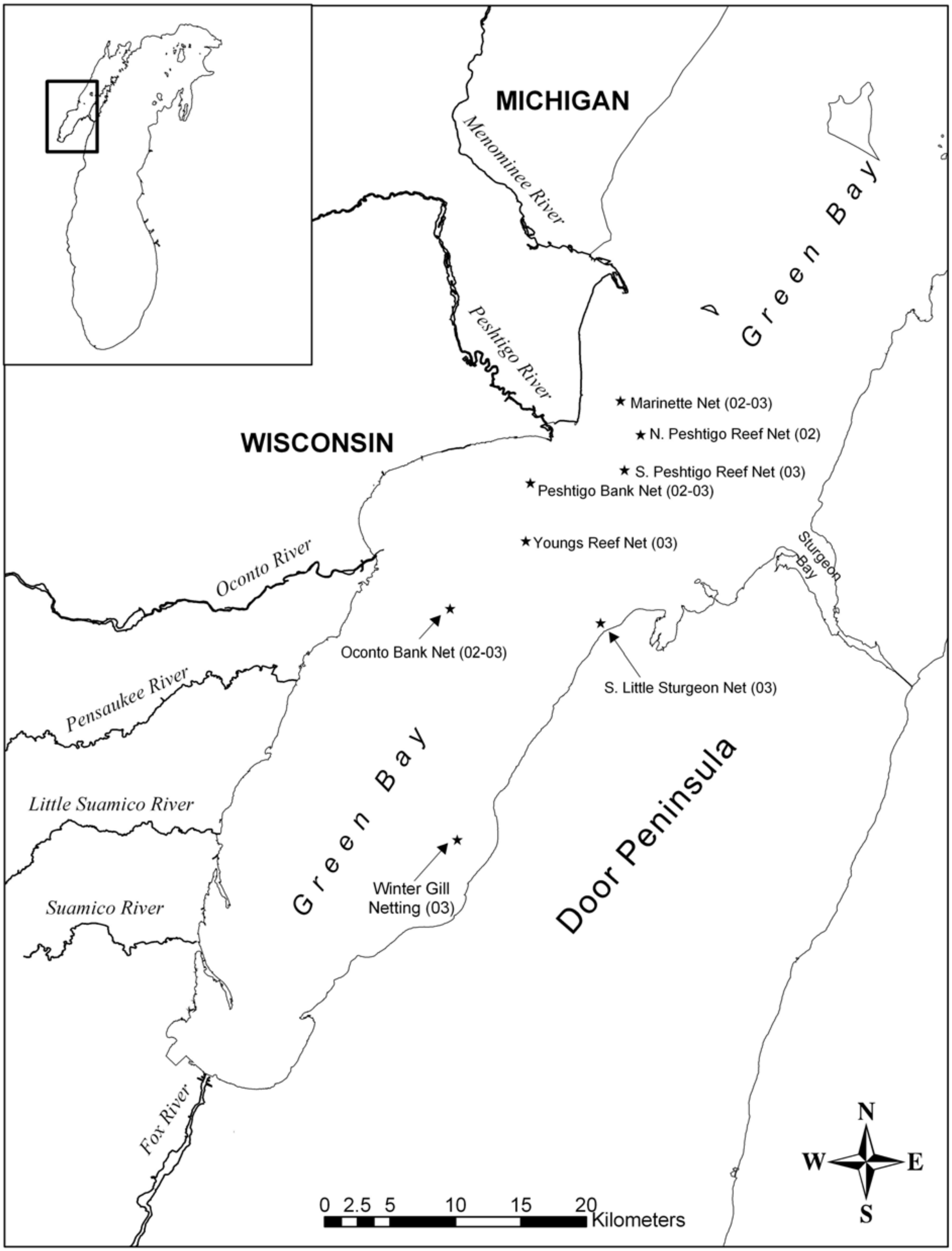


Figure 9. Sampling locations where targeted open water assessments were conducted in Green Bay, 2002-2003. The numbers in parentheses indicate the years that work was conducted at each location.

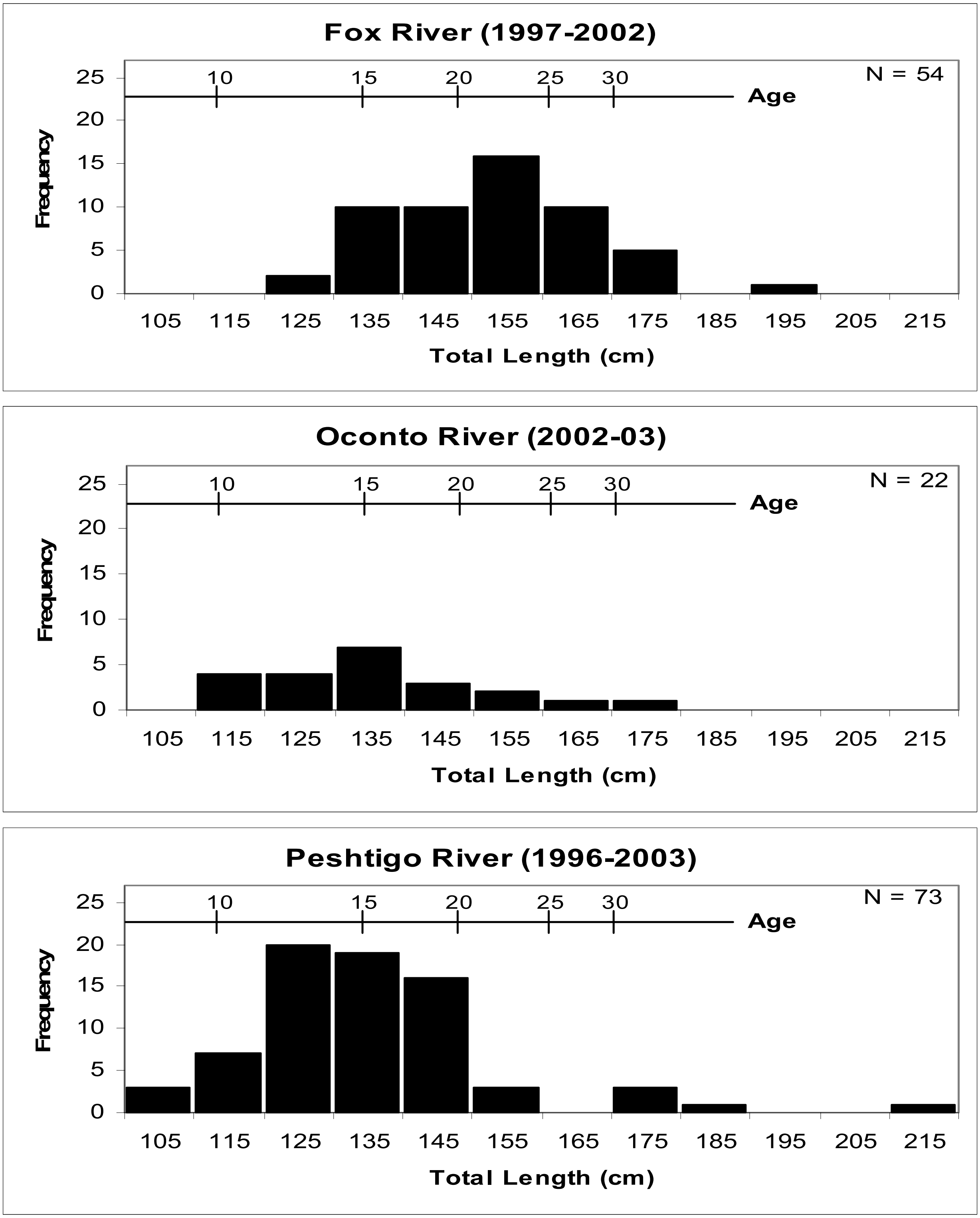
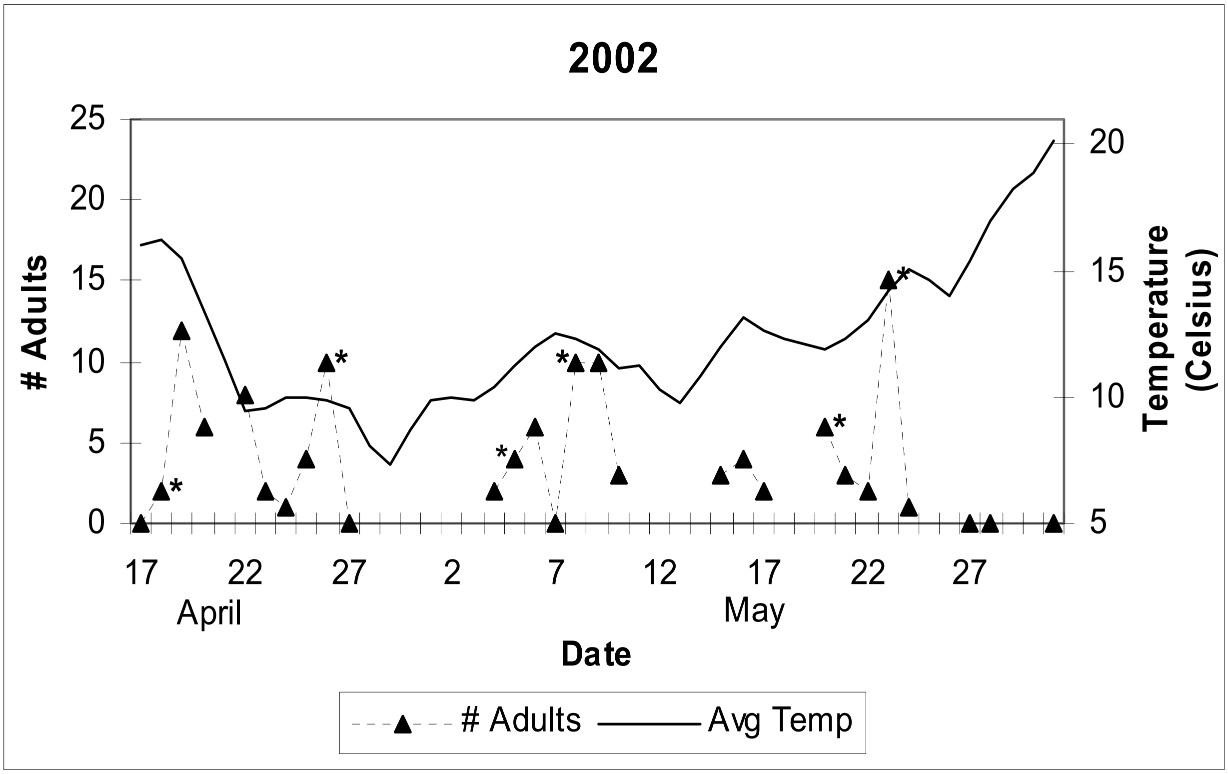


Figure 10. Length-frequency distributions for lake sturgeon captured during spawning run assessments in the Fox, Oconto, and Peshtigo Rivers, 1996-2003. The estimated age line was constructed using size-at-age data from 102 lake sturgeon captured in Green Bay and surrounding tributaries during 2001-2003.



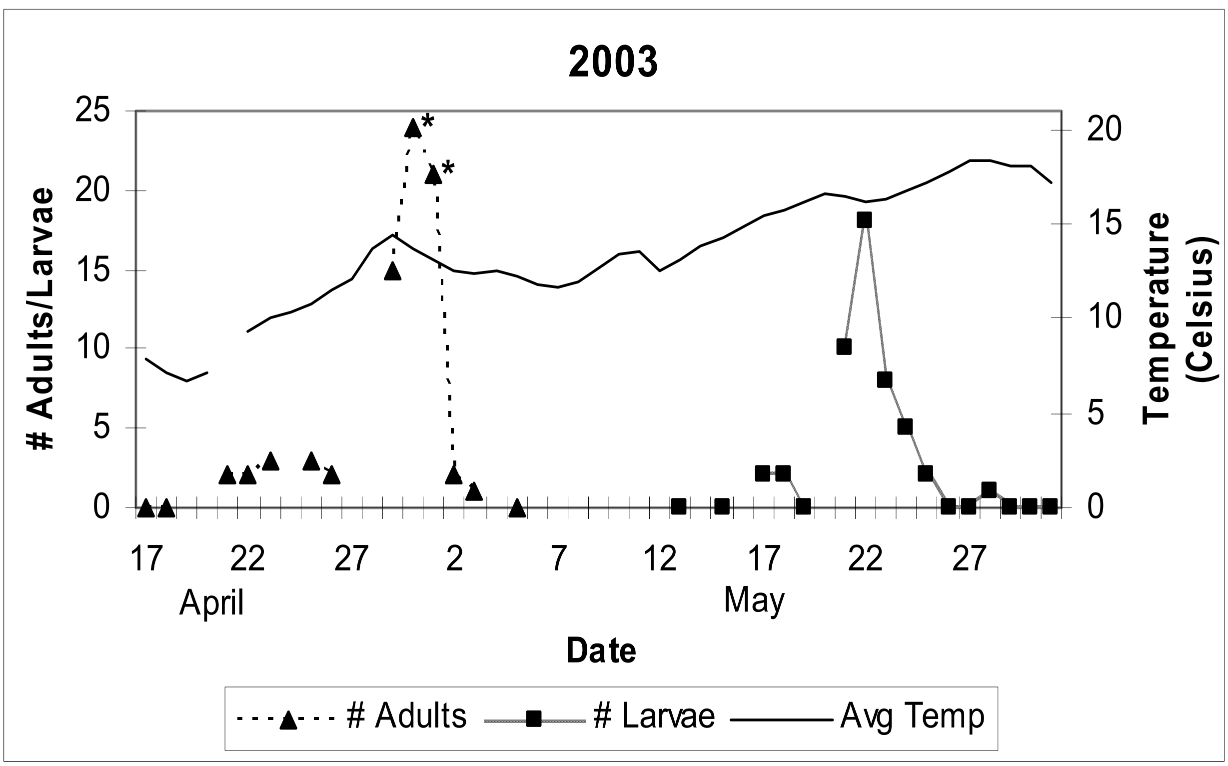
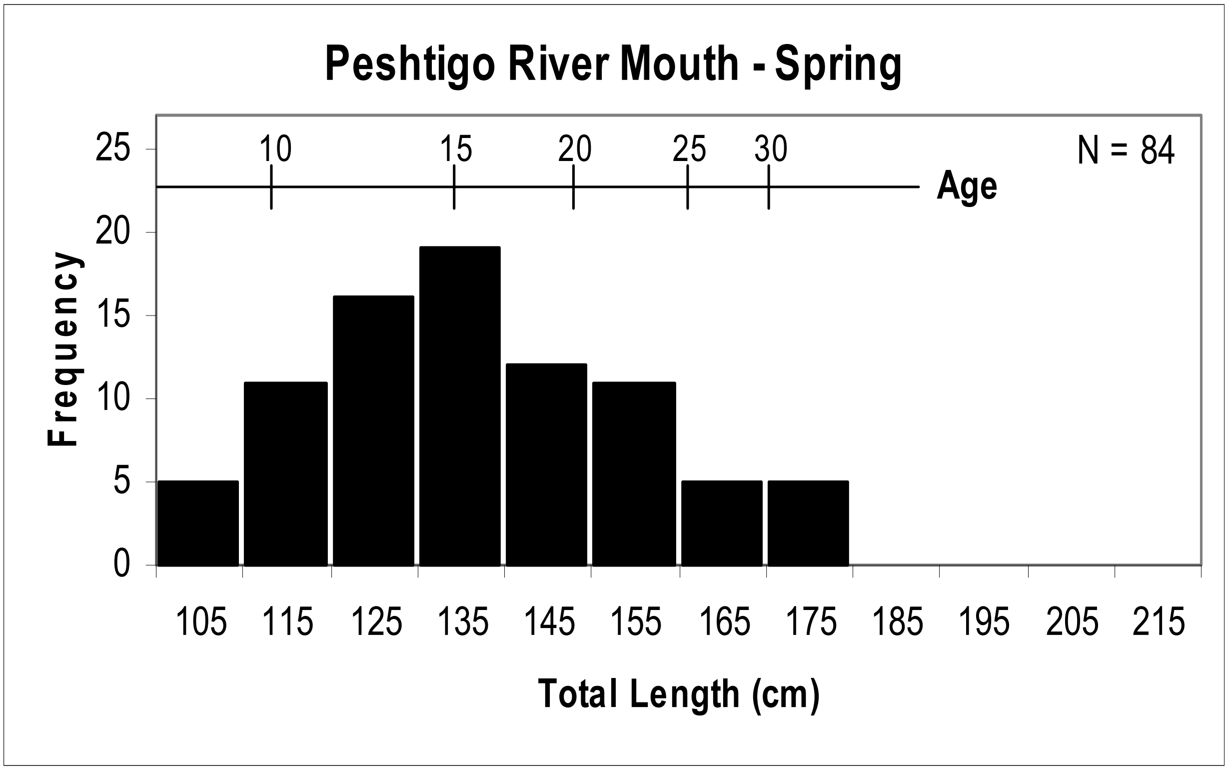


