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Aspects of Bowfin and Northern Sunfish Biology and Ecology

by

David Sanderson-Kilchenstein

A thesis submitted to the Department of Environmental Science and Biology of the State University of New York College at Brockport in partial fulfillment of the requirements for the degree of Master of Science

December 2015

Aspects of Bowfin and Northern Sunfish Biology and Ecology

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David Sanderson-Kilchenstein

APPROVED BY:

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Abstract

Bowfin (*Amia calva*) are currently being harvested at high rates in the Mississippi River system for the sale of their roe as a caviar alternative. I evaluated the effect that this industry could have if it expands to include the Great Lakes by describing population characteristics of bowfin from Braddock Bay, Monroe Co., NY. Pectoral fin ray sections were used to age 51 bowfin, and back-calculated length-at-age data were used to fit the Von Bertalanffy growth model. Theoretical maximum length was estimated to be 753 mm TL, the coefficient of growth 0.262, and time at length zero -0.023 years. These values resemble populations described from the upper Mississippi River that grow slower and live longer than populations in the south, and therefore would be affected more by commercial harvesting. Aquaculture could provide an alternative to wild harvest, but no established protocols exist. I attempted captive breeding (tanks and ponds) and tested the acceptance of a commercial and a handmade artificial diet. The 55 bowfin did not respond well to captivity: no breeding was observed and most fish lost weight, but they lost significantly less weight on the handmade artificial diet ($P = 0.007$). Low-intensity culture of bowfin may not be possible using the conditions I tested while artificial propagation likely will require induction by hormone injection.

For many years, wild northern sunfish (*Lepomis peltastes*) in New York State have been restricted to a single 3.7 km section of lower Tonawanda Creek (LTWC), Erie County near Buffalo, NY, and the species is listed "threatened" in the state. A recovery program has been carried out by NYS Department of Environmental

Conservation (NYSDEC) since 2005 to reintroduce the species into historic waters other than lower Tonawanda Creek and to establish new populations in other apparently suitable areas. I sampled on 30 days in 2013 and 2014 by boat and backpack electroshocking in the 3.7 km section of LTWC and at stocking sites within the Niagara River watershed. No pure northern sunfish were captured at any sites. I compared data from 2005, when boat electrofishing of LTWC produced 23 northern sunfish, to my 2013-2014 data to investigate changes in the fish community. From 2005 to 2013 capture of the aggressive, non-native green sunfish (*L. cyanellus*) increased from 27.7 to 288.3 fish caught per hour of electroshocking (CPUE), a 941% increase. Sensitive species have diminished, including darters and logperches (*Etheostoma* and *Percina* spp., respectively; -91% CPUE) and redhorses (*Moxostoma* spp.; -48% CPUE), and invasive species have increased, such as round goby (*Neogobius melanostomus*; +200% CPUE). Analysis of similarities (ANOSIM) revealed a significant difference in the LTWC fish community between years (R = 0.806, P = 0.001), and non-metric multidimensional scaling (nMDS) showed a strong separation of fish communities between the two sampling periods. Several suspected hybrid sunfish were collected in 2013 and 2014, and microsatellite DNA analysis confirmed eight bluegill (*L. macrochirus*) x northern sunfish hybrids, as well as 19 other *Lepomis* hybrids. It is likely that the fish community of LTWC has changed so it can no longer support northern sunfish. Future stocking efforts should focus on water bodies with suitable habitat conditions and low green sunfish and round goby abundance.

Dedication

This thesis is dedicated to, first, my parents for their undying love, support, and guidance: my mother who taught me to thirst for knowledge and my father who taught me to explore natural phenomena. Second, I also dedicate this thesis to the love of my life, Noelle Hatton, who not only helped with both chapter's field and lab work, but has unwaveringly stood by me through the writing process.

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General Introduction

Separate studies were conducted on two species of fish native to western New York and endemic to North America—bowfin (Amiidae: *Amia calva*) and northern sunfish (Centrarchidae: *Lepomis peltastes*). Though seemingly disparate, both studies were designed to aid in native fish conservation at different stages of threat and decline: the bowfin being an abundant, pre-restoration species potentially subject to high commercial exploitation for their roe ("caviar") and the northern sunfish being nearly-state extirpated, post-restoration. As non-game fish species, bowfin and northern sunfish have received little attention historically—bowfin are found to be unpalatable by many, and northern sunfish are too small to be an important food or game fish.

Bowfin have recently gained much attention in the lower Mississippi River and in Georgia due to a quickly expanding industry for the harvest and sale of their roe (Porter *et al.* 2013). In order for a fishery to remain sustainable, information on population characteristics is needed, such as growth, recruitment, fecundity, etc., and these evaluations are only now being made in Louisiana (Davis 2006), Georgia (Porter *et al.* 2013), and Wisconsin/Iowa/Illinois (Koch *et al.* 2009). Scientists recently have postulated that this industry could expand to include the Great Lakes (Dabrowski n.d.), but no reliable studies exist on any bowfin populations.

Northern sunfish once occupied eight waters of the Lake Erie and Lake Ontario basins in New York State. For many years they have only been detected in a single reach of lower Tonawanda Creek (LTWC) of the upper Niagara River watershed, Erie County, and a recovery plan was initiated in 2005 by the NYS Department of Environmental Conservation to reintroduce them in historical waters and establish new populations within their historic range. The plan began with a full assessment of LTWC (Wells 2009) which captured 23 individuals that were used to stock production ponds, along with northern sunfish transported from the Moira River in Ontario, Canada, and the Huron River in Michigan. From 2006 to 2013, over 19,000 northern sunfish were stocked, and sporadic sampling detected recruitment occurring in several of the stocked locations. More extensive sampling has been needed to reassess the last wild population in LTWC and to thoroughly evaluate the success of the restocking efforts in the Niagara River watershed.

Chapter 1

Population Characteristics of Bowfin (*Amia calva*) from a Great Lakes Coastal Wetland, with an Investigation of Captive Breeding and Artificial Diet

Introduction

The bowfin (*Amia calva* Linnaeus, 1776) is a top-level predatory fish, feeding primarily on small fish and crustaceans, commonly found in freshwater marshes and backwaters throughout the majority of the Mississippi River drainage, many Atlantic drainages from Florida to the Hudson River, and the Great Lakes and St. Lawrence drainages (Scott & Crossman 1973). They can grow to nearly a meter in length, breathe air through a vascularized lung, and live up to 30 years (Page & Burr 2011). They are primitive ray-finned fish and the only extant species within the order Amiiformes. In their northern range, they were considered an unpalatable competitor of sportfish and were targeted for eradication by fisheries managers until the 1970s (Miles 1913; Scarnecchia 1992). In their southern range, however, they have been a component of Creole cuisine and are now being harvested for the sale of their roe.

Commercial harvest

Commercial interest in bowfin roe began in the southern U.S. in the early 1990s and is growing rapidly (Koch *et al.* 2009a) because the trade of sturgeon caviar is highly limited and relies on overseas imports. Paddlefish (*Polyodon spatula*), gars (Lepisosteidae), and now bowfin provide a domestic source of roe that is marketed as a black caviar alternative. Bowfin are abundant throughout most of their range and commercial harvest is unrestricted in all states except Louisiana. The industry for bowfin roe has expanded to include Georgia (Porter *et al*. 2013) and may eventually include the Great Lakes region (Dabrowski n.d.). However, very little is understood about the ecological role of this large predatory fish or what the effect of commercial harvesting would be in their northern range.

Need for aquaculture

The demand for bowfin roe is such that its culture likely would be profitable. In 2003, the commercial catch in Louisiana totaled 92,000 kg of whole bowfins for flesh and roe, the latter selling for $80/kg (Koch *et al.* 2009a). Koch *et al*. (2009a) projected population dynamics of the species under current and predicted harvest rates in the Upper Mississippi River (UMR) system. They warned that like sturgeon the bowfin’s long lifespan and high juvenile mortality make the species vulnerable to over-exploitation. Aquaculture would alleviate the ecological burden of wild harvest and meet the high demand for a caviar alternative.

Life history

Adult bowfins display distinct sexual dimorphism year-round; males have a black spot outlined in yellow, termed the ‘ocellus’ or eye-spot, on the upper caudal peduncle, while females either lack the spot or have only a faint dot. Males and females mature at age 2 in Louisiana (Davis 2006) and between ages 3 and 5 in

Quebec (Cartier & Magnin 1967). During the breeding season, the paired fins, anal fin, and bellies become bright green in males (Scott & Crossman 1973; Page & Burr 2011). In Lower Michigan, the breeding season of bowfin in small inland lakes near the Huron River is from late April to early June, when water temperatures are 16° to 19° C. Males build a bowl-shaped nest 30 to 90 cm in diameter, 10 to 20 cm deep along the shores of marshes. Although male-male aggression occurs, nest densities can be as high as seven per 6 m x 9 m area. Males construct nests by chewing the stalks of submerged plants and fanning away muck. On rare occasions they will utilize naturally occurring features, such as exposed fibrous roots, with no further preparation. Females then deposit eggs that stick to the stubble or exposed roots. Males remain guarding the nests and may mate with several females. The larvae hatch within 8-10 days and are 8 mm long, at which point they attach themselves to surrounding vegetation with the use of an adhesive pad located dorsally on the head. After the yolk is depleted (15–19 days after fertilization), the hatchlings forage in tightly-packed schools led by the male parent (Reighard 1903). Schools contain between a few dozen to a few thousand young-of-the-year (YOY). The YOY fledge the schools when they are 100 mm total length (TL; Scott & Crossman 1973).

Population characteristics

Bowfin in the Upper Mississippi River grow more slowly and larger, live longer and mature later than southern populations in Louisiana and Georgia (Koch *et al.* 2009a; Porter *et al.* 2013). This latitudinal gradient suggests that populations in the Great Lakes should resemble those in the UMR. Slower growth rates, later maturities and longer life spans increase the risk of over-exploitation. Data are needed on populations from the Great Lakes to evaluate the potential impact of commercial harvesting.

Four populations of bowfin have been described recently—two from the UMR (Pools 11 and 13; Koch *et al.* 2009a), one from the upper Barataria estuary of southeast Louisiana (Davis 2006), and one from a reservoir in south Georgia, Lake Lindsay Grace (Porter *et al.* 2013). Additionally, Holland (1964) reported on a population from the Mingo Swamp in southeastern Missouri (Figure 1A). These studies used the gular plate (Holland 1964; Davis 2006) and first pectoral fin ray sections (Koch *et al.* 2009a; Porter *et al.* 2013) to estimate age and measure growth. Other populations have been described from higher latitudes using scales or otoliths for aging: Schiavone (1982) for Butterfield Lake, New York; Cooper & Shafer (1954) for Whitmore Lake, Michigan; and Cartier & Magnin (1967) for the Montreal region of Quebec province, Canada. Koch *et al.* (2009b) compared the precision of these structures in aging bowfin of the UMR and found that scales and otoliths were unreliable, the gular plate was satisfactory, and first pectoral ray sections were significantly more precise. No population of bowfin from the Great Lakes region has been described using a reliable aging method.

Bowfin in captivity

Survival

Bowfin have been reported to survive in mud by aestivating (Dence 1933; Neill 1950; Green 1966), and juveniles tolerate hypoxic conditions with no reduction in the rate of growth (Dabrowski *et al.* 2012a). Due to aggressive behavior and cannibalism, Huner (1994) reported 92% mortality over an eight-month period among 50, 51-mm TL YOY bowfin placed in a rectangular tank (0.9 x 2.1 x 0.15 m). Horn & Riggs (1973) held six bowfin (438 ± 43 mm TL) for 77 days to test the effect of water temperature on their rate of air-breathing. All but one died when exposed to 35.2° C, which they postulated is the critical thermal maximum for the species.

Reproduction

Recently, bowfin have been induced to spawn out of season by hormone injection (Dabrowski *et al.* 2012a). Huner (1994) reported successful spawning in southern Louisiana on two occasions in an 8 ha wooded slough stocked with 12, 1.3–1.8 kg adult bowfin immediately before the breeding season. However, other attempts did not produce spawning: two bare-bottomed ponds, two bare-bottomed canals for two seasons, and a vegetated pond. Green (1966) was successful in propagating bowfin in Alabama in a 1.3 ha pond filled after a season of being dry and allowed to become overgrown with terrestrial plants.

Feeding

Huner (1994) found that bowfin in captivity, both adult and YOY, rejected dry artificial feed and accepted a handmade wet pellet of ground fish, a commercial moist pellet, and cut-bait such as chopped beef liver and heart, chopped shad, and fresh, dead crayfish and shrimp. Bowfin broodstock in Louisiana were reported to accept a floating commercial alligator gar pellet, as well as cut shrimp and fish (personal communication, Dr. Allyse Ferrara, Nicholls State University). Dabrowski *et al.* (2012a) reported successful weaning of hatchlings from brine shrimp to a formulated feed at 25 mm TL.

Growth

Young-of-the-year bowfin are one of the fastest growing freshwater fish; female fingerlings can grow up to 10% body weight per day between 20 and 200 g (Dabrowski *et al.* 2012b). In production ponds in southern Louisiana, bowfin can reach 508 mm TL and weigh 680 g in the first year (Huner 1994).

Objectives

In sum, little is known about bowfin life history in the wild and how to propagate them in captivity. The goal of my study was to evaluate the potential impacts of—and develop an in-captivity alternative to—commercial harvesting. The objectives for attaining this goal were:

- To describe age and growth characteristics of bowfin from a Great Lakes coastal wetland and compare them to data from other areas of the U.S.

- To explore the ability of wild bowfin to survive and reproduce in the laboratory, and
- To determine whether adult bowfin would accept a prepared diet in place of live fish.

Methods

Bowfin collections

Fifty-five bowfin were collected from coastal wetlands along the southern shore of Lake Ontario in Monroe County, New York. Thirty-six bowfin were captured from 20 October to 12 November 2012 using fyke nets set overnight in Braddock Bay (n=34) and Long Pond (n=2). Rectangular fyke nets had a 4.7 mm bar mesh with a rectangular opening of 1.3 m x 1.0 m and a 4.5 m main lead, and round fyke nets had a 25.4 mm bar mesh with a 1.3 m round opening and a 7.6 m main lead. Two bowfin were collected on 24 September 2012 from the mouth of Sandy Creek using boat electroshocking, and 17 bowfin were collected on 14 June 2013 in Braddock Bay using nighttime boat electroshocking.

Upon capture, each bowfin was weighed, measured, photographed, and both first pectoral fin rays were collected. The 55 bowfin were divided among the various experiments as described in Appendix A. Attempts to capture bowfin also occurred in Buck Pond, East Creek, and Rush Creek, Monroe County, New York, but were unsuccessful (Figure 1; Appendix B)

Site descriptions

Braddock Bay, Long Pond, and Buck Pond are in a wetland complex managed by NYSDEC as the Braddock Bay Fish and Wildlife Management Area. They are also parts of the U.S. Environmental Protection Agency-designated Rochester Embayment Area of Concern and a U.S. Department of State Significant Coastal Fish and Wildlife Habitat (Figure 1).

Braddock Bay is roughly 1.3 x 0.7 km and has an open connection to Lake Ontario. Two navigable tributaries, Salmon and Buttonwood Creeks, flow from the west into the north and south corners, respectively. The bay is surrounded by a large margin of emergent marsh dominated by cattail, *Typha* spp., a few residential properties, and two marinas. The bay consists of a mix of dredged channels, shallow sandy bottoms, and shallow, muck-bottomed wetlands dominated by a diverse array of submerged and floating aquatic macrophytes. Long Pond is the largest embayment, roughly 2.4 km x 0.8 km, and is connected to the lake by a channel. Almost the entire shoreline of Long Pond is residential property, the average depth is greater (2.1 m), and there is far less wetland area and very little submerged aquatic vegetation. Buck Pond is a very shallow (average depth 0.5 m), hypereutrophic marsh with very dense submerged aquatic vegetation (CADMUS 2010). The two bowfin captured in Sandy Creek were caught in the 1-hectare back-barrier wetland, consisting of submerged aquatic macrophytes surrounded by cattail. East and Rush Creeks are small tributaries draining from cattail-dominated wetlands between Sandy Creek and Braddock Bay (Figure 1B).

Population characteristics

Using standard fisheries techniques, the 51 bowfin captured from Braddock Bay were compared to previously described bowfin populations—two from the UMR (Pools 11 and 13; Koch *et al.* 2009a), one from the upper Barataria estuary of southeast Louisiana (Davis 2006), one from a reservoir in south Georgia, Lake Lindsay Grace (Porter *et al.* 2013), and one from the Mingo Swamp in southeastern Missouri (Holland 1964; Figure 1A). Using methods adapted from Koch & Quist (2007), the first pectoral fin rays of each fish were sectioned and digitally photographed. Age and proportional growth increments were measured using graphics software ImageJ V 1.46. The Dahl-Lea technique (Quist *et al.* 2013) was used to back-calculate length-at-age:

$$L_i = L_c(\frac{S_i}{S_c})$$

where L_i is the back-calculated length at annulus *i*, L_c is the length of the fish at capture, S_i is the radius length to annulus *i*, and S_c is the radius length of the fin ray at capture. Mean length-at-age data were then used to fit the von Bertalanffy growth model to the male and female samples:

$$L_t = L_\infty[1 - e^{-K(t-t_0)}]$$

where L_t is the estimated length at time *t*, L_∞ is the theoretical maximum length, *K* is a coefficient of growth rate, and t_0 is the theoretical time (age) at zero length.

Mean length-at-age data were also used to calculate percent annual growth at each age, for each population using the formula:

$$\frac{Mean\ Length_{n+1} - Mean\ Length_{n}}{Mean\ Length_{n}}$$

where *n* is the age. Mean length-at-age data were obtained using the Dahl-Lea technique (Quist *et al.* 2013) for the Braddock Bay population; from raw data published in Holland (1964) for the Mingo Swamp population; and data for the UMR Pools 11 and 13 (Koch *et al.* 2009a), the Barataria estuary (Davis 2006), and Lake Lindsay Grace (Porter *et al.* 2013) populations were provided by Dr. Michael Quist (personal communication, University of Idaho).

Adapted low-cost method for sectioning pectoral fin rays

Each bowfin's first pectoral fin rays were removed as close to the pectoral girdle as possible. Ancillary bones and tissue were gently removed from the rays. The distal end of each ray was inserted into a lump of putty, and a greased 1 cm x 1 cm x 3 cm metal tube was placed around the rays (Figure 2A). Clear epoxy was poured into the tube to form a cast. After pushing the casts out of their tubes they were placed into a 1 cm x 1 cm x 3 cm metal sectioning tube, which had a 2 mm longitudinal gap along one side to allow pressure from a bench vise to hold the cast in place (Figure 2B). Thin (0.2–0.3 mm) sections were cut with a jeweler's saw fit with a 4/0 (64 teeth/inch) blade. Both sides of each section were polished by wet-sanding with 600 grit sandpaper.

The five most readable sections of each cast were fixed between two microscope slides using clear epoxy (Figure 2C). A digital single lens reflex camera fit with a 1x relay adapter captured images of the sections magnified 10x using a compound light microscope. Some fin rays were larger than the field of view, in which case their images were stitched using Microsoft® Image Composite Editor V1.4.4 (http://research.microsoft.com/en-us/um/redmond/projects/ice/). The clearest micrograph of each fish was selected, and annuli were measured down the long lobe of the fin ray section (Figure 2D) using ImageJ V1.46 (http://imagej.nih.gov/ij/).

Captive breeding study

Five tanks and two aquaculture ponds were tested for their conduciveness to breed bowfin from 24 October 2012 to 28 July 2013. Two 0.04 ha ponds were used as pseudo-controls and both were stocked with two males and three females (personal communication, Dr. Allyse Ferrara). Due to their differing sizes, tanks 1 and 2 each housed one male and two females and tanks 3–5 each housed one male and one female. Fish were allowed to feed *ad libitum* on live prey. In the event of mortality, a dead bowfin was replaced if one of the same sex and roughly equal size was available. Each bowfin’s size, duration of captivity, and tank/pond placement is shown in Appendix A. At the end of the experiment all tanks and ponds were thoroughly checked for nests, eggs, and bowfin YOY.

Recirculating aquaculture system design

A Recirculating Aquaculture System (RAS) was assembled in an unused storage building at the College’s aquaculture ponds site. The system was self-designed, mostly self-funded, had many problems with water quality initially, and was redesigned twice to solve the water quality problems.

The five tanks were initially plumbed into two fully-recirculating systems (Figure 3). System 1 included Tanks 1 and 2—a 152 cm x 76 cm x 121 cm, 1,415 L stainless steel tank and a 182 cm diameter x 90 cm, 2,341 L circular fiberglass tank. This system housed six bowfin and had 340 L of biofiltration with 226 L/min aeration and 38 L/min flow plumbed in-line with both tanks. System 2 included Tanks 3–5 which were 127 cm x 81 cm x 91 cm, 567 L Rubbermaid® agricultural stock tanks. This system also had tanks housing 14 bowfin used in a pilot feeding experiment from fall 2012 to 9 June 2013. System 2 housed a total of 20 bowfin and contained 1,570 L of biofiltration with 210 L/min aeration, 170 L of carbon filtration, and 136 L/min flow. All filters on System 2 were plumbed with feedback to the sump tank, and aeration in both systems was only applied to the filters.