Figure 11. Daily water temperatures, numbers of adult lake sturgeon observed, and numbers of larval sturgeon collected in the Fox River below De Pere Dam during April-May, 2002-2003.



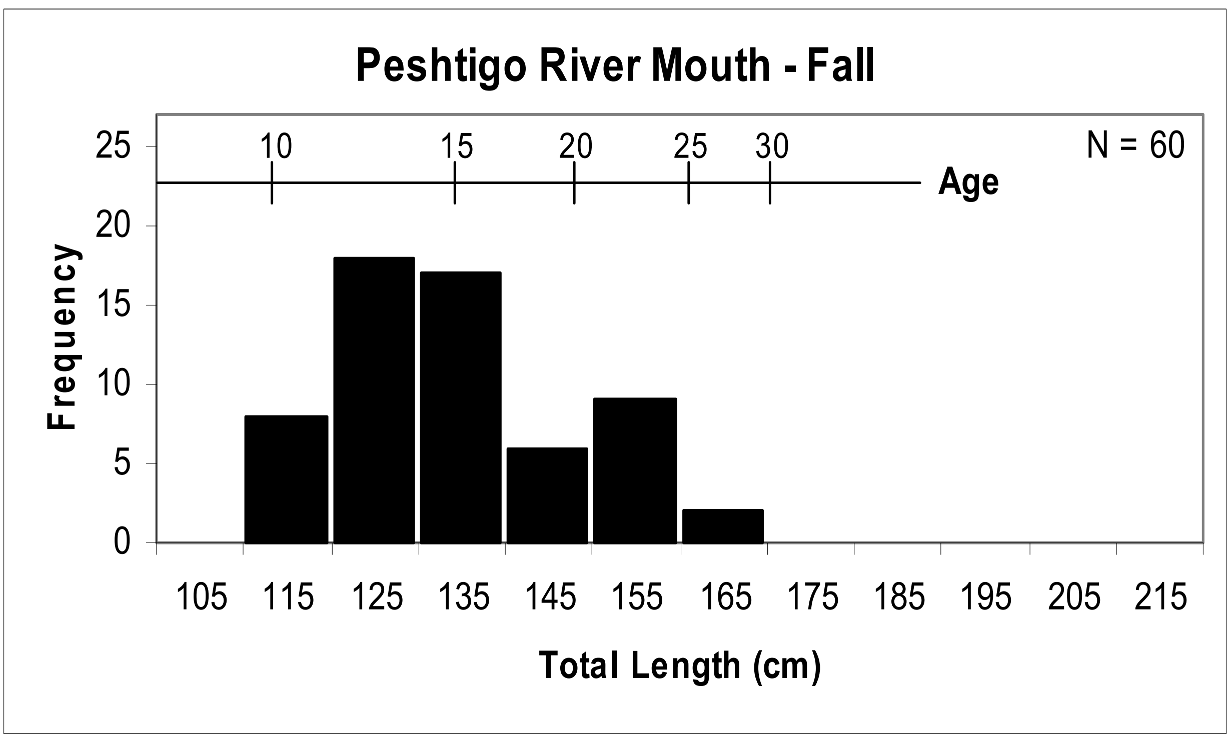
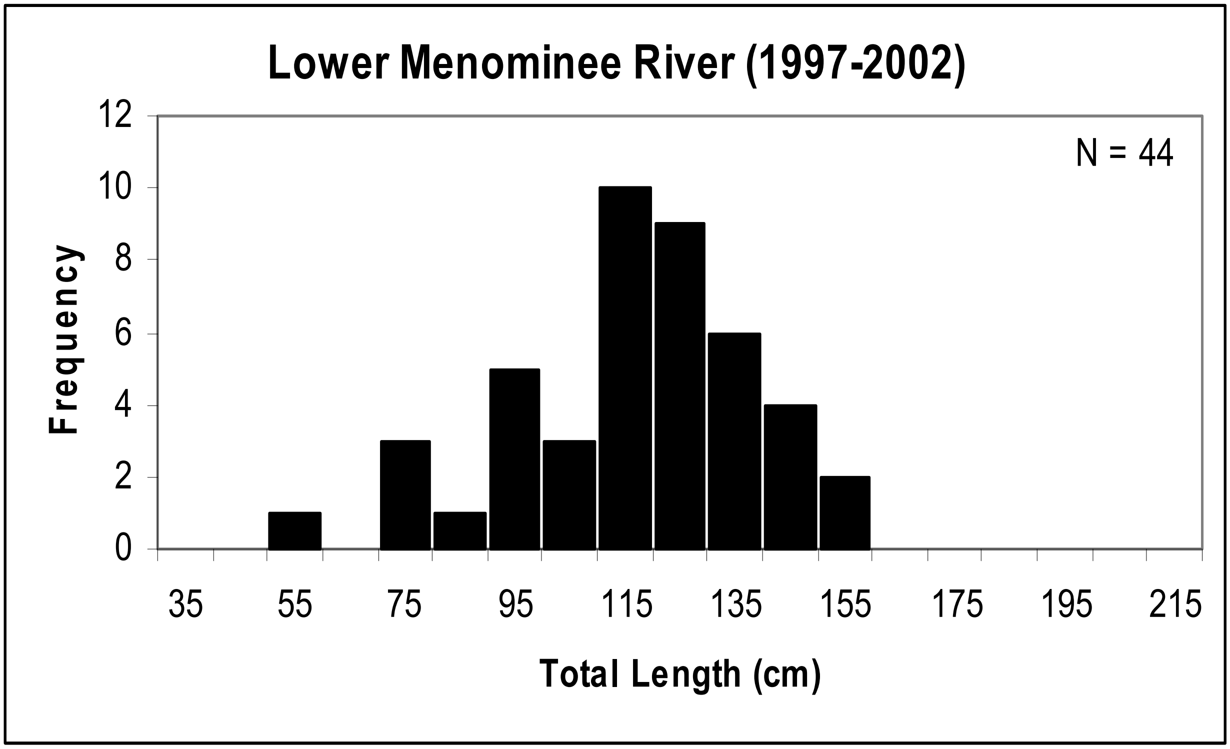


Figure 12. Length-frequency distributions for lake sturgeon captured at the mouth of the Peshtigo River during spring and fall, 2002-2003. The estimated age line was constructed using size-at-age data from 102 lake sturgeon captured in Green Bay and surrounding tributaries during 2001-2003.



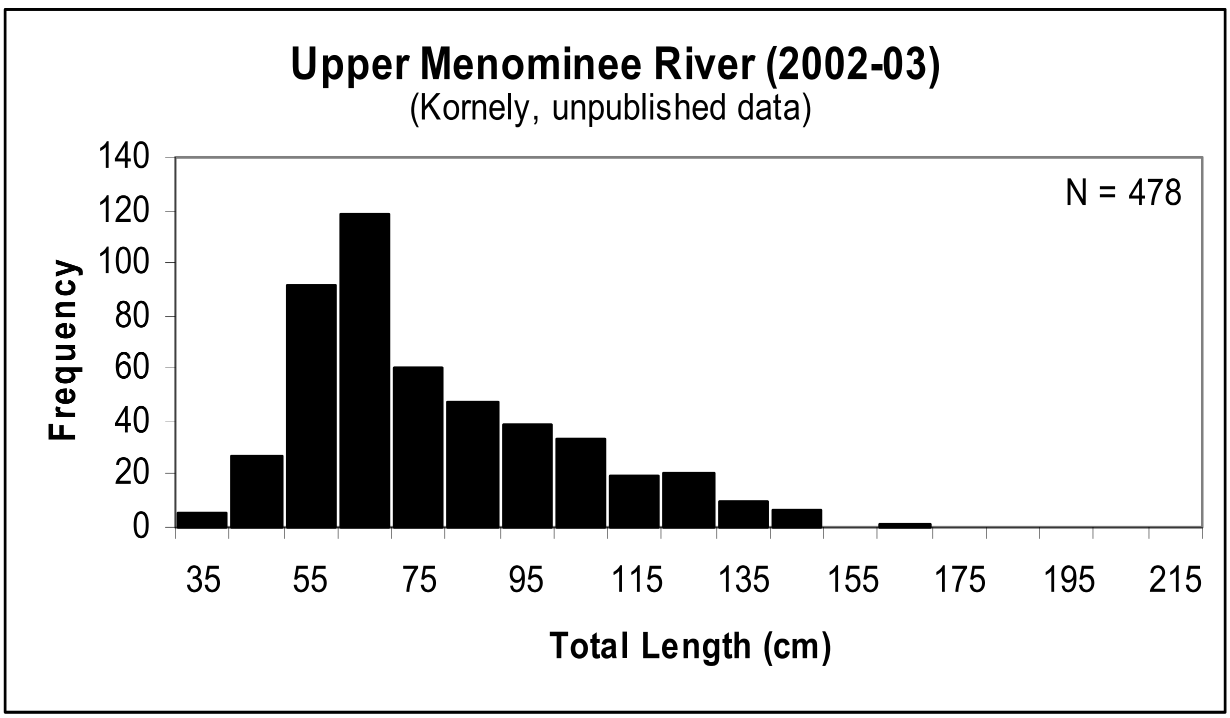


Figure 13. Length-frequency distributions for lake sturgeon captured in the Menominee River below Menominee Dam (Lower Menominee River) during the present study and for sturgeon collected during Wisconsin Department of Natural Resources' summer assessments below Grand Rapids Dam (Upper Menominee River).

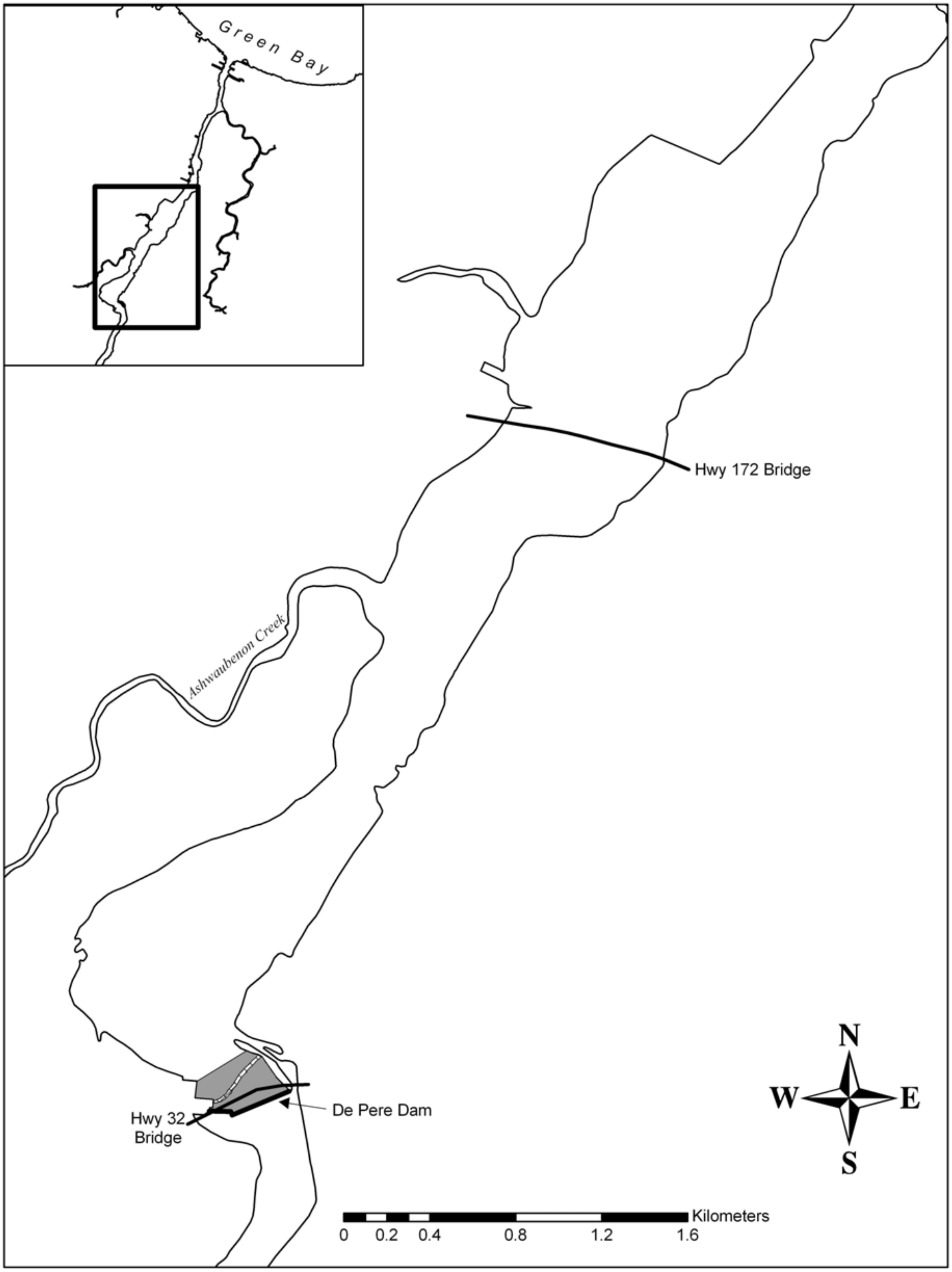


Figure 14. Potential lake sturgeon spawning habitat in the Fox River. The gray areas represent potential spawning habitat, and the cross-hatched area represents marginal spawning habitat.