Due to deteriorating water quality, water from an adjacent aquaculture pond was used to modify the systems to partial flow-through on 11 May 2013 (Figure 4). This was done by delivering 19 L/min of fresh pond water into a gravel filter for each system. Water overflowed from each system's sump tank and was pumped back to the pond. Due to continued issues with water quality, the systems were converted to fully flow-through on 24 June 2013 by replacing the recirculation pumps with a 100 L/min pumped supply of pond water (Figure 5).

Environmental conditions in the RAS

The indoor tanks were designed to mimic natural conditions as much as possible. Temperature was kept ambient above freezing by using fans to introduce outside air and to distribute heat from a large electric heater set to 4.4° C in winter only. Light timers were adjusted weekly to sunrise/sunset timetables. Tank lights were suspended 20 cm above each tank and all natural light was blocked. Decayed organic muck was collected from Braddock Bay and placed in each tank to a depth of 24 cm. Flow rates were kept minimal, with turnover rates of roughly 1–2 h. Disturbances of fish were minimized by hanging linen screens around the tanks, isolating vibrations from pumps and aerators by suspending supply and return pipes from the ceiling and not resting them on any tanks, and not using lights at night.

Water quality, including nitrate, nitrite, ammonia, pH, and temperature, was recorded several times each week (Figures 6 & 7). Dissolved oxygen was recorded less frequently; of 37 measurements on both systems, values were between 39–108 % saturation with a mean of 78 ± 16%. Nitrate, nitrite, and ammonia were measured with Aquarium Pharmaceuticals® test kits. Temperature and pH were measured with a YSI® pH100 handheld digital meter. Dissolved oxygen was measured with a YSI® DO200 handheld digital meter.

Aquaculture ponds

The ponds, built in 1986, were 2 m deep and plastic-lined with 10 cm of organic muck atop 30 cm of native clay. They differed in their peripheral and submerged vegetation, catchment area, and water chemistry. Pond 1 was surrounded by sparse cattail and shrubs, and the water column fills to the surface annually with *Potamogeton crispus* (curly-leaf pondweed); its catchment area was roughly 0.5 hectares of turf and crushed limestone. The embankment of Pond 2 consisted of dense shrubs, brush, and trees over 2 m tall; the amount of open water was reduced by a 2 m margin of dense cattail. The lower 2/3rds of the water column fills annually with *Ceratophyllum demersum* (coontail), and the pond has virtually no catchment (Figure 8). Temperature, pH, turbidity, alkalinity, and conductivity were measured in each pond (Table 1).

Both ponds were seined prior to stocking with bowfin. Pond 1 contained mature stocks of *Carassius auratus* (goldfish), *Perca flavescens* (yellow perch), and *Pimephales promelas* (fathead minnows). Pond 2 was devoid of fish but heavily populated with large tadpoles. Thousands of goldfish and minnows (<60 mm TL) from Pond 1 were stocked into Pond 2. All fish greater than 60 mm TL were removed from Pond 1. The ponds were aerated to provide an ice-free zone from 31 December 2012 to 28 February 2013.

Artificial diet study

Three diets—Purina Mills® (Aquamax), Ground Fish (GF), and live prey (Control)—were presented to 12 bowfin for 86 days from 2 July to 25 September 2013. Fish were captured on 14 June 2013 in Braddock Bay by nighttime boat electroshocking. The fish were placed individually into 121 cm x 60 cm x 30 cm, 226 L stainless steel tanks with a 3.2 L/m supply of fresh pond water, 55 W/m^2 fluorescent lighting, and smooth gravel substrate. They were allowed to acclimate to captivity for 18 days on a diet of one small goldfish (40–60 mm TL) per day. Water quality, including nitrate, nitrite, ammonia, pH, and temperature, was recorded several times each week (Figure 7). Dissolved oxygen was recorded less frequently; of 12 measurements, values were between 44–99% saturation with a mean of 71% (± 19% SD). Nitrate, nitrite, and ammonia were measured with Aquarium Pharmaceuticals® test kits. Temperature was measured using digital data loggers and pH was measured with a YSI® pH100 handheld digital meter. Dissolved oxygen was measured with a YSI® DO200 handheld digital meter. Percent consumption was used to compare the acceptance of the diets; it was calculated as the number of pellets consumed ÷ number presented for the artificial diets and as the total mass of prey consumed ÷ total mass of prey presented for the control diet. All food and prey items were tracked for consumption. A Kruskal-Wallis non-parametric one-way analysis of variance was used to compare the percent change in each bowfin's mass under the three diets, which was found using the formula:

$$\frac{final\ weight - initial\ weight}{initial\ weight}$$

Diet composition

The Aquamax diet was a 19 mm extruded floating pellet with high protein, low fat content and a mean weight of 4.5 g (± 0.68 SD, n = 351). The GF diet was a 19 mm moist pellet with a mean weight of 4.9 g (± 1.5 SD, n = 390). It was made with 10% vitamin-enriched flour and 90% ground frozen freshwater fish, comprised mostly of *Oncorhynchus tshawytscha* (Chinook salmon), *Salmo trutta* (brown trout), *Salmo salar* (Atlantic salmon), *Oncorhynchus mykiss* (rainbow trout), *Salvelinus namaycush* (lake trout), *Catostomus* and *Moxostoma* spp. (suckers), and *Perca flavescens* (yellow perch). These two diets were analyzed for nutritional content by

Cumberland Valley Analytical Services, Inc. Maugansville, Maryland (Table 2). The control diet consisted of juvenile *Lepomis* spp. (sunfish), goldfish, *Notropis atherinoides* (emerald shiners), fathead minnows, large tadpoles, and crayfish. All prey items were less than 70 mm TL and 40 mm in height, the latter to minimize size-selective feeding (Mundahl *et al.* 1998).

Preparing the ground fish (GF) pellets

The heads, skin, and spines of frozen freshwater fish were removed prior to grinding with a residential-grade food processor. About 25% of this product was further blended in a commercial blender and mixed with flour. The mixture was then squeezed into a "rope" onto trays using a meat grinder. After freezing, the rope was cut into 3 cm-long segments. These were then placed into a forced-air laboratory oven for 3 hours at 69° C, below the temperature at which vitamin C denatures (NCBI 2015).

Feeding

Feeding took place in random order of tanks each day between 11:00 am and 10:30 pm. Pellets were presented one-at-a-time by tethering them to the tank lids with string. If a pellet was consumed during the feeding process, it was replaced. A minimum of 15 minutes had to transpire before leaving the room to allow the last fish a chance to eat multiple pellets. The weight of each pellet was recorded. The control diet was divided into three categories based on shape: minnows, sunfish and goldfish, and tadpoles and crayfish. Two items of each category were kept in the tanks to minimize any effect of prey preference. Total weight of prey presented was recorded (Appendix C).

Results and Discussion

Bowfin collections

Catch per unit effort (CPUE) of bowfin was highly variable across sites (Table 3). Catches within Braddock Bay were highly temperature dependent: no bowfin were captured on 10 November, a night with temperatures below freezing, but 34 bowfin were captured during three warmer nights in roughly the same location that fall (Appendix B). Long and Buck ponds were each sampled once, both on cold days. Therefore, the low CPUE values of the other water bodies were likely due to temperature, and should not be interpreted to mean a low abundance of bowfin. The two other studies that reported CPUE, Davis (2006) and Porter *et al.* (2014), used very different methods of capture and therefore are not comparable, but are included in Table 3 simply to compile recent data on bowfin CPUE.

Population characteristics

The 51 bowfin sampled in Braddock Bay from 20 October 2012 to 14 June 2013 were on average 579 ± 90 (SD) mm TL, 1880 ± 1018 g, 4.2 ± 1.4 years in age, and the sex ratio was nearly 1:1 (Table 4). By fitting the von Bertalanffy growth model using back-calculated length-at-age estimates (Appendix D), the theoretical maximum length (L_∞) of this population was estimated to be 753 mm TL, with a coefficient of growth (K) of 0.262, and a time at length zero (t_0) of -0.023 years (Table 5). Females were longer ($P < 0.001$), heavier ($P < 0.001$), and grew faster than males (Table 4; Figure 9), which is consistent with previously described populations (Holland 1964; Davis 2006; Koch *et al.* 2009a; Porter *et al.* 2013).

These results support the latitudinal gradient described by Porter *et al.* (2013) in that Lake Ontario bowfin closely resembled those of the UMR, which were the most similar in latitude, growth rate and theoretical maximum length (Table 5; Figure 10). The population from the Mingo Swamp had values for growth in-between the Lake Ontario and UMR populations and the Barataria Estuary and Lake Lindsay Grace populations (Figures 1 & 10). Annual growth rates were higher at higher latitudes for ages 1–4, with Lake Ontario having the highest rates and the Barataria estuary having a low, nearly linear trend (Figure 11).

My age and growth results may be inaccurate due to small sample sizes for some ages; there was one age-1 bowfin and two each of ages 6, 7, and 8. The method of sectioning by hand was also very meticulous and more time-consuming than using a low-speed isometric saw as described in Koch & Quist (2007). Varying thicknesses, trapped air bubbles, and unpolished cuts obscured several sections from being read. Furthermore, the population of bowfin that I examined displayed a large amount of double-banding and cross-over of annuli on the sectioned fin rays (indicating deposition of semi-annual marks; personal communication, Dr. Michael Quist, University of Idaho).

Water quality of the indoor system

The initial RAS system encountered highly fluctuating pH values and harmful levels of ammonia, nitrite, and nitrate from its conception on 24 October 2012 to 11 May 2013 (Figures 6&7). This was likely due to an overloading of the system with biomass, despite the large amount of biofiltration (Figure 3), from both the bowfin themselves, totaling 39 kg (Appendix A), and the enormous amount of freshly disturbed, oxygenating, and actively decomposing organic muck used for bowfin substrate. The temperature of this system was also higher than Pond 1 from 2 April to 11 May 2013 (Figure 7). The captive conditions experienced by the indoor bowfin did not match natural conditions, which may have caused stress that led to the mortality observed (Appendix A). Converting to a partial flow-through system on 11 May 2013 (Figure 4) somewhat alleviated these issues, and converting to a fully flow-through system on 24 June 2013 (Figure 5) with water from an adjacent pond almost completely alleviated these issues (Figure 7).

Captive breeding

Breeding did not occur in any tank or pond. The only possible signs of breeding occurred 13–16 June 2013 in Pond 1 when a male was observed stirring the sediment near the shoreline, however no nest was built. Breeding coloration was displayed by the indoor bowfin and the males and females were often seen lying side-by-side.

Only five of 123 female bowfins captured by Davis (2006) spawned in the upper Barataria Estuary of southeastern Louisiana, who noted that females can reabsorb eggs and “skip spawning” if environmental conditions are unfavorable. Many conditions were unfavorable in my indoor tanks: lack of submerged vegetation; extremely loose sediment devoid of roots; vertical tank walls; disturbance; elevated, flashy temperatures; and the presence of ammonia and nitrite (Figures 6 & 7). These factors existed over a long period of confinement and likely caused the skipped spawning, as well as five mortalities (Appendix A: F5, F11, F15, X5, M15).

In my ponds, shorelines may have been too steep to allow nest construction. The ponds also may have been too small, as bowfin in Great Lake coastal wetlands migrate daily (McKenna 2008) over unknown, yet large ranges (Jacobus & Webb 2005). It is unknown where bowfin overwinter in the Great Lakes, so perhaps the ponds restricted seasonal migration. The two reports of successful pond-propagation, Huner (1994) and Green (1966), used much larger ponds (8 & 1.3 ha) in the southern U.S. stocked with wild fish just before the breeding season. Huner (1994) also reported several unsuccessful attempts in smaller, un-vegetated ponds and canals.

Artificial diet

Live prey was the most accepted diet, and ground fish was more accepted than the Aquamax diet (Figure 12). While the two artificial diets were similar in nutritional content (Table 2), the ground fish diet was expected to be more palatable because it was made from 90% unprocessed fish. All diets resulted in an average loss in weight of the adult bowfin (Table 6). Two bowfin gained weight, Y4 and Y5 of the Aquamax and ground fish groups (18% and 3% of original body weight, respectively), however eight bowfin lost more than 5% body weight (Figure 13). Bowfin fed the ground fish diet lost less weight than those fed the other two diets (Kruskal-Wallis one-way ANOVA, *F* [2, 9] = 9.19, *P* = 0.007).

Since the control group of bowfin readily accepted live prey yet lost weight, these fish likely were stressed, not provided with enough food, or both. Many of the fish were as long as the tanks were wide. Most of the bowfin were shy and would wait for the room to be vacated before eating. Future studies should provide food *ad libitum* to bowfin in larger tanks with no disturbances by an observer. The shyness of some fish lessened with time, particularly with X1, a large female on the ground fish diet. This particular bowfin was very eager and would aggressively consume multiple pellets every four to seven days. No fish of the Aquamax group consumed a pellet while an observer was in the room (Appendix C).

Conclusions

The population sampled in this study resembled those of UMR Pools 11 and 13 in growth and population characteristics, but more data are needed on population dynamics, such as recruitment, mortality, and abundance to fully assess the potential impact of commercial harvesting in the Great Lakes. Lake-wide surveys using multiple collection gears and mark-recapture studies are recommended.

The method I used to section pectoral fin rays by hand is recommended only if a low-speed isometric saw is not available. My method ultimately worked, but is unsuitable for large-scale projects with a limited budget because many sections had to be cut in order to ensure at least one readable fin ray section.

Intensive aquaculture of this species (tanks and RASs) will require induced spawning, which Dabrowski (2012a) has recently accomplished. Container size should be maximized and water quality kept consistent with conditions in the wild. A moist-pellet diet would probably be the most accepted feed. Extensive culture will require large ponds (>1 ha) with gently sloping, heavily vegetated areas 1 m or less in depth for breeding. Very little aggression was observed, even in the indoor tanks, so bowfin may tolerate high stocking rates. A semi-domesticated strain could possibly be developed since a few bowfin (e.g. Y4, Y5, X1; Appendix C) adjusted to captivity very well. Further research is needed to identify ideal diets for the maintenance of brood stock and grow-out of hatchlings, as well as on environmental conditions that will promote growth and reproduction of bowfin in captivity for aquaculture purposes.

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Tables

Table 1. Water parameters measured in Pond 1 and Pond 2. Samples were taken at the surface 2 m from shore. Turbidity was measured with a LaMotte® SCL-08 Electronic Aquaculture Lab colorimeter kit. Conductivity, dissolved oxygen (DO), and alkalinity were measured with a YSI® multi-parameter meter. Temperature and pH were measured with a YSI® pH100 handheld digital meter.

Date	Pond	Time	Temp (C)	pH	Conductivity (uS/cm)	DO (mg/L)	Alkalinity (mg $CaCO_3$/L)	Turbidity (FTU)
10/24/12	1	16:30	13.0	8.00				25
	2	16:30	12.0	7.40				1
12/27/2012	1	17:00	1.1	8.75	150	13.1	94.7	
	2	17:00	1.4	8.52	108	9.5	66.0	
3/22/2013	1	13:30	9.8	8.38				
	2	13:30	8.8	7.90				
4/10/13	1	14:00	16.6	7.52				
	2	14:00	14.9	7.66				

Table 2. Laboratory analysis of two artificial diets, Ground Fish (GF) and Purina Mills® Aquamax performed by Cumberland Valley Analytical Services, Inc., Maugansville, Maryland. Two columns, wet weight and dry weight (DW), are presented for each sample.

Feed	**GF 1**	**GF 1 DW**	**GF 2**	**GF 2 DW**	**Aquamax**	**Aquamax DW**
Moisture (%)	49.4	-	49.6	-	7	-
Dry Matter (%)	50.6	-	50.4	-	93	-
Crude Protein (%)	24.4	48.2	24.5	48.6	46.7	50.2
Crude Fat (%)	6.9	13.6	6.9	13.7	8.4	9.1
Ash (%)	3	6	3.5	6.9	8.6	9.2
Starch (%)	-	-	11.2	22.2	-	-
Crude Fiber (%)	0.4	0.8	0.3	0.5	4.7	5.1
Calcium (%)	0.57	1.13	0.74	1.47	1.92	2.07
Phosphorus (%)	0.64	1.27	0.56	1.1	1.34	1.44
Magnesium (%)	0.06	0.11	0.05	0.11	0.17	0.19
Potassium (%)	0.44	0.88	0.44	0.87	1.17	1.25
Sodium (%)	0.093	0.184	0.092	0.183	0.263	0.282
Iron (ppm)	57	113	63	125	490	527
Manganese (ppm)	10	21	8	16	95	102

Feed	GF 1	GF 1 DW	GF 2	GF 2 DW	Aquamax	Aquamax DW
Zinc (ppm)	60	119	39	78	222	239
Copper (ppm)	5	10	3	5	23	25

Table 3. Catch per unit effort (CPUE) of bowfin sampled duuring October–November 2012 and June 2013 with 24-hour fyke net–sets and boat electroshocking from coastal wetlands in Monroe County, New York, with a comparison to CPUE reported in recent studies. Units are in bowfin captured per hour net-set, electroshocking power-on time, or hook and line fishing, with total hours of effort in parentheses. Boat electroshocking was biased toward bowfin habitat in this study but followed unbiased transects in Porter *et al.* 2014; therefore, these numbers are not comparable.

	Current study			**Porter *et al.* 2014**	**Davis 2006**
Gear	**Braddock Bay**	**Long Pond**	**Buck Pond**	**Lake Lindsay Grace (GA)**	**Barataria Estuary (LA)**
Rectangular fyke nets[1]	0.13 (*264*)	0.01 (*72*)	0 (*144*)		
Round fyke nets[2]		0.02 (*48*)			
Boat electroshocking	17.71 (*0.96*)			2.71 (*30.3*)	
Gill nets[3]					0.25 (*422.7*)
Hook and line[4]					1.32 (*57*)

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[1] Rectangular fyke nets had a 4.7 mm bar mesh with a rectangular opening of 1.3 m x 1.0 m and a 4.5 m main lead

[2] Round fyke nets had a 25.4 mm bar mesh with a 1.3 m diameter opening and a 7.6 m main lead.

[3] Gill nets were monofilament, 1.8 x 22.9 m, with bar mesh sizes ranging from 38–101 mm.

[4] Hook and line (angling) methods included topwater, floating lures as well as drift and bottom bait fishing.

Table 4. Comparison of total length (TL), weight (g), and ages (years) of female and male bowfin collected from 20 October 2012 to 14 June 2013 in Braddock Bay, Monroe County, New York using a two-tailed, unpaired t-test.

	Parameter	**N**	**Mean**	**Standard Deviation**	**Range**	**Significance (M vs. F)**
Female	TL (mm)	26	627.4	98.4	439, 791	
	Weight (g)		2450.6	1075.4	803, 4100	
	Age (y)		4.5	1.7	2, 8	
Male	TL (mm)	25	527.8	70.2	213, 2148	*P* < 0.001 (L)
	Weight (g)		1287.1	484.5	289, 629	*P* < 0.001 (W)
	Age (y)		3.9	1.0	1, 6	*P* = 0.292 (Age)
Combined	TL (mm)	51	578.5	98.7	289, 791	
	Weight (g)		1880.3	1017.8	213, 4100	
	Age (y)		4.2	1.4	1, 8	

Table 5. Estimated parameters of the von Bertalanffy growth equation for bowfin populations across a latitudinal gradient. Parameter L_∞ represents the theoretical maximum length (mm), K is a coefficient of growth rate, and t_0 is the theoretical age at zero length. Populations marked with an asterisk were analyzed using the gular plate; all others used sectioned first pectoral fin rays. Parameters for Upper Mississippi River Pools 11 and 13 (Koch *et al.* 2009a) and Lake Lindsay Grace (Porter *et al.* 2014) were provided by co-author M. Quist; the Barataria Estuary data were published in Davis (2006); and the Mingo Swamp data were calculated from raw data published in Holland (1964).

Waterbody (state)	**N**	L_∞	**K**	t_0
Lake Ontario (NY)	51	752.8	0.262	-0.023
Female	*26*	*722.7*	*0.310*	*0.082*
Male	*25*	*720.1*	*0.253*	*-0.104*
Pool 11 UMR (WI/IA)	118	809.2	0.229	-0.086
Pool 13 UMR (IL/IA)	138	783.3	0.235	0.004
Mingo Swamp (MO)*	178	1232.0	0.097	-1.179
Female	*102*	*1088.5*	*0.127*	*-0.897*
Male	*76*	*922.0*	*0.125*	*-1.378*
Lake Lindsay Grace (GA)	76	603.8	0.625	-0.779
Barataria Estuary (LA)*	288	1131.6	0.078	-3.523

Table 6. Percent consumption of two artificial diets, Purina Mills® Aquamax and Ground Fish, and a control diet of live prey presented to bowfin over an 86-day period 2 July to 25 September 2013, with summary statistics of the bowfin used in each treatment (n=4). Percent consumption for the artificial diets was calculated as the number of pellets consumed/number presented; the control diet was calculated as the total mass of prey consumed/total mass of prey presented. All food and prey items were tracked for consumption.