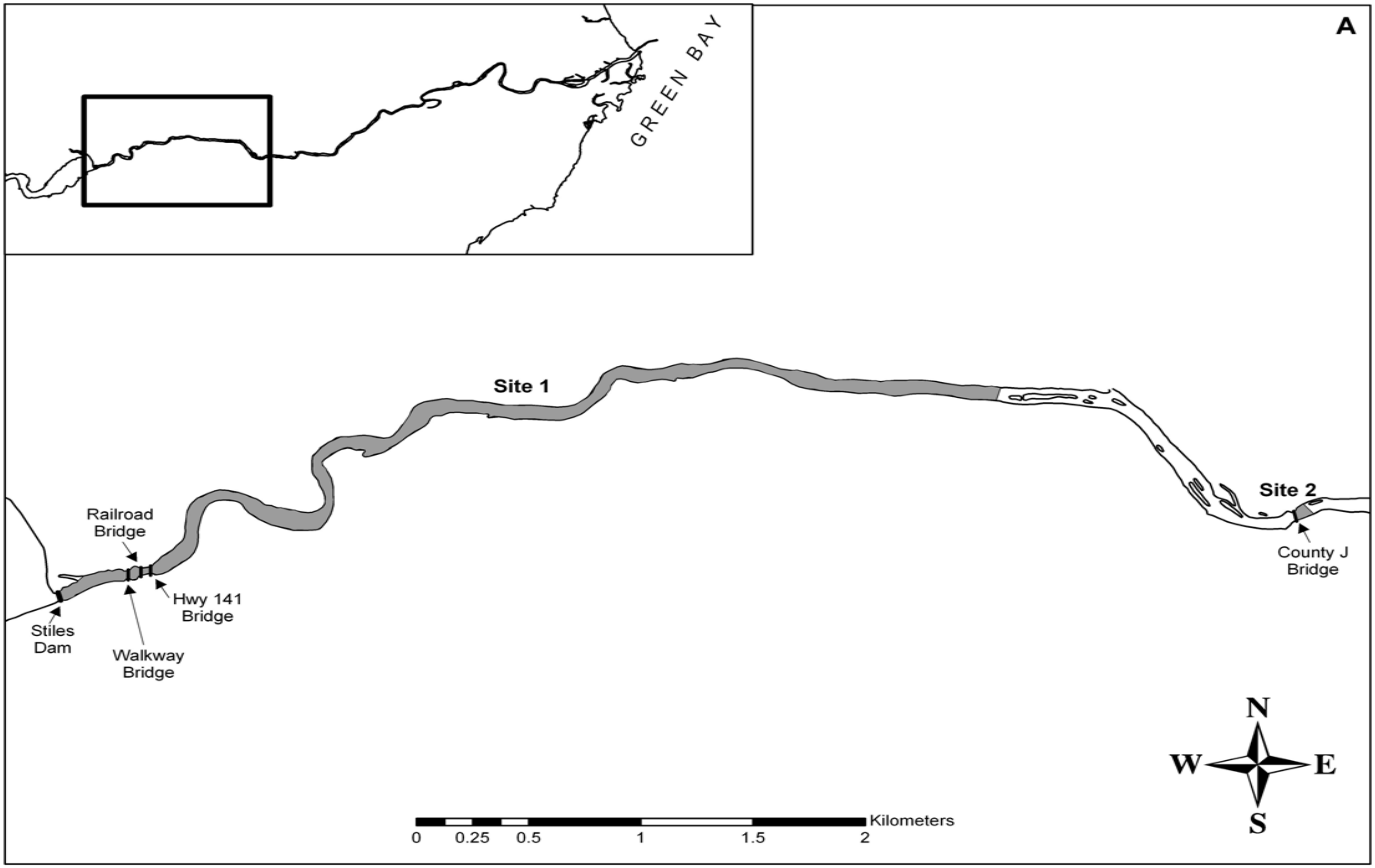
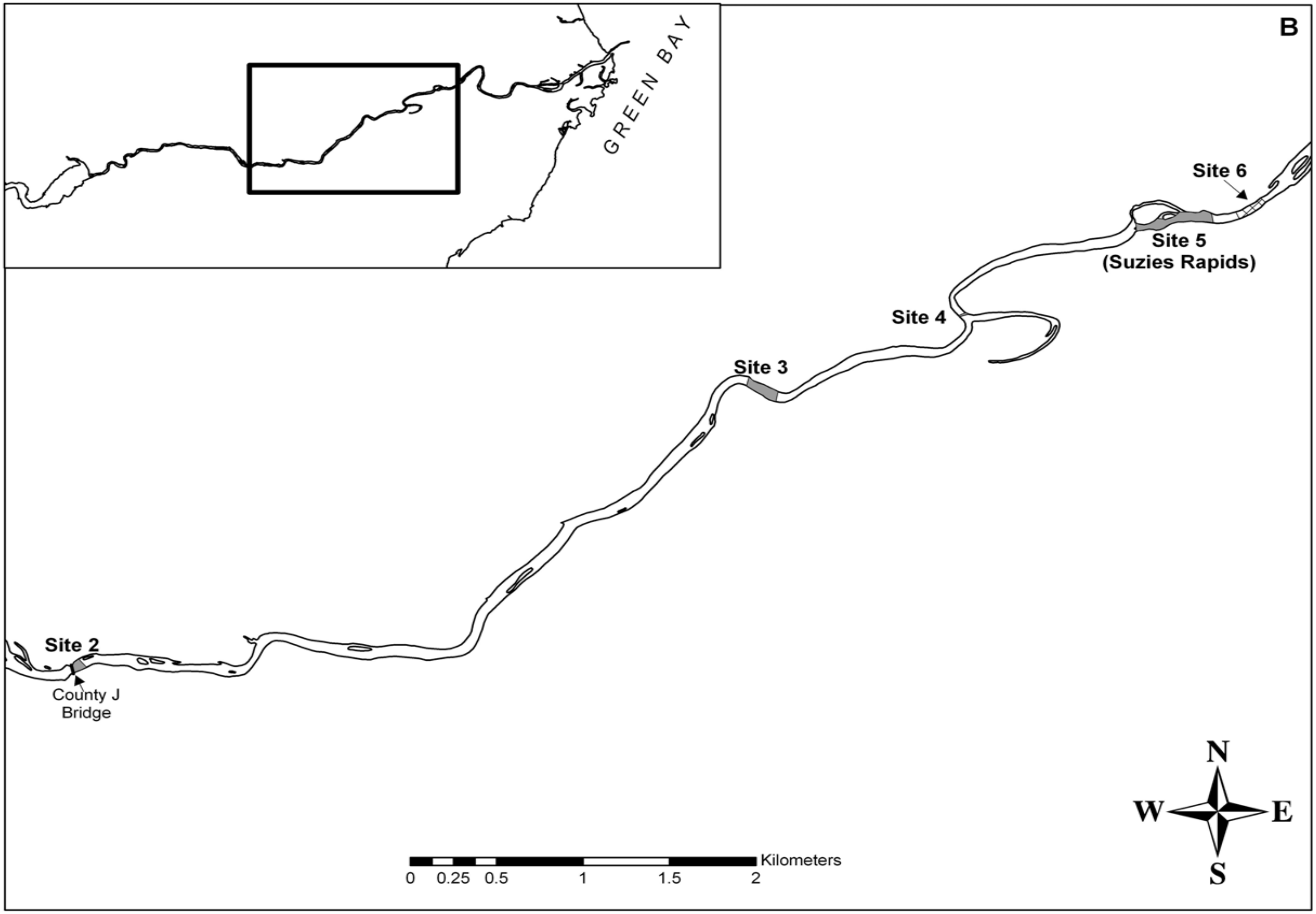
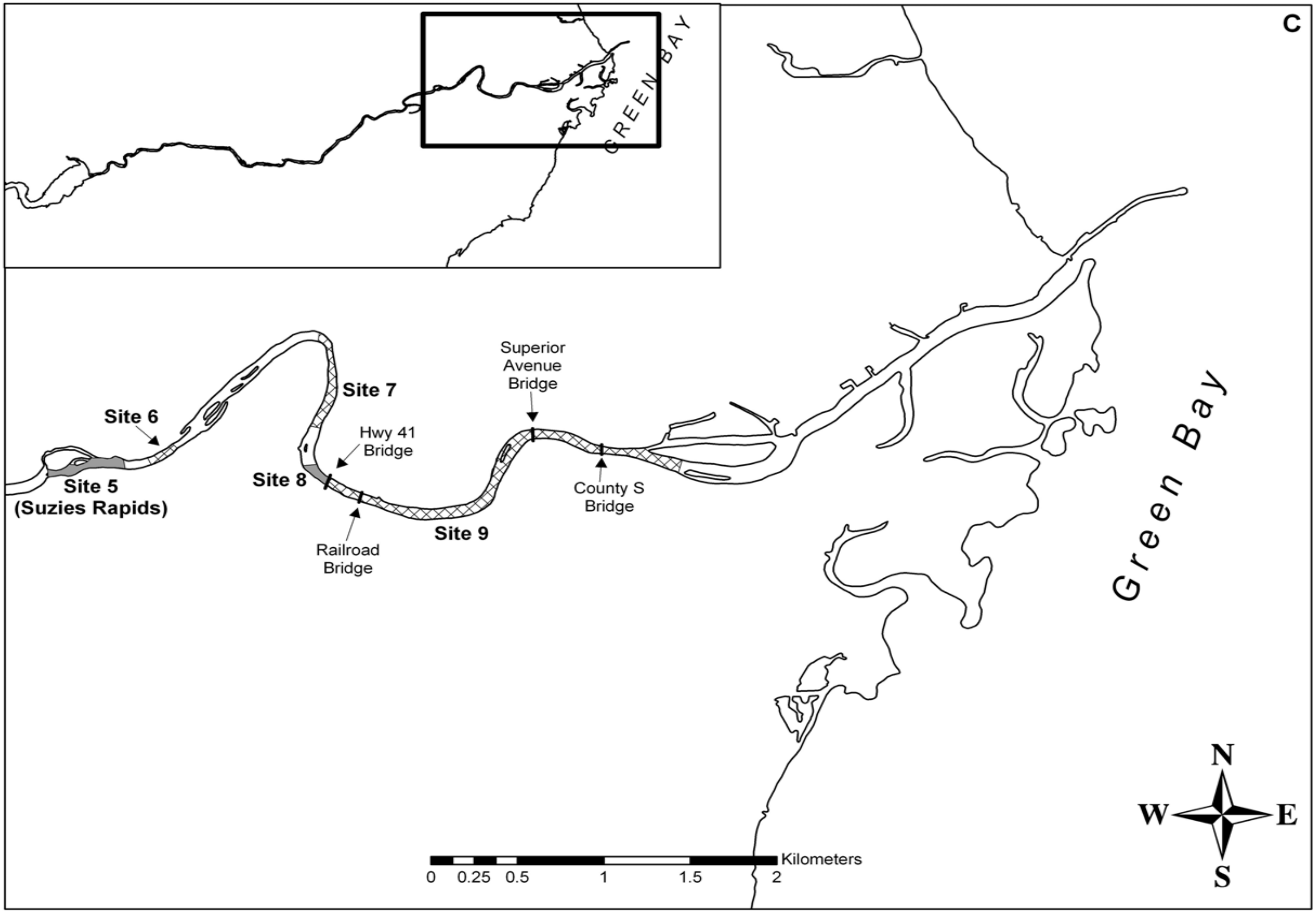


Figure 15. Potential lake sturgeon spawning habitat in the (A) upper, (B) middle, and (C) lower reaches of the Oconto River. The gray areas represent potential spawning habitat, and the cross-hatched areas represent marginal spawning habitat.