Diet	**Aquamax**			**Ground Fish**			**Control**		
	Mean	**SD**	**Range**	**Mean**	**SD**	**Range**	**Mean**	**SD**	**Range**
Age (y)	5.0	2.2	3, 8	3.3	1.7	1, 5	4.5	0.6	4, 5
Total Length (mm)	538.0	104.5	459, 692	493.7	144.5	289, 628	538.2	48.2	481, 592
Weight (g)	1380.7	1087.8	526, 2975	1163.0	732.5	213, 2000	1313.7	401.0	870, 1796
Δ Weight (g)	-98.2	144.2	-255, 94	-35.5	51.3	-110, 7	-166.2	80.4	-266, -93
Percent Consumption (%)	62.25	3.0	59, 66	82.75	19.2	54, 94	94.9	0.7	94, 96

Figures

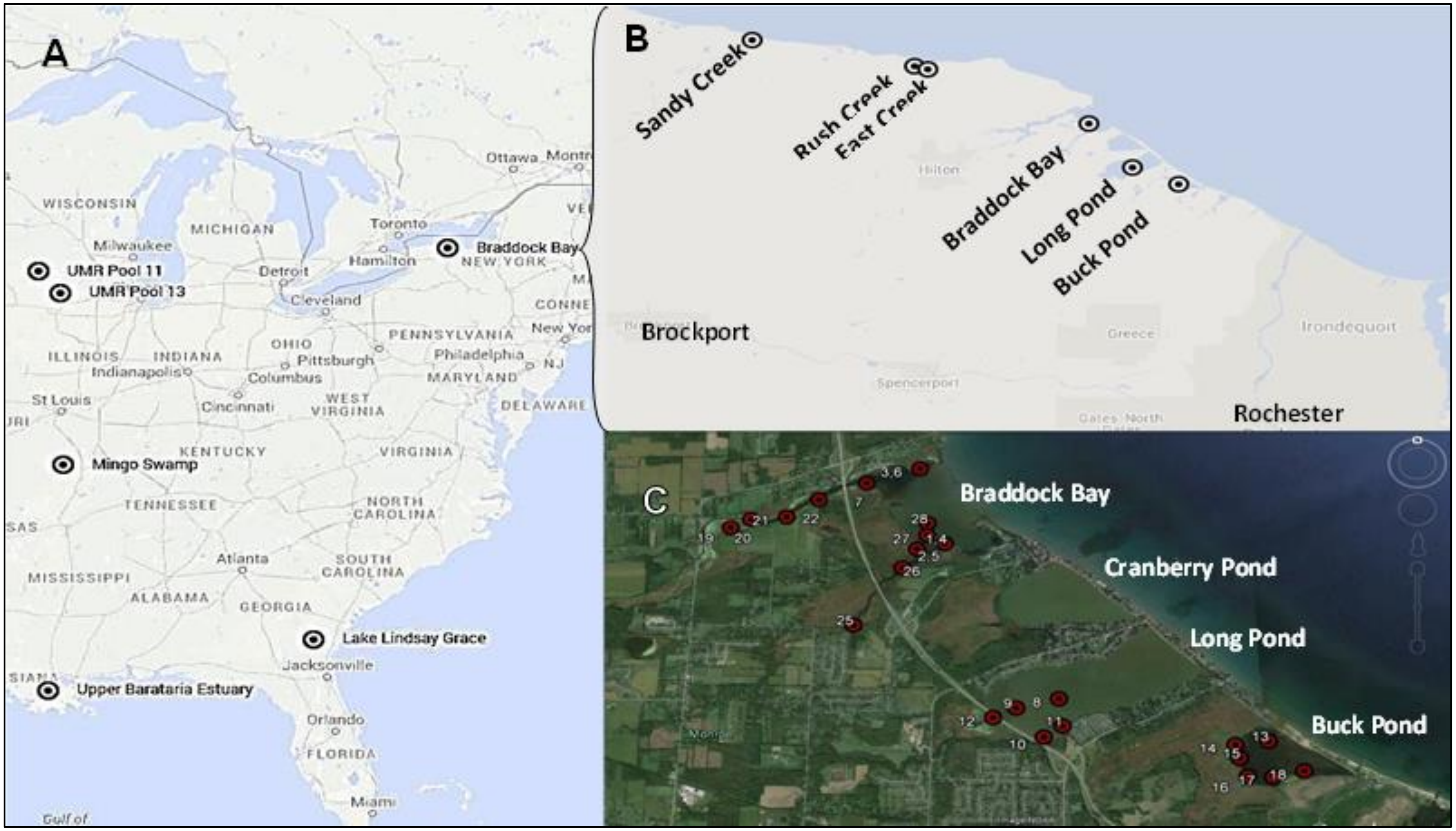

Figure 1. Maps of sampling locations of this study in relation to previously described bowfin populations (A), waterbodies sampled for this study (B), and the placement of fyke nets set from 20 October to 12 November 2012 (C).

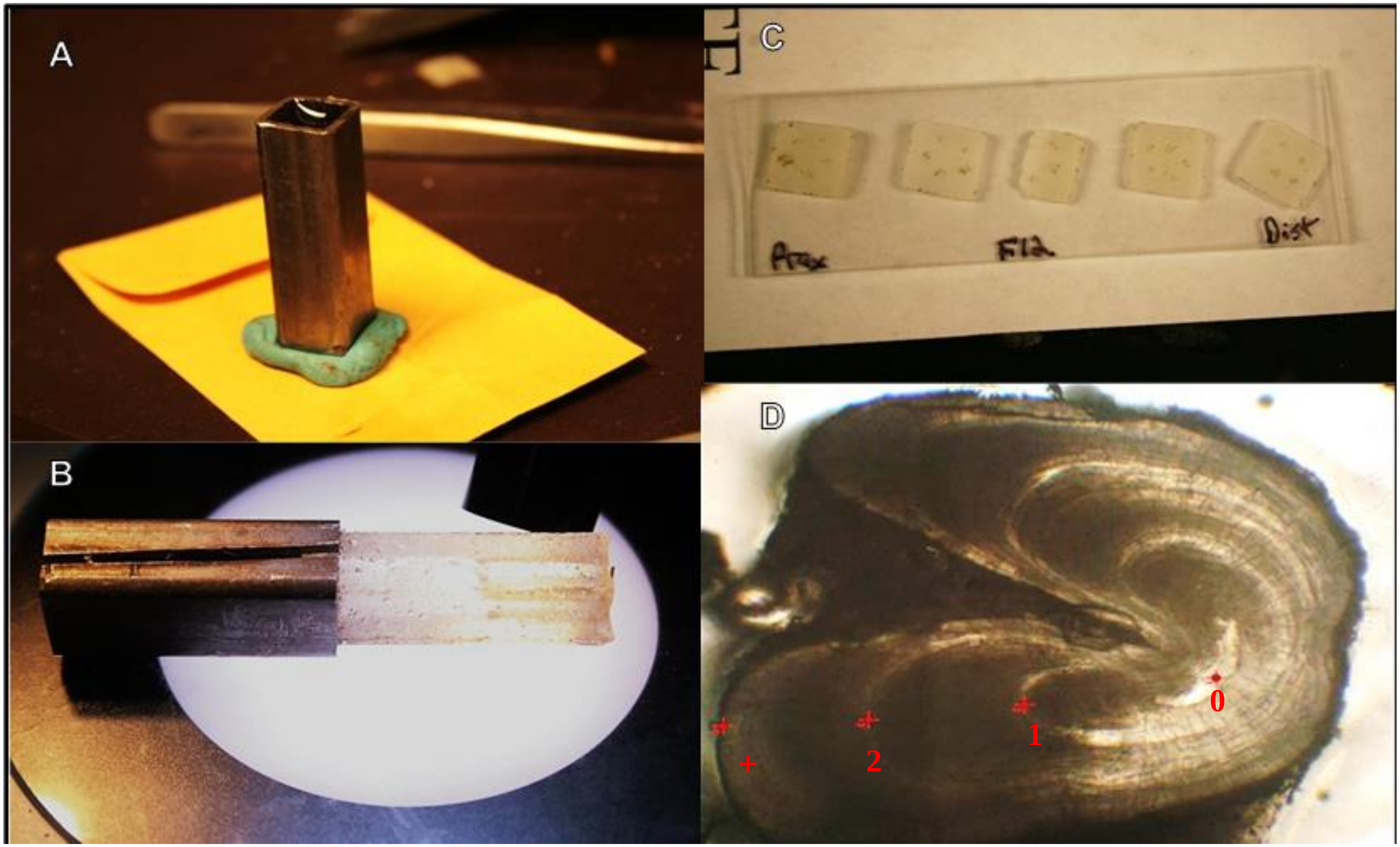

Figure 2. Images of pectoral fin rays being cast in epoxy (A), a cured cast inserted into the sectioning tube (B), sections ready to be fixed on microscope slides (C), and an image of a sectioned pectoral fin ray of a 2+ year old female bowfin (539mm TL, 1,466 g) captured in Braddock Bay on 12 November 2012 (D).

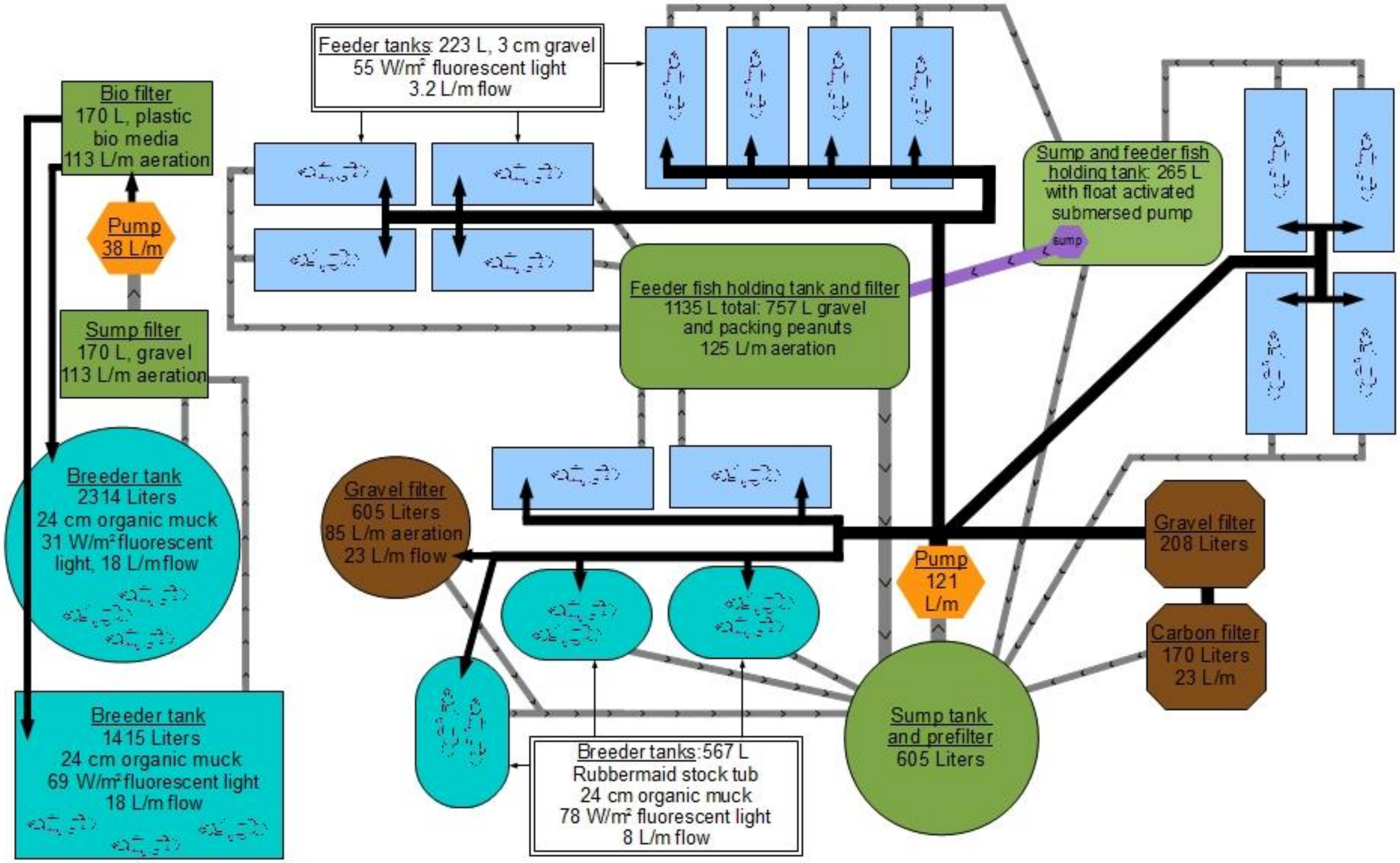

Figure 3. Layout of the Recirculating Aquaculture System (RAS) used from 20 October 2012 to 11 May 2013.

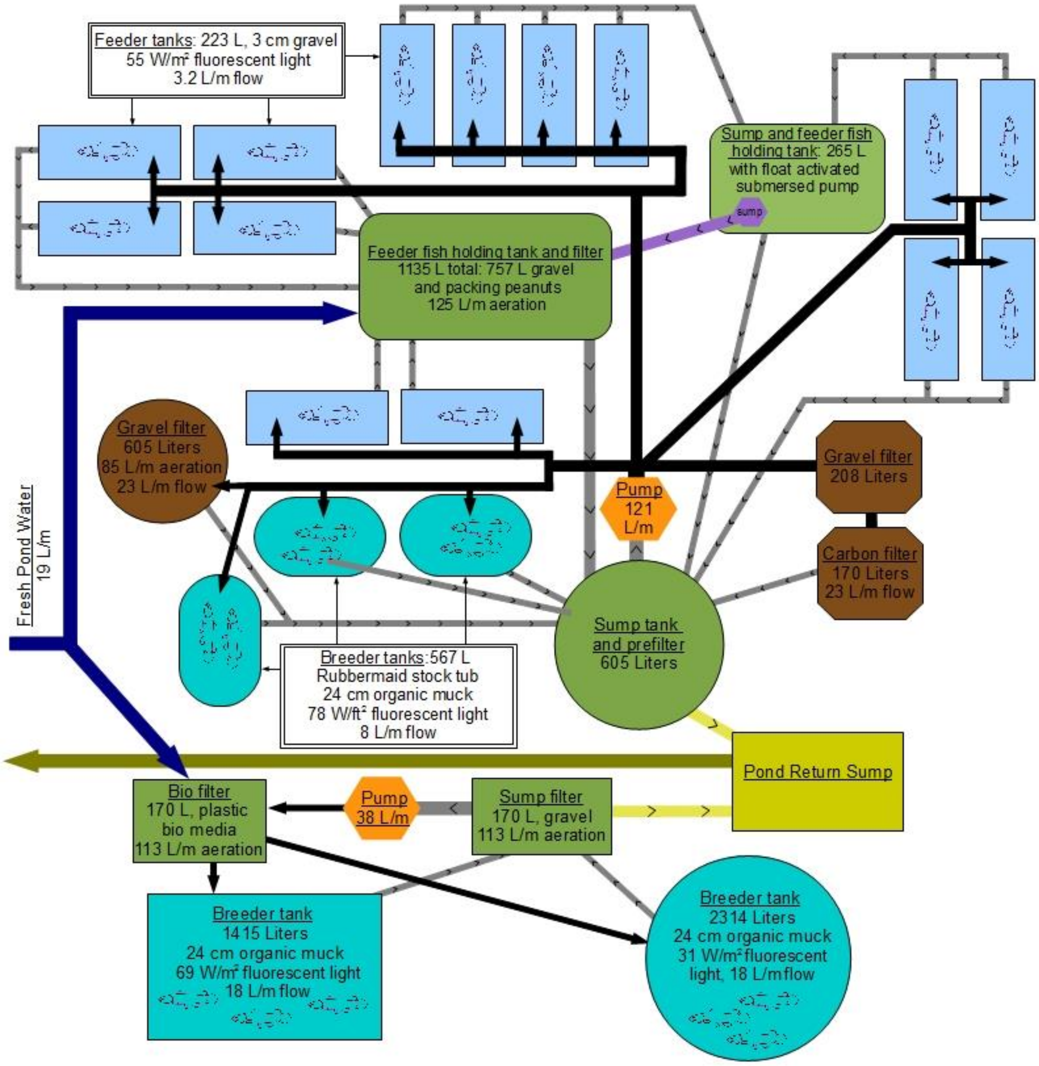

Figure 4. Layout of the partial flow-through Recirculating Aquaculture System used from 11 May to 24 June 2013.

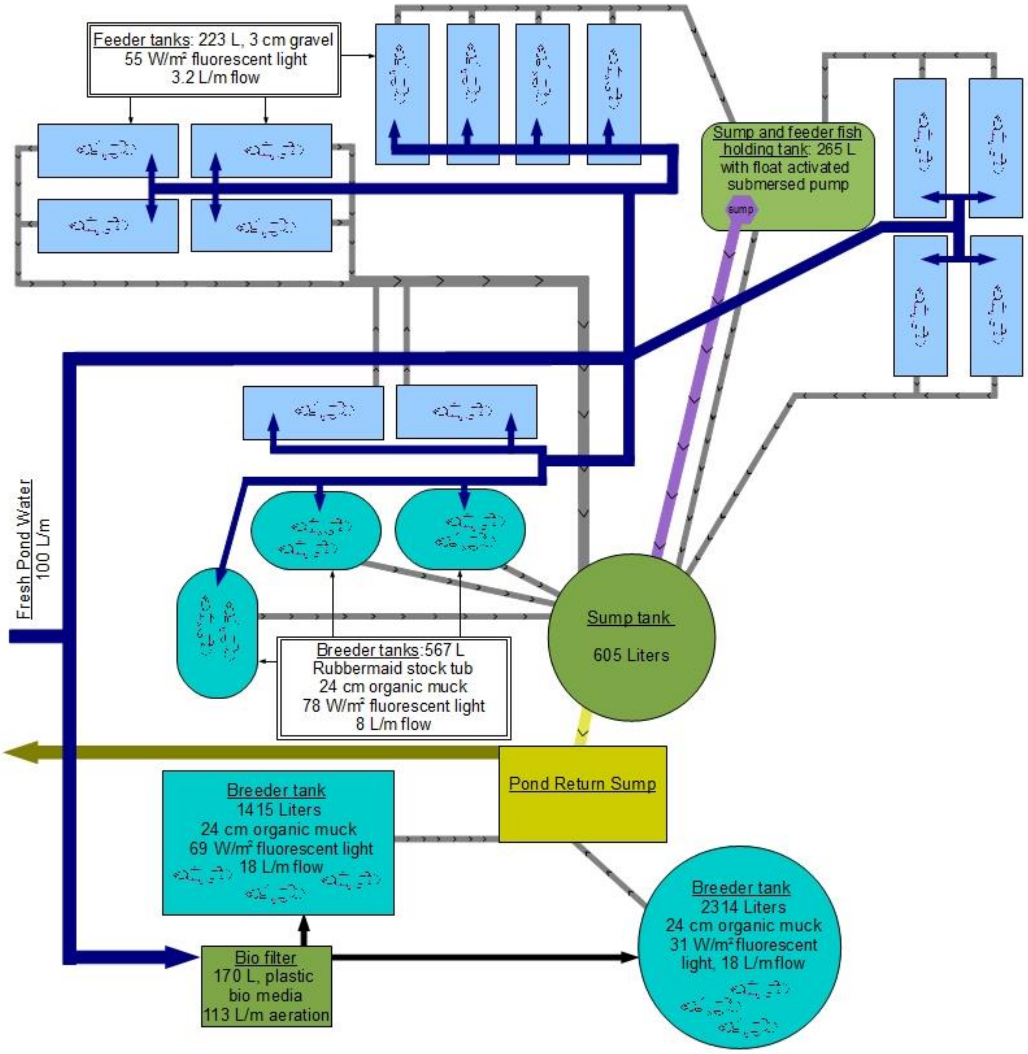

Figure 5. Layout of the fully flow-through tank system from 24 June to 27 September 2013.