B
GREEN BAY
Site 2
County J Bridge
Site 3
Site 4
Site 5 (Suzies Rapids)
Site 6
N
W
E
S
0
0.25
0.5
1
1.5
2
Kilometers


C
GREEN BAY
Green Bay
Site 5
(Suzies Rapids)
Site 6
Site 7
Site 8
Site 9
Hwy 41
Bridge
Railroad
Bridge
Superior
Avenue
Bridge
County S
Bridge
N
W
E
S
0
0.25
0.5
1
1.5
2
Kilometers

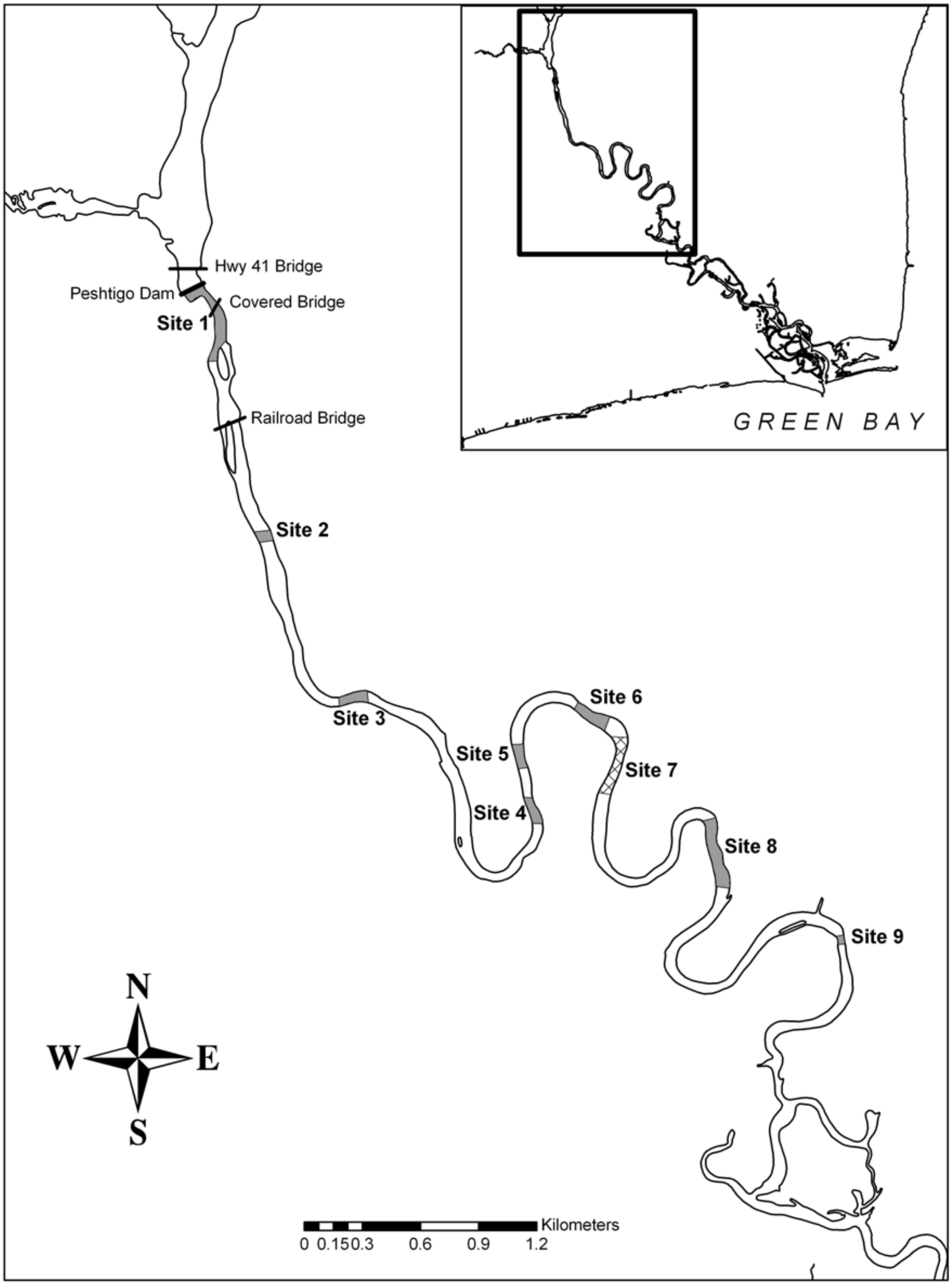


Figure 16. Potential lake sturgeon spawning habitat in the Peshtigo River. The gray areas represent potential spawning habitat, and the cross-hatched area represents marginal spawning habitat.

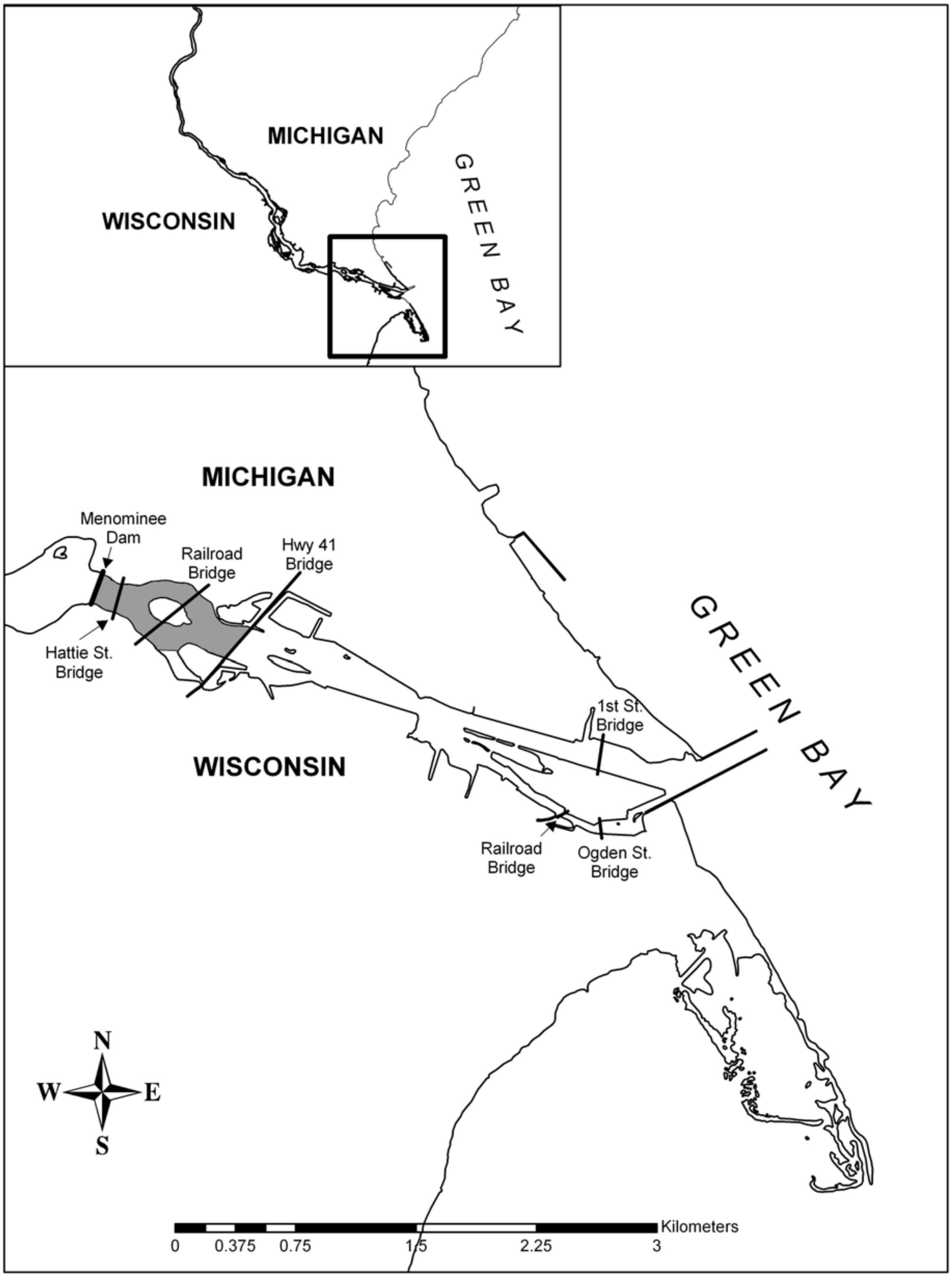


Figure 17. Potential lake sturgeon spawning habitat in the Menominee River. The gray area represents potential spawning habitat.

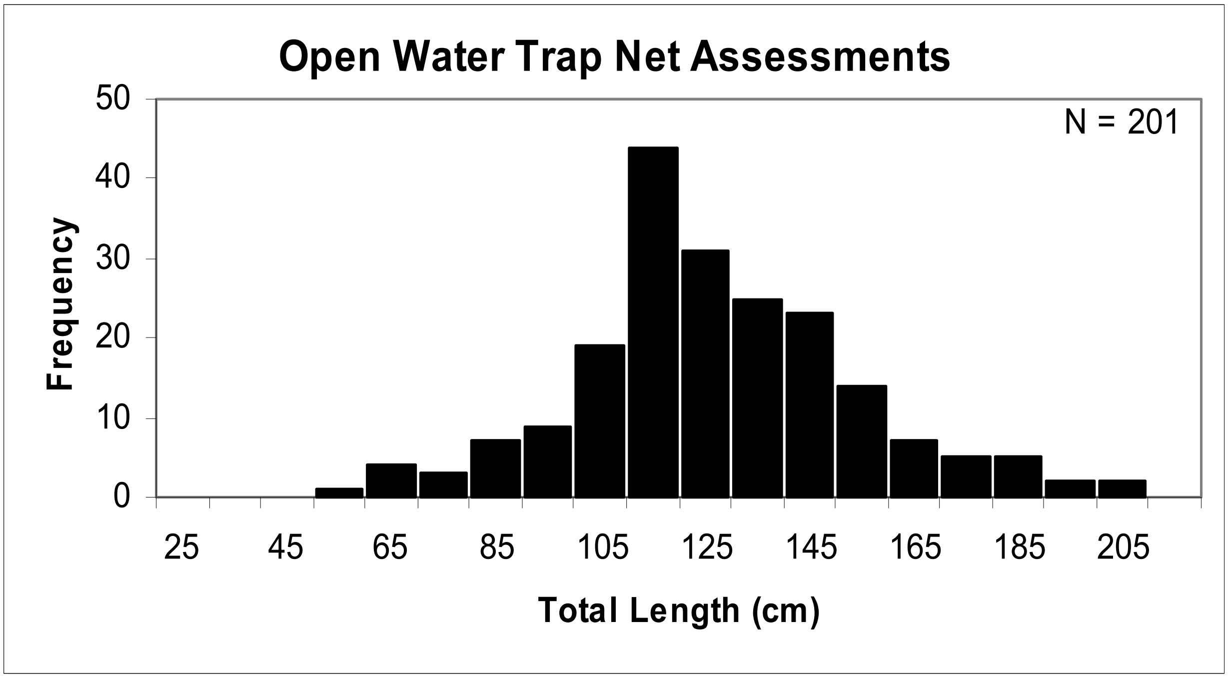


Figure 18. Length-frequency distributions for lake sturgeon captured during the open water trap net assessments in Green Bay, 2002-2003.

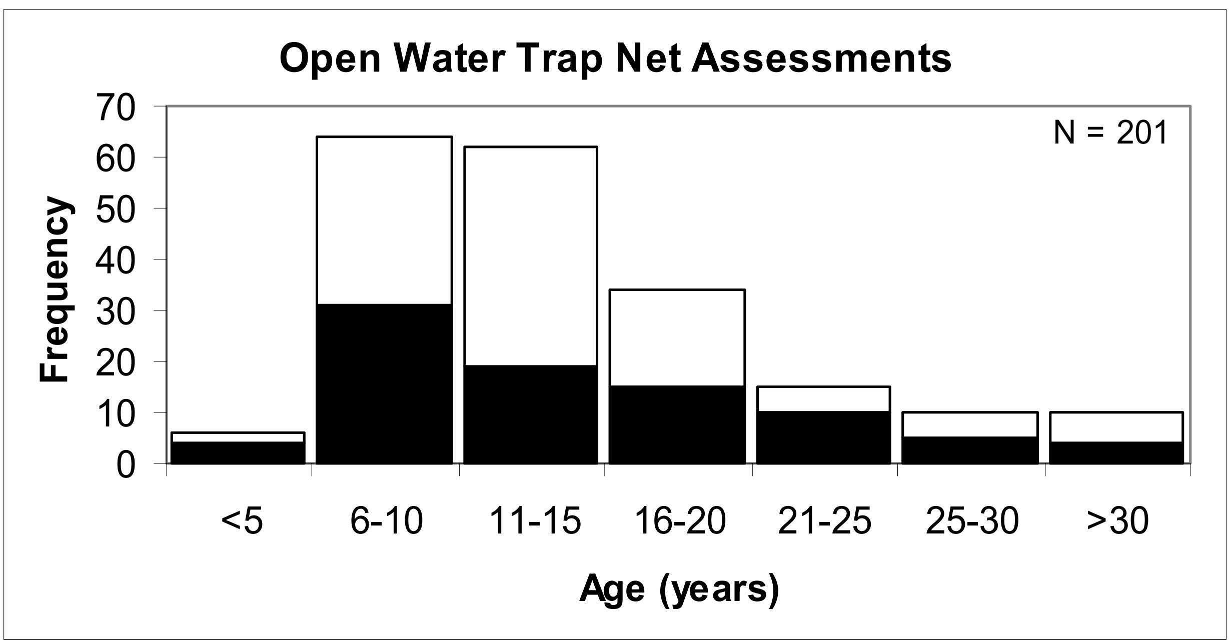


Figure 19. Age-frequency distributions for lake sturgeon captured during the open water trap net assessments in Green Bay, 2002-2003. Solid bars represent ages determined from pectoral fin rays, and hollow bars represent calculated ages derived from size-at-age data for 102 lake sturgeon captured in Green Bay and surrounding tributaries during 2001-2003.

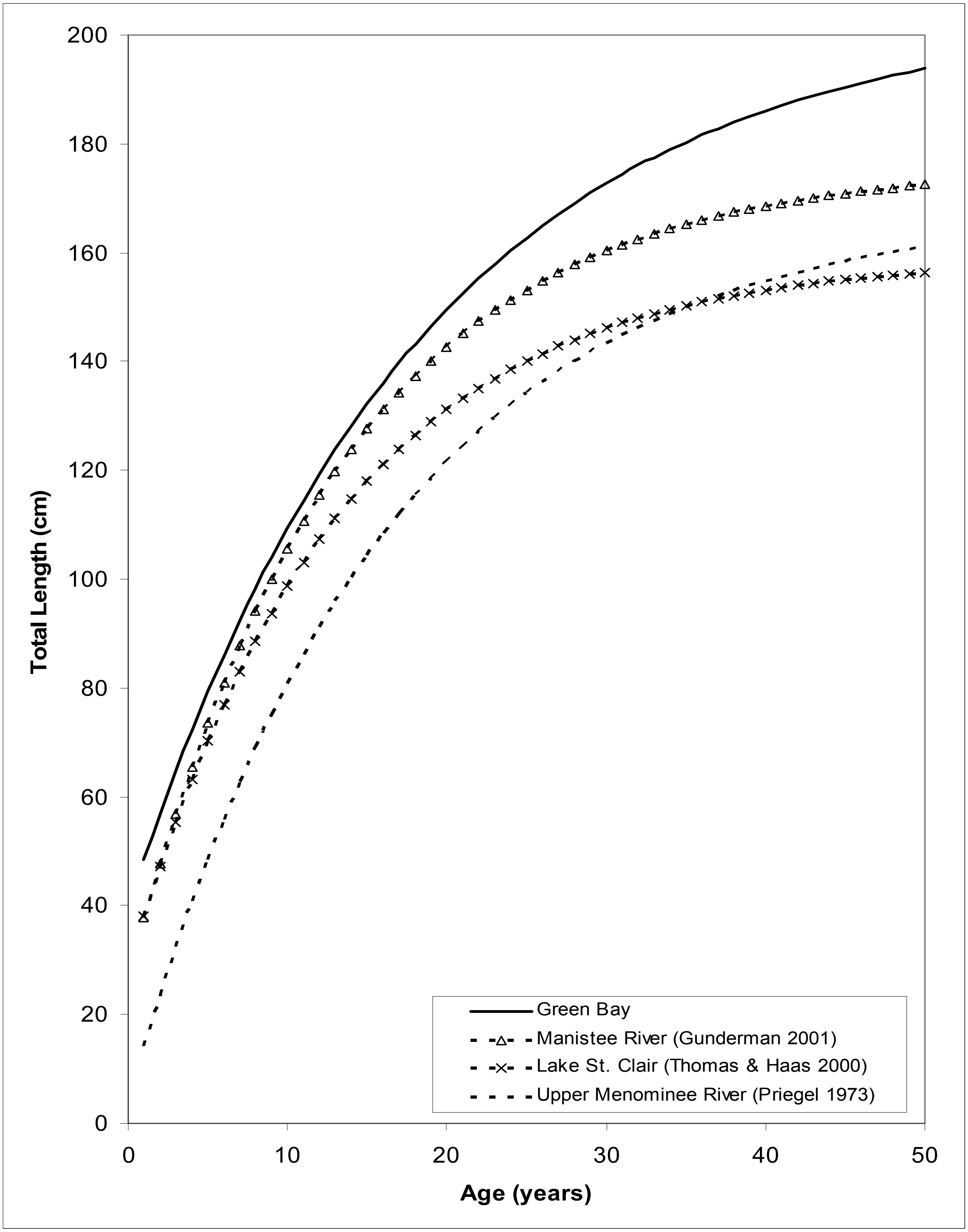


Figure 20. Von Bertalanffy growth curves for lake sturgeon from Green Bay (present study; 2002-2003), the Manistee River (Gunderman 2001), Lake St. Clair (Thomas and Haas 2000), and the upper Menominee River (Priegel 1973).

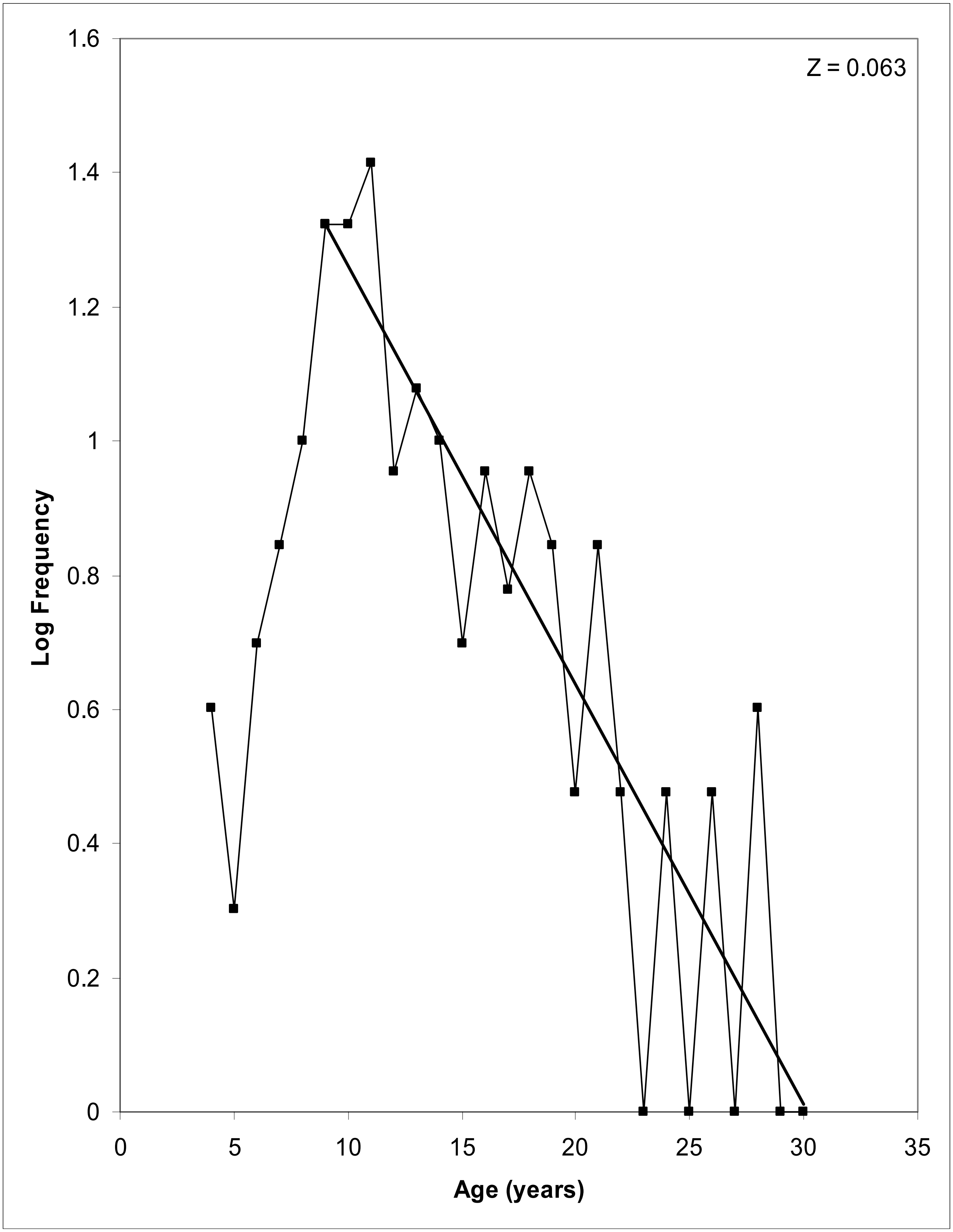


Figure 21. Catch curve for lake sturgeon captured during the open water trap net assessments in Green Bay, 2002-2003. Z equals instantaneous rate of total mortality.

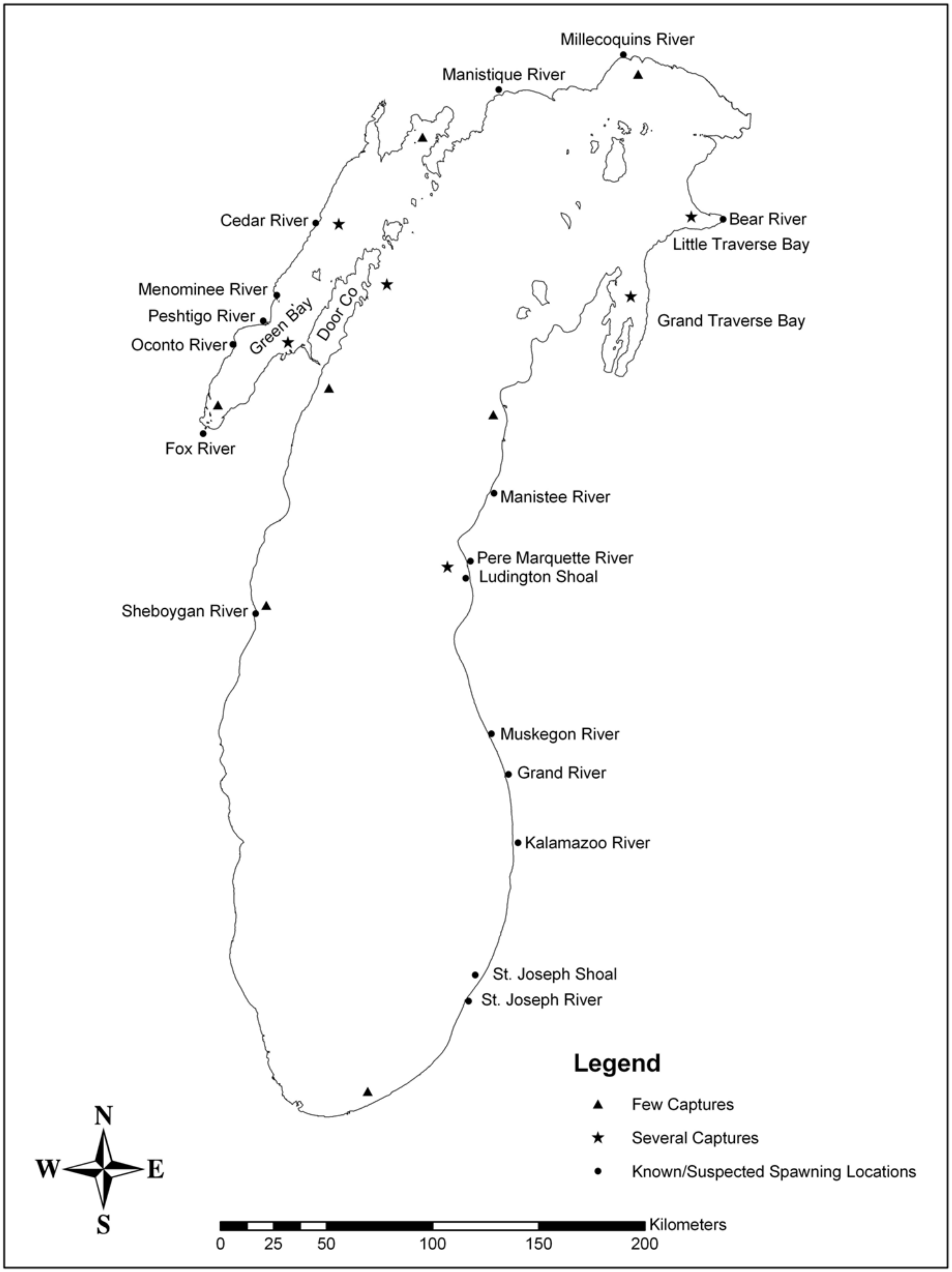
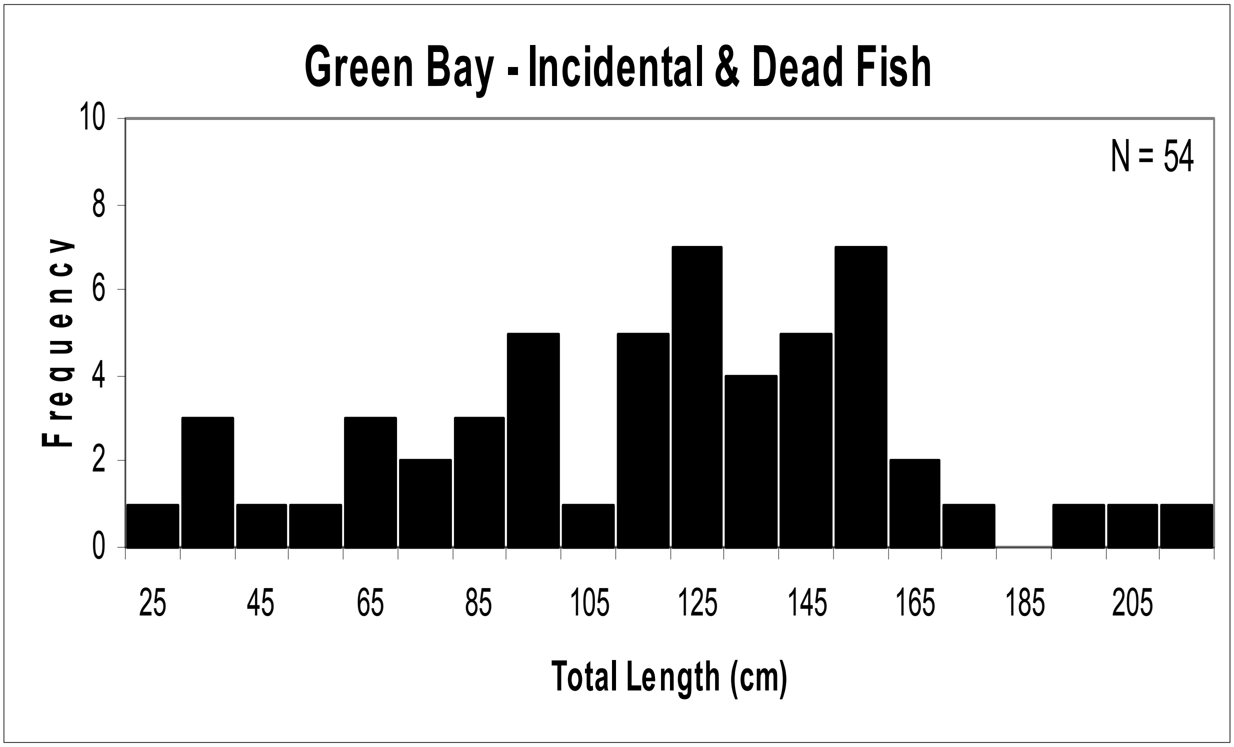


Figure 22. Locations where incidental lake sturgeon captures have been reported, and known and suspected lake sturgeon spawning locations in Lake Michigan and surrounding tributaries.