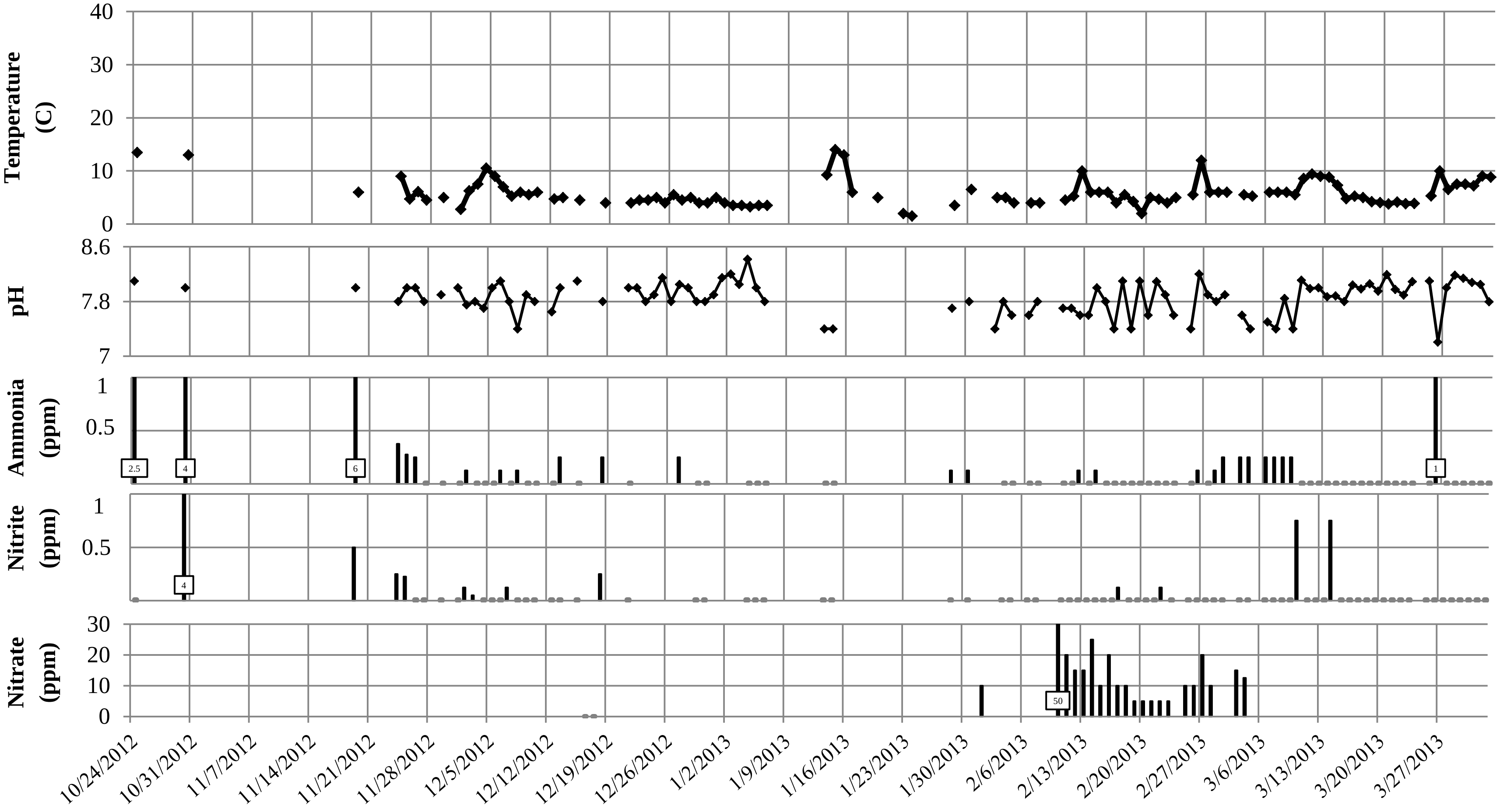

Figure 6. Water quality of the indoor system 24 October 2012 to 1 April 2013. Temperature was measured with a digital portable pH probe in Systems 1 and 2 and averaged. Gray marks on the x-axes indicate a measurement of zero.

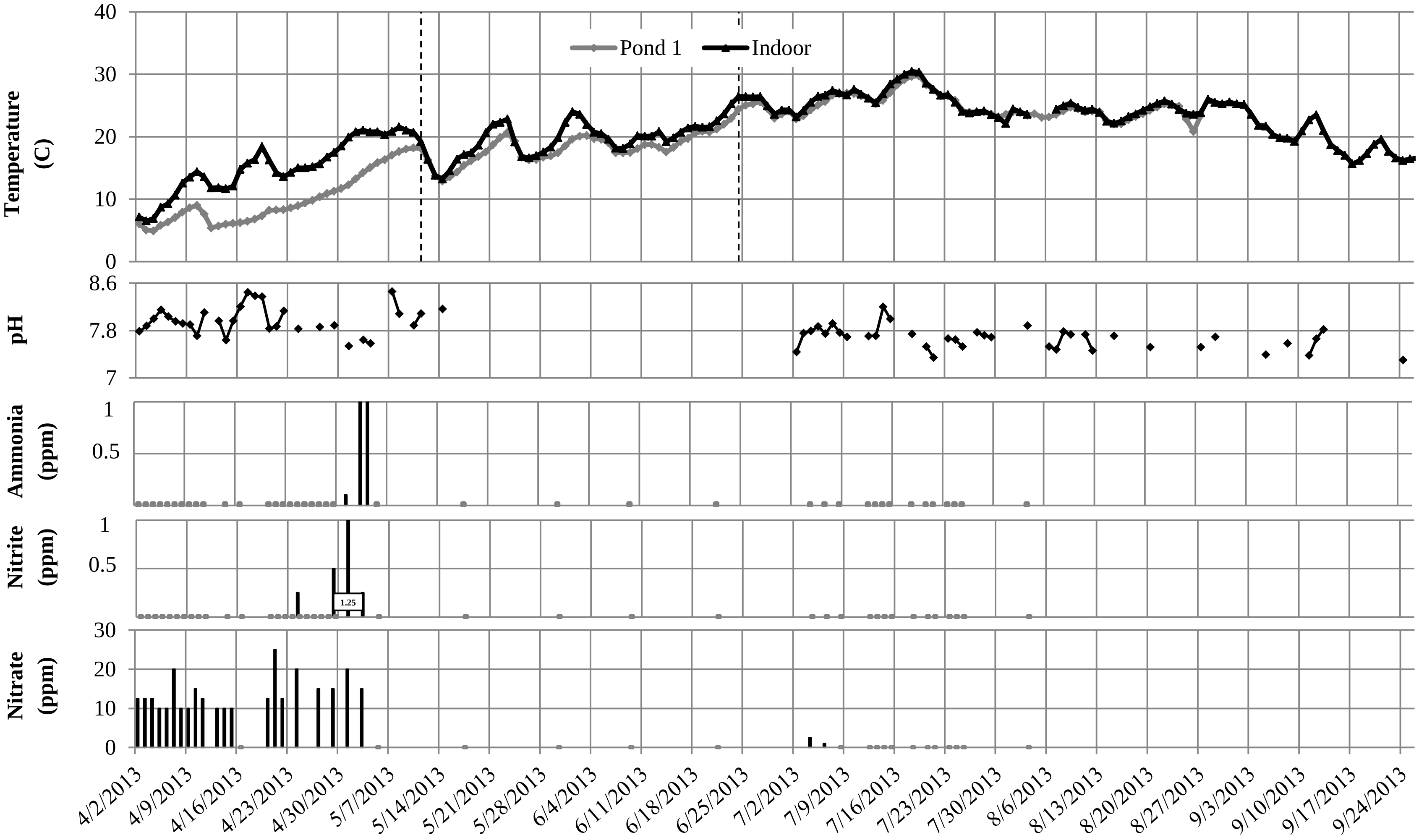

Figure 7. Temperature of Pond 1 and water quality of the indoor system from 2 April to 25 September. Temperature was measured with digital data loggers. The system was converted from fully recirculating to partial flow-through on 11 May, and to fully flow-through on 24 June 2013. Gray marks on the x-axes indicate a measurement of zero.

(bottom).

Figure 8. Photographs taken on 24 October 2012 of Pond 1 (top) and Pond 2 (bottom).

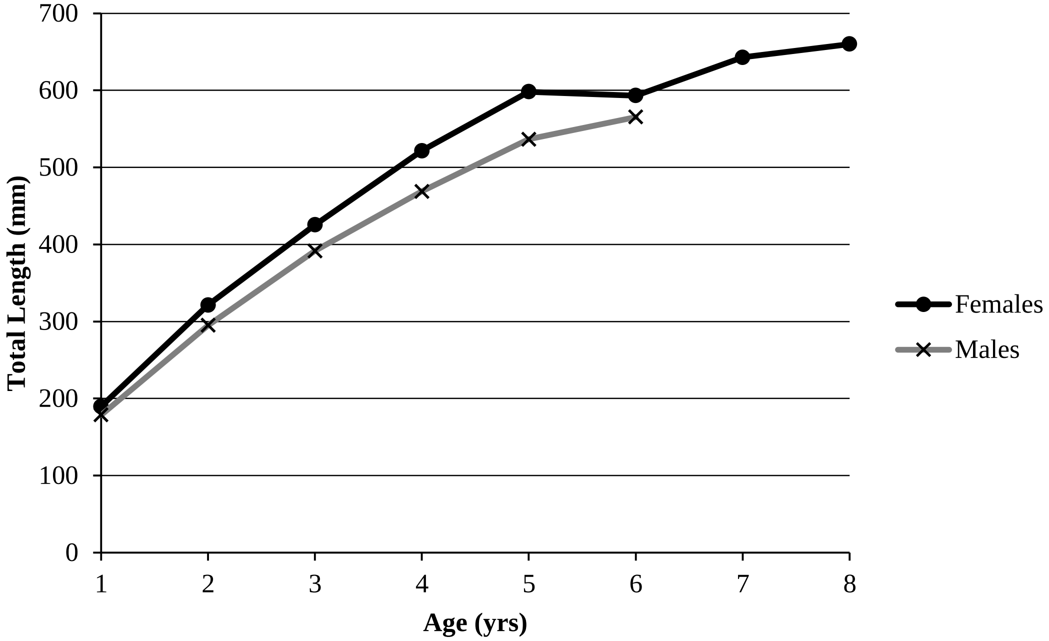

Figure 9. Mean back-calculated length-at-age of female (n=26) and male (n=25) bowfin collected 20 October 2012 to 14 June 2013 from Braddock Bay, Monroe County, New York. Annular radii were measured digitally from micrographs of sectioned pectoral fin rays, for which raw data is included in Appendix D.