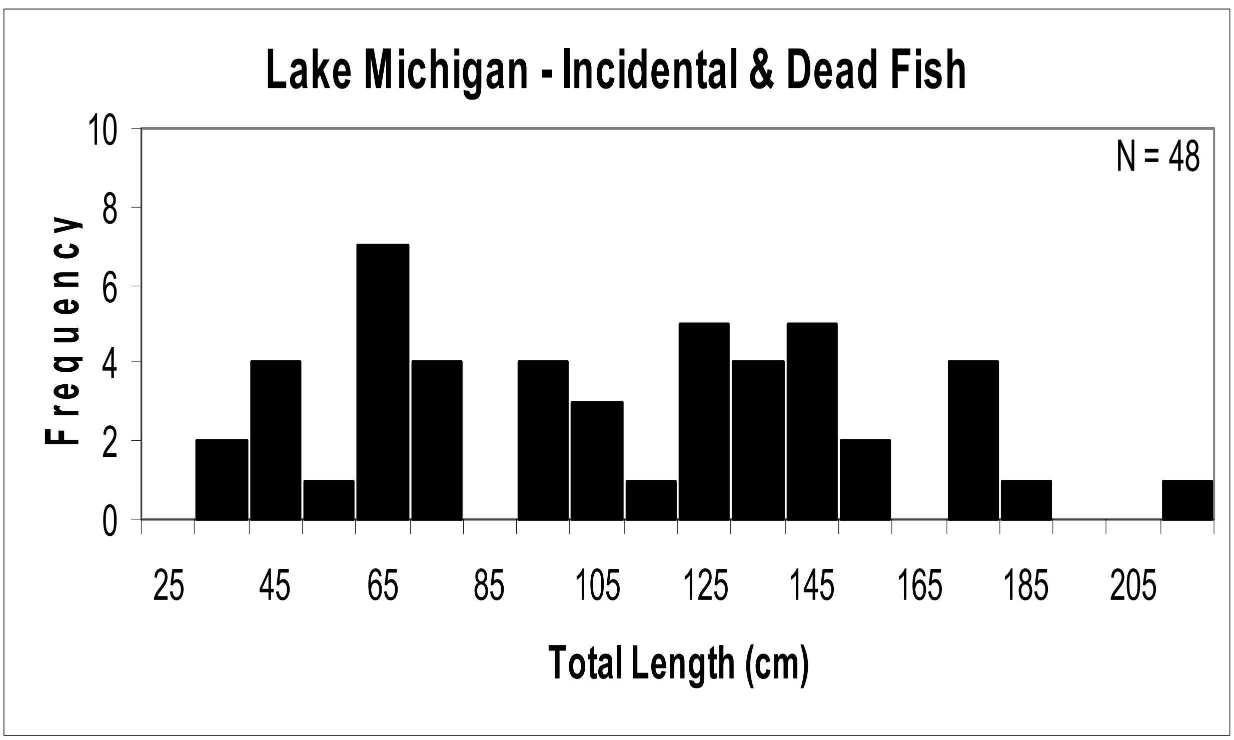


Figure 23. Length-frequency distributions for lake sturgeon found dead or captured incidentally by volunteer commercial fishers, agency assessment crews, and consulting firms in Green Bay and Lake Michigan, 1996-2003.

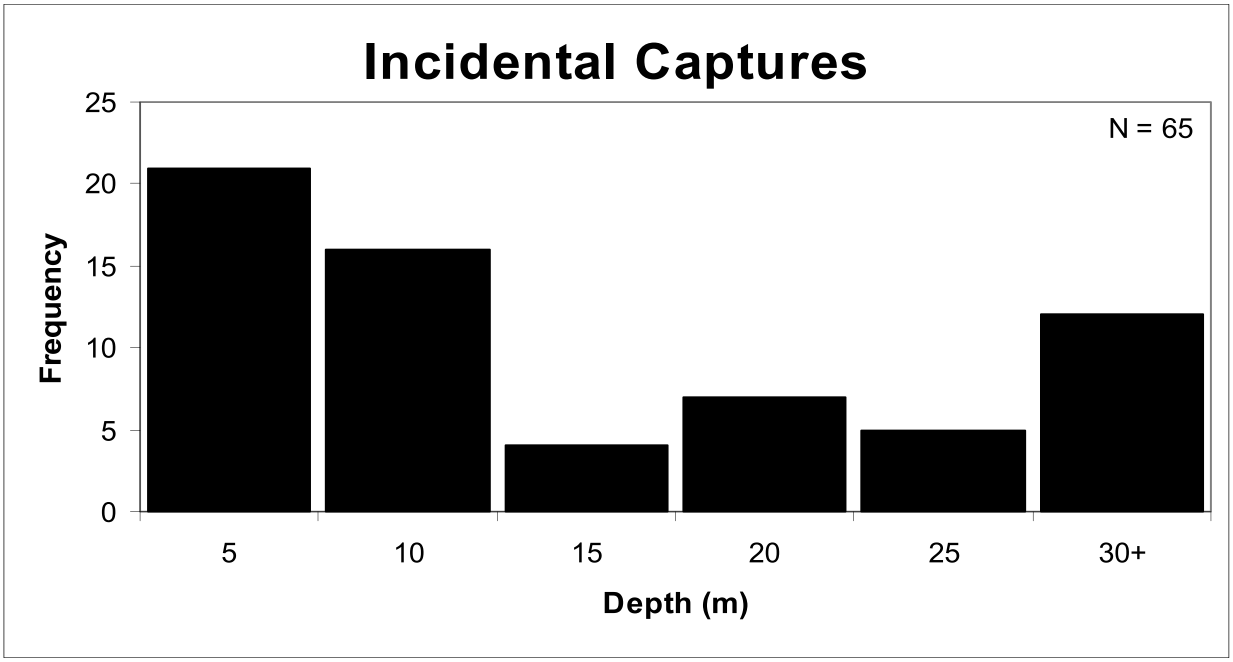


Figure 24. Distribution of lake sturgeon captures by water depth for incidental captures by volunteer commercial fishers, agency assessment crews, and consulting firms in Lake Michigan (including Green Bay), 1996-2003.

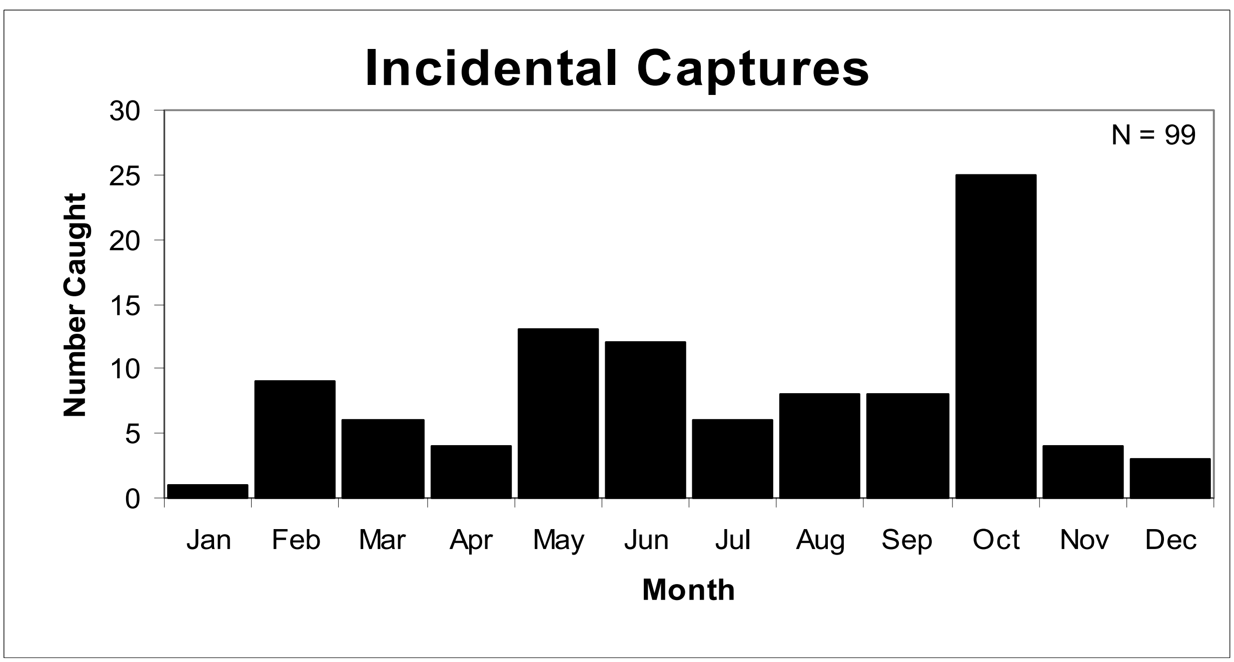


Figure 25. Number of incidental lake sturgeon captures by volunteer commercial fishers, agency assessment crews, and consulting firms by month in Lake Michigan (including Green Bay), 1996-2003.

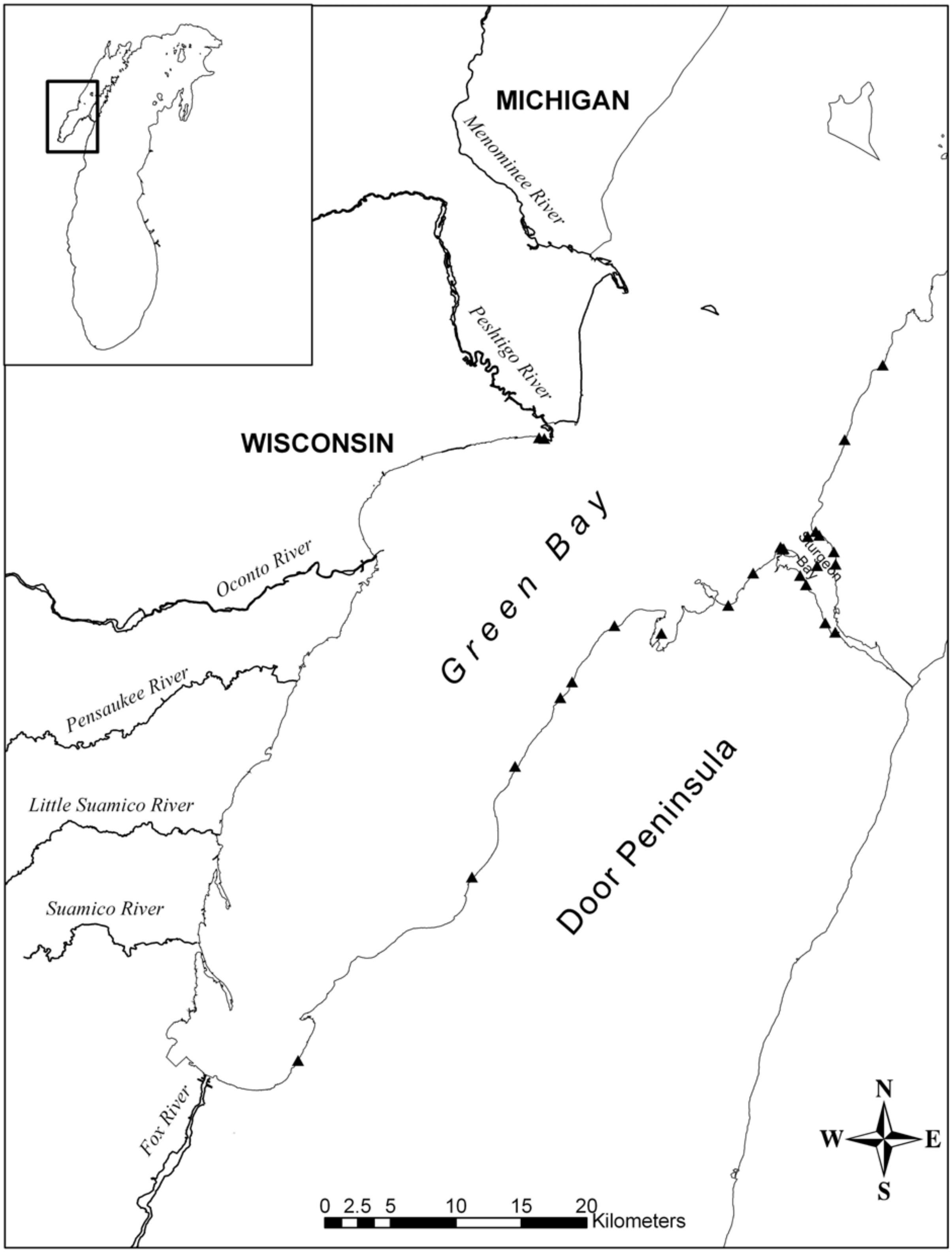


Figure 26. Locations where dead lake sturgeon were found by agency personnel and private citizens during 2002-2003.

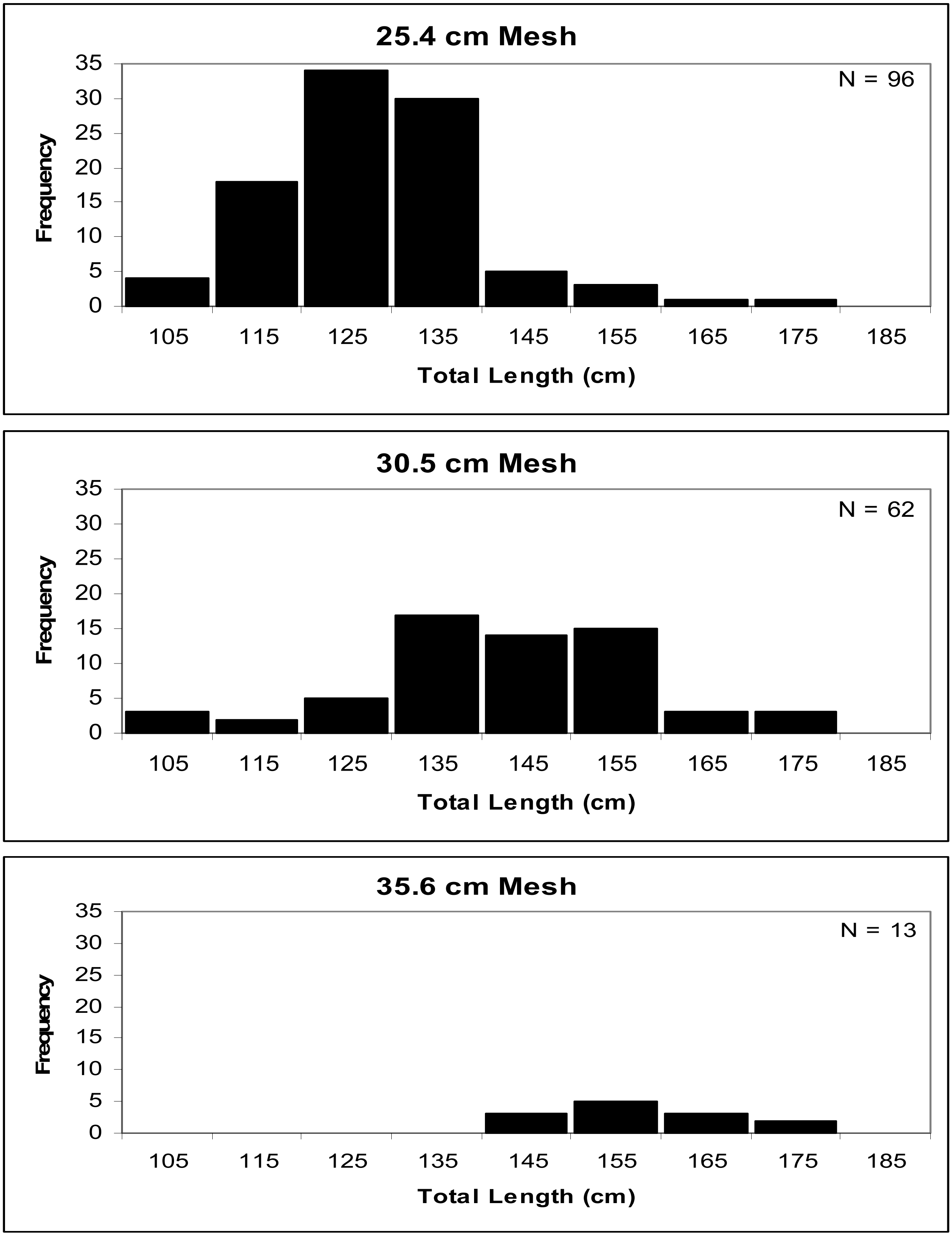


Figure 27. Length-frequency distributions for lake sturgeon captured using gill nets of various mesh sizes in the Peshtigo and Oconto Rivers (including river mouths), 2002-2003.

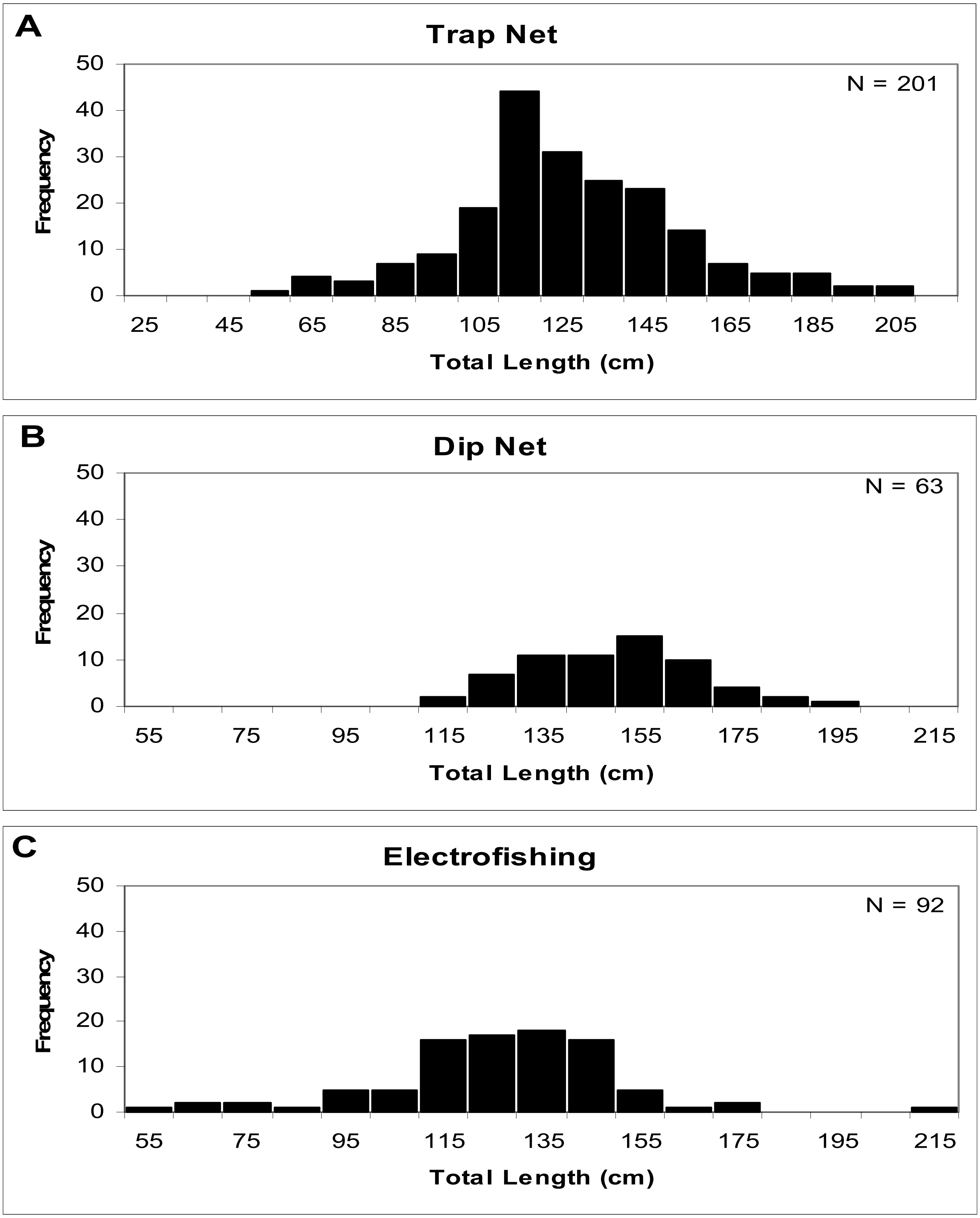


Figure 28. Length-frequency distributions for lake sturgeon captured using three different gear types: (A) trap nets in Green Bay (2002-2003), (B) dip nets in the Fox and Peshtigo Rivers (1998-2001), and (C) electrofishing in the Fox, Oconto, Peshtigo, and Menominee Rivers (1997-2003).

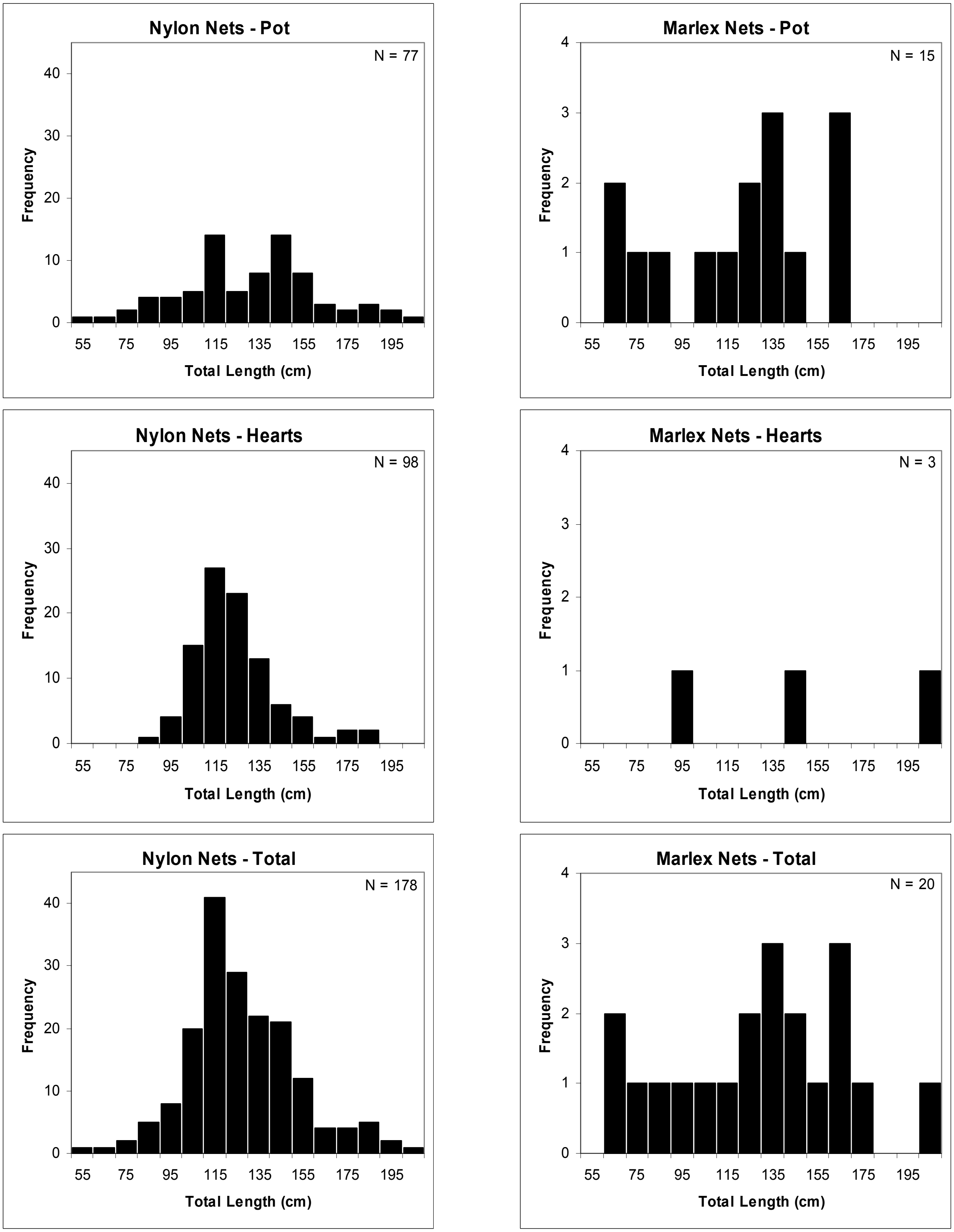


Figure 29. Length-frequency distributions for lake sturgeon captured in nylon and Marlex trap nets during the open water assessments in Green Bay, 2002-2003.

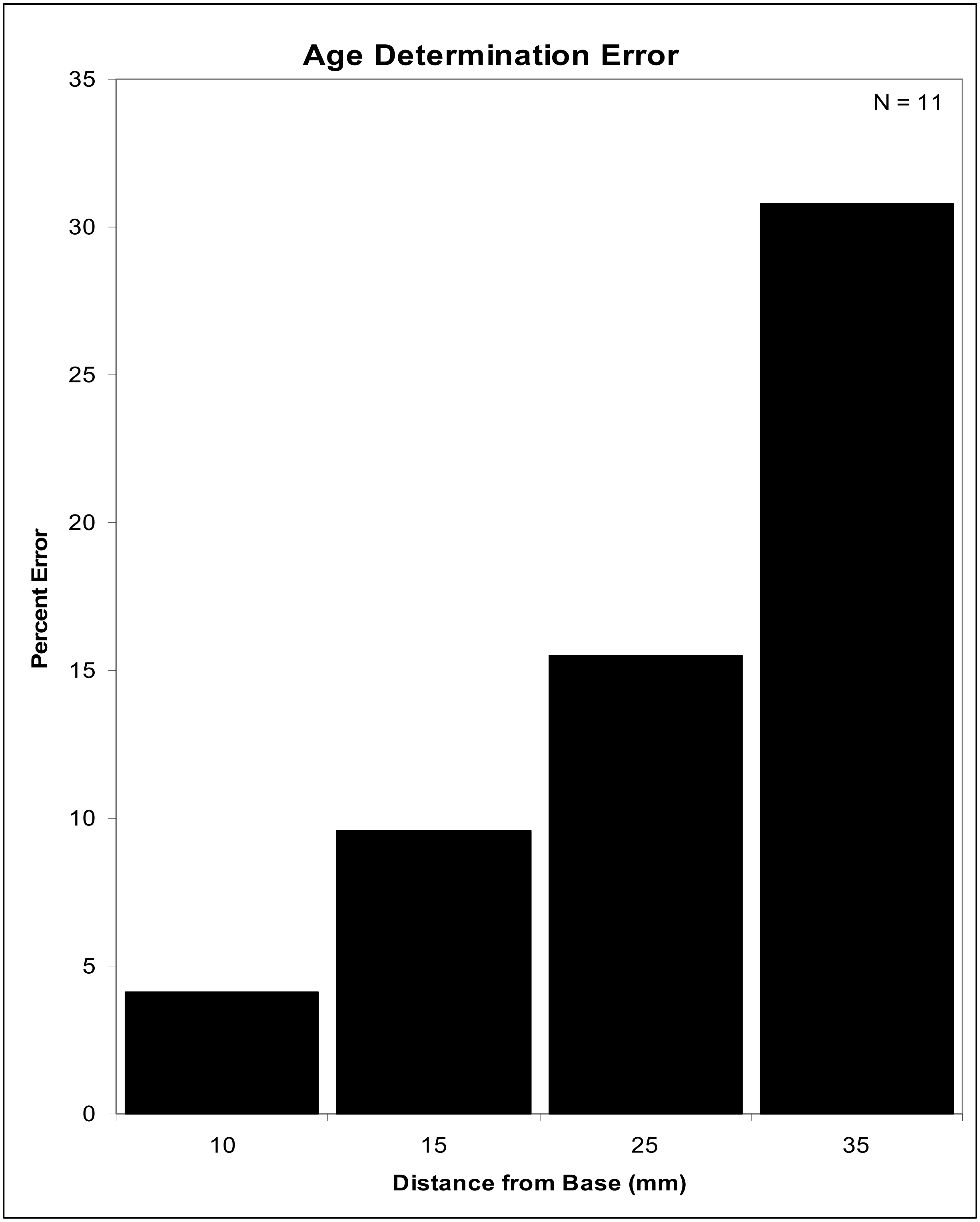


Figure 30. Percent error for age estimates obtained from cross-sections taken at four different locations along pectoral spine samples collected from eleven lake sturgeon captured in Green Bay and Grand Traverse Bay, 1996-2003. (Percent Error = $(Age_{5\ mm} - Age_{d})/Age_{5\ mm} * 100$ where d = distance from fin joint)

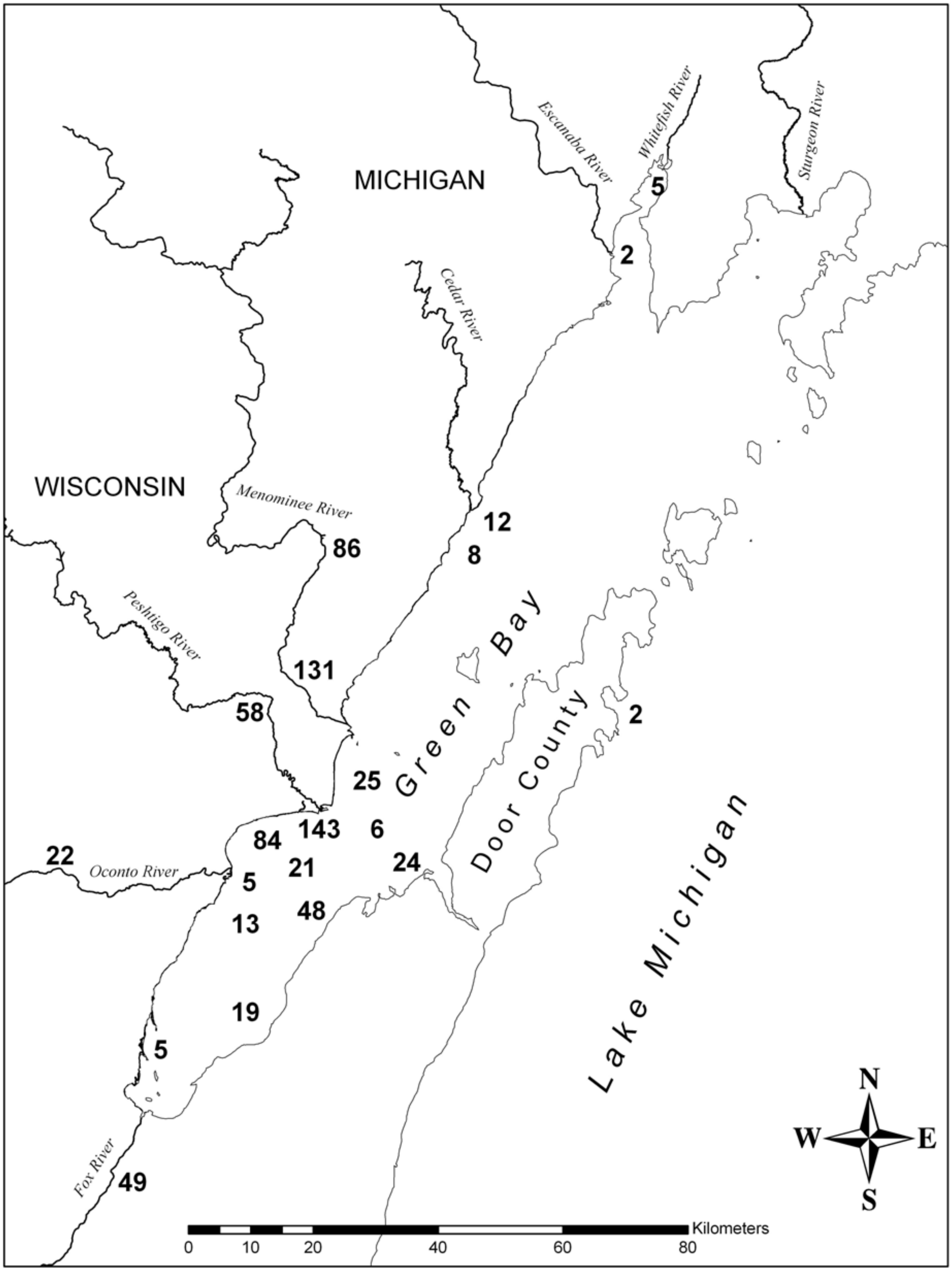


Figure 31. Numbers of lake sturgeon genetic samples collected at various locations throughout Green Bay, 1999-2003.

APPENDICES

Appendix 1. Drift netting effort and numbers of larval lake sturgeon captured per night in the Fox River, 2002 (data from Stantec Consulting Services, Inc. 2003).

Date	Stream Width (m)	Mean Depth[1] (m)	Distance from Spawning Site (RKM)	# Nets	Sampling Time[2]	Net Hours	# Larvae Caught
11 May	330	---	0.1	3	19:30-02:15	13.75	0
12 May	330	---	0.1	3	20:30-06:30	29.75	0
13 May	330	---	0.1	3-7	21:00-02:00	23.25	0
					Total	56.75	0

[1] Mean depth at net locations
[2] Sampling time began when the first net was deployed and ended when the last net was removed.

Appendix 2. Drift netting effort and numbers of larval lake sturgeon captured per night in the Fox River, 2003 (data for 17-31 May from Stantec Consulting Services, Inc. 2003).

Date	Stream Width (m)	Mean Depth[1] (m)	Distance from Spawning Site (RKM)	# Nets	Sampling Time[2]	Net Hours	# Larvae Caught
13 May	260	---	0.3	3-4	20:45-02:00	16.25	0
15 May	260	1.9	0.3	4	21:45-02:15	16.50	0
17 May	260	---	0.3	3	20:45-02:15	15.75	2
18 May	260	---	0.3	3	19:45-02:00	18.25	2
19 May	260	---	0.3	3	20:00-02:15	18.00	0
21 May	260	---	0.3	5	20:15-02:45	30.00	10
22 May	260	---	0.3	5	20:00-02:15	30.25	18
23 May	260	---	0.3	5	18:45-01:15	31.25	8
24 May	260	---	0.3	5	19:00-01:15	30.25	5
25 May	260	---	0.3	5	19:00-02:15	35.00	2
26 May	260	---	0.3	5	19:45-01:45	29.25	0
27 May	260	---	0.3	5	20:00-02:00	29.00	0
28 May	260	---	0.3	5	20:00-02:15	30.00	1
29 May	260	---	0.3	5	19:45-02:00	30.00	0
30 May	260	---	0.3	5	21:30-01:45	19.50	0
31 May	260	---	0.3	5	19:45-01:45	29.50	0
01 June	260	---	0.3	5	19:45-01:45	29.00	0
					Total	437.75	48

[1] Mean depth at net locations
[2] Sampling time began when the first net was deployed and ended when the last net was removed.

Appendix 3. Drift netting effort and numbers of larval lake sturgeon captured per night in the Oconto River, 2002.

Date	Stream Width (m)	Mean Depth[1] (m)	Distance from Spawning Site (RKM)	# Nets	Sampling Time[2]	Net Hours	# Larvae Caught
04 June	62	---	0.3	4	20:00-23:30	8.00	0
05 June	62	1.0	0.3	4	20:30-02:00	20.25	0
07 June	62	1.0	0.3	4	21:00-01:45	18.25	0
09 June	62	0.9	0.3	4	20:15-01:45	21.25	0
11 June	62	---	0.3	4	22:45-02:30	14.00	0
13 June	62	---	0.3	4	21:45-02:00	16.00	0
17 June	78	---	8.4	2-4	21:00-01:45	12.25	0
18 June	62	---	0.3	4	21:45-01:30	7.25	0
19 June	78	---	8.4	3-4	21:10-01:45	16.5	0
20 June	62	---	0.3	4	21:45-01:45	15.5	0
					Total	149.25	0

[1] Mean depth at net locations
[2] Sampling time began when the first net was deployed and ended when the last net was removed.

Appendix 4. Drift netting effort and numbers of larval lake sturgeon captured per night in the Oconto River, 2003.

Date	Stream Width (m)	Mean Depth[1] (m)	Distance from Spawning Site (RKM)	# Nets	Sampling Time[2]	Net Hours	# Larvae Caught
12 May	62	1.1	0.3	4	22:15-02:15	14.00	0
14 May	62	1.2	0.3	4	21:00-02:00	19.25	0
16 May	62	1.1	0.3	4	20:45-01:45	19.75	0
18 May	62	1.0	0.3	4	20:45-01:00	16.25	0
20 May	62	1.0	0.3	4	20:30-01:15	18.00	0
22 May	62	1.0	0.3	4	20:15-01:00	18.75	2
26 May	62	0.8	0.3	4	20:45-01:00	16.75	0
28 May	62	0.8	0.3	4	21:00-01:30	17.00	2
30 May	62	0.6	0.3	4	20:30-01:00	17.25	1
01 June	62	0.8	0.3	4	20:15-01:00	18.00	1
03 June	62	0.8	0.3	4	20:30-01:00	17.00	0
05 June	62	0.8	0.3	4	20:15-01:00	19.00	0
08 June	62	0.8	0.3	4	20:45-01:00	16.00	0
					Total	227.00	6

[1] Mean depth at net locations
[2] Sampling time began when the first net was deployed and ended when the last net was removed.

Appendix 5. Drift netting effort and numbers of larval lake sturgeon captured per night at the upstream site in the Peshtigo River, 2002. (See report for GLFT project 109 for information on downstream netting locations.)

Date	Stream Width (m)	Mean Depth[1] (m)	Distance from Spawning Site (RKM)	# Nets	Sampling Time[2]	Net Hours	# Larvae Caught
21 May	79	0.5	0.1	4	21:00-02:00	20.00	0
22 May	79	0.6	0.1	4	21:00-02:00	20.00	0
23 May	79	0.6	0.1	4	21:00-02:00	20.00	0
24 May	79	0.6	0.1	4	21:00-02:00	20.00	0
25 May	79	0.6	0.1	4	21:00-02:00	20.00	0
26 May	79	0.6	0.1	4	21:00-02:00	20.00	0
27 May	79	0.6	0.1	4	21:00-02:00	20.00	0
28 May	79	0.6	0.1	4	21:00-02:00	20.00	0
29 May	79	0.6	0.1	4	21:00-02:00	20.00	0
30 May	79	0.6	0.1	4	21:00-02:00	20.00	0
31 May	79	0.6	0.1	4	21:00-02:00	20.00	0
1 June	79	0.6	0.1	4	21:00-02:00	20.00	4
2 June	79	0.6	0.1	4	21:00-02:00	20.00	55
					Total	260.00	59

[1] Mean depth at net locations
[2] Sampling time began when the first net was deployed and ended when the last net was removed.

Appendix 6. Drift netting effort and numbers of larval lake sturgeon captured per night at the upstream site in the Peshtigo River, 2003. (See report for GLFT project 109 for information on downstream netting locations.

Date	Stream Width (m)	Mean Depth[1] (m)	Distance from Spawning Site (RKM)	# Nets	Sampling Time[2]	Net Hours	# Larvae Caught
11 May	79	0.7	0.1	3	21:00-02:00	15.00	0
12 May	79	0.8	0.1	3	21:00-02:00	15.00	4
13 May	79	0.9	0.1	3	21:00-02:00	15.00	0
14 May	79	1.0	0.1	3	21:00-02:00	15.00	1
15 May	79	0.8	0.1	3	21:00-02:00	15.00	1
16 May	79	0.8	0.1	3	21:00-02:00	15.00	0
17 May	79	0.7	0.1	3	21:00-02:00	15.00	0
18 May	79	0.7	0.1	3	21:00-02:00	15.00	0
19 May	79	0.7	0.1	3	21:00-02:00	15.00	0
20 May	79	0.7	0.1	3	21:00-02:00	15.00	0
21 May	79	0.7	0.1	3	21:00-02:00	15.00	0
22 May	79	0.6	0.1	3	21:00-02:00	15.00	3
23 May	79	0.7	0.1	3	21:00-02:00	15.00	8
24 May	79	0.6	0.1	3	21:00-02:00	15.00	12
25 May	79	0.6	0.1	3	21:00-02:00	15.00	24
26 May	79	0.5	0.1	3	21:00-02:00	15.00	34
27 May	79	0.5	0.1	3	21:00-02:00	15.00	12
28 May	79	0.5	0.1	3	21:00-02:00	15.00	3
29 May	79	0.6	0.1	3	21:00-02:00	15.00	63
30 May	79	0.4	0.1	3	21:00-02:00	15.00	35
31 May	79	0.5	0.1	3	21:00-02:00	15.00	160
01 June	79	0.5	0.1	3	21:00-02:00	15.00	148
02 June	79	0.5	0.1	3	21:00-02:00	15.00	54
03 June	79	0.5	0.1	3	21:00-02:00	15.00	16
04 June	79	0.5	0.1	3	21:00-02:00	15.00	11
05 June	79	0.4	0.1	3	21:00-02:00	15.00	22
06 June	79	0.5	0.1	3	21:00-02:00	15.00	3
07 June	79	0.6	0.1	3	21:00-02:00	15.00	0
08 June	79	0.5	0.1	3	21:00-02:00	15.00	0
09 June	79	0.6	0.1	3	21:00-02:00	15.00	0
10 June	79	0.7	0.1	3	21:00-02:00	15.00	0
11 June	79	0.8	0.1	3	21:00-02:00	15.00	0
12 June	79	1.0	0.1	3	21:00-02:00	15.00	0
					Total	495.00	614

[1] Mean depth at net locations
[2] Sampling time began when the first net was deployed and ended when the last net was removed.

Appendix 7. Drift netting effort and numbers of larval lake sturgeon captured per night in the Menominee River, 2003.

Date	Stream Width (m)	Mean Depth[1] (m)	Distance from Spawning Site (RKM)	# Nets	Sampling Time[2]	Net Hours	# Larvae Caught
27 May	425	---	0.7	3	21:00-23:00	6.00	2
29 May	425	---	0.7	3	20:15-21:30	3.00	1
02 June	425	---	0.7	3	20:00-23:15	9.00	17
04 June	425	---	0.7	3	20:30-23:30	9.00	1
					Total	27.00	1

[1] Mean depth at net locations
[2] Sampling time began when the first net was deployed and ended when the last net was removed.