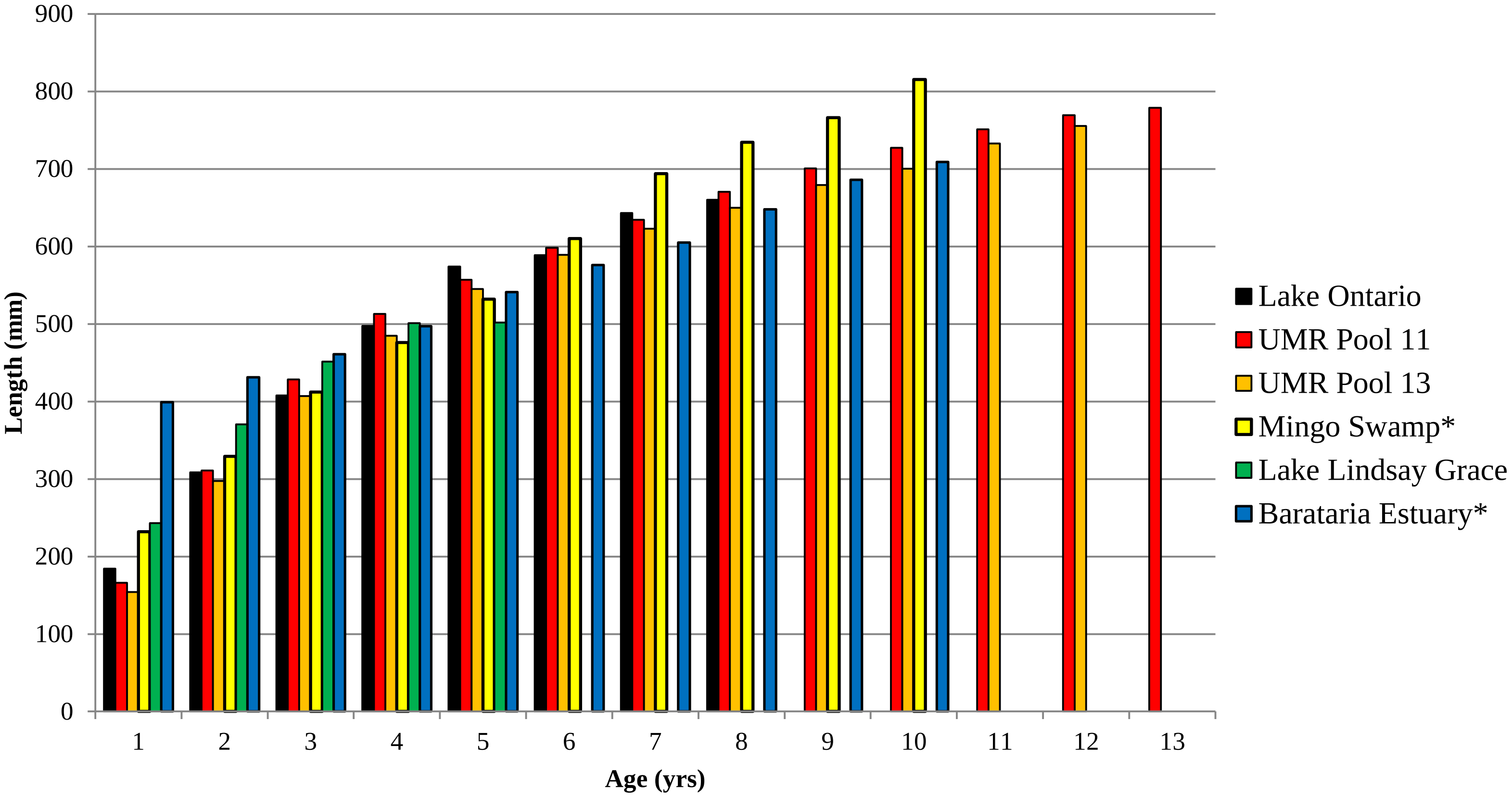

Figure 10. Mean back-calculated length-at-age of bowfin populations along a latitudinal gradient. Populations marked with an asterisk were analyzed using the gular plate; all others used sectioned first pectoral fin rays. Data for Upper Mississippi River (UMR) Pools 11 and 13 (Koch *et al.* 2009a) and Lake Lindsay Grace (Porter *et al.* 2014) were provided by co-author M. Quist; the Barataria Estuary data were published in Davis (2006); and the Mingo Swamp data were calculated from raw data published in Holland (1964).

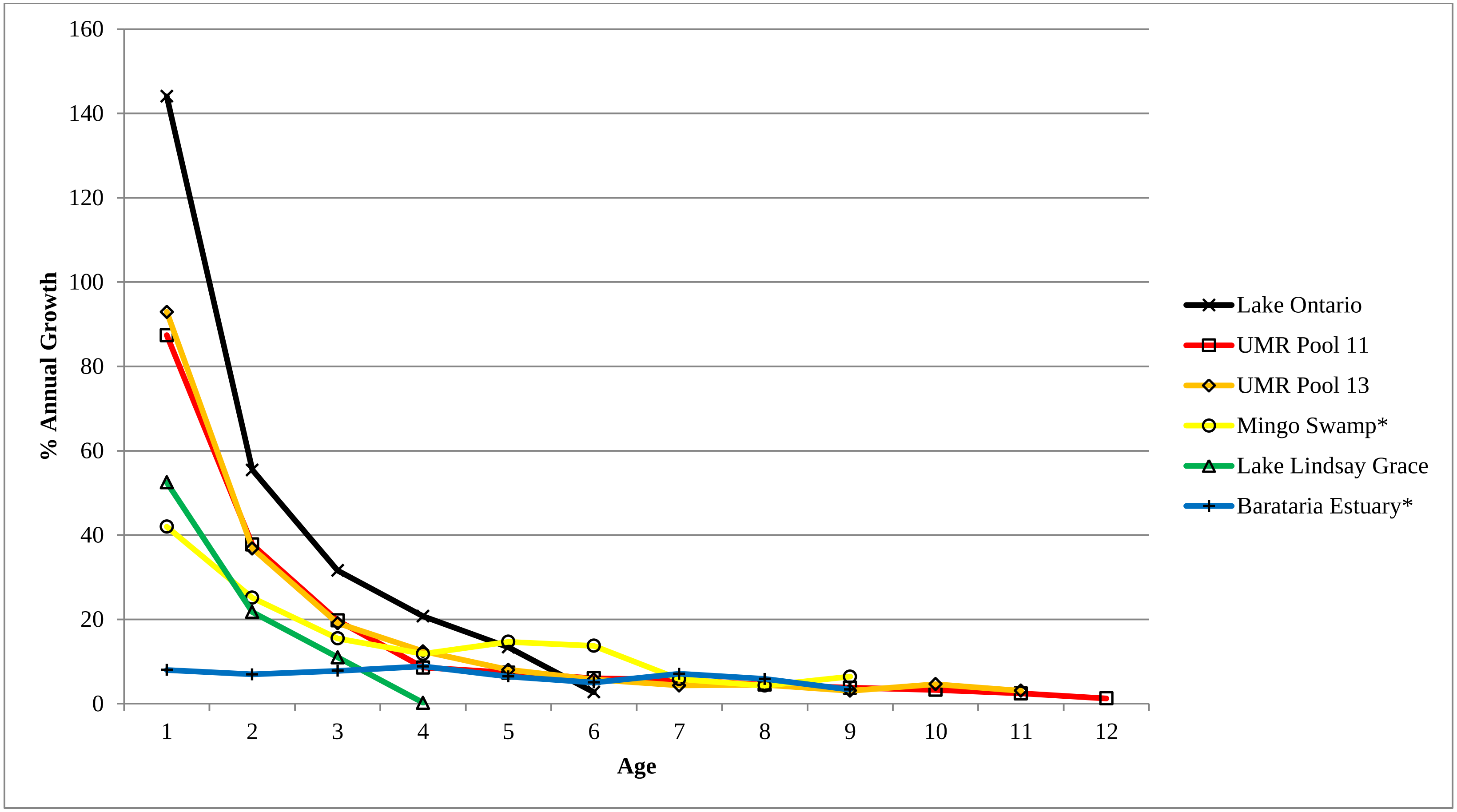

Figure 11. Percent annual growth of bowfin populations along a latitudinal gradient. Populations marked with an asterisk were analyzed using the gular plate; all others used sectioned first pectoral fin rays. Data for Upper Mississippi River (UMR) Pools 11 and 13 (Koch *et al.* 2009a), the Barataria Estuary (Davis 2006), and Lake Lindsay Grace (Porter *et al.* 2014) were provided by Dr. M. Quist (U. of Idaho); and the Mingo Swamp data were calculated from raw data published in Holland (1964).

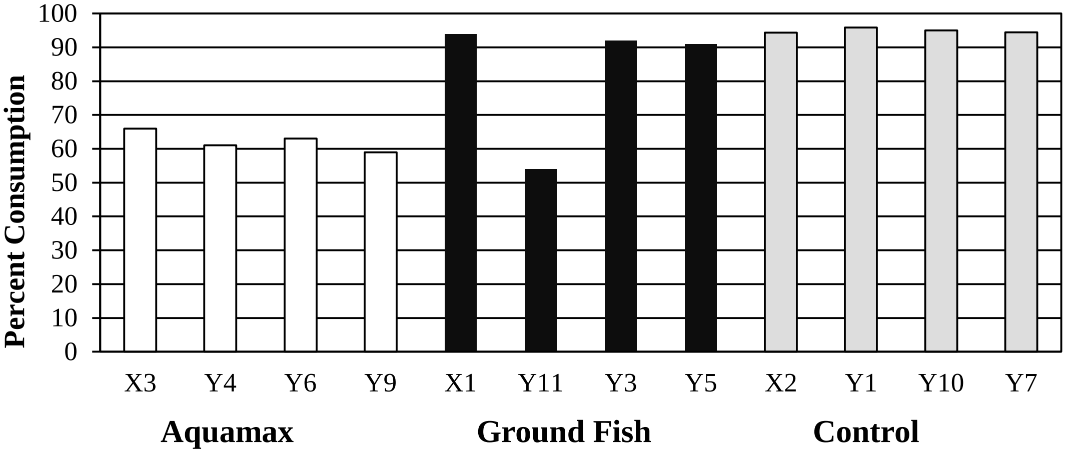

Figure 12. Percent consumption of two artificial diets and a control diet of live prey presented to adult bowfin in captivity over 86 days from 2 July to 25 September 2013. Percent consumption for the artificial diets was calculated as the number of pellets consumed/number presented; the control diet was calculated as the total mass of prey consumed/total mass of prey presented. All food and prey items were tracked for consumption. Fish ID codes correspond to Appendix A. Codes beginning with "X" were females and "Y" were males.

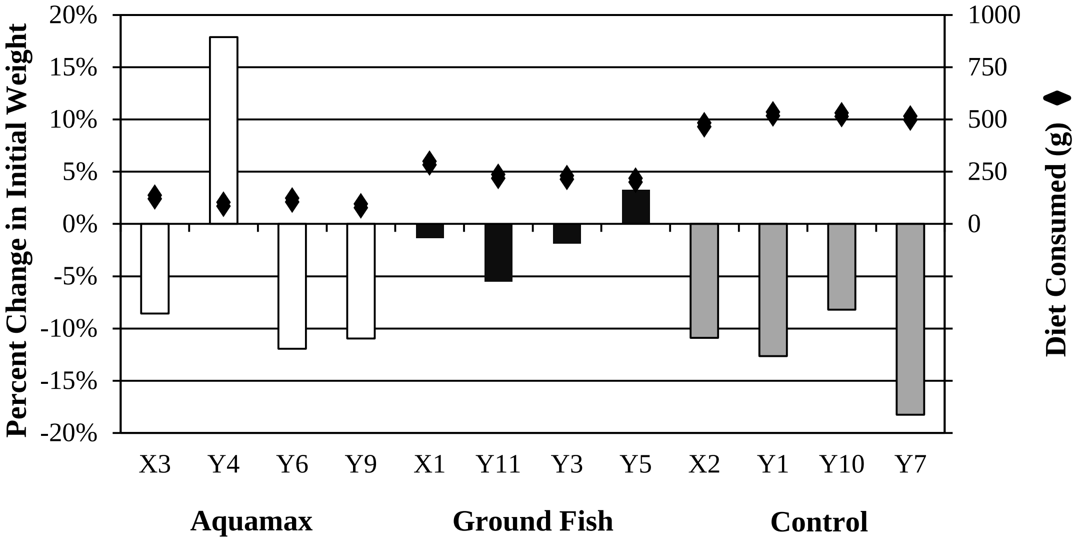

Figure 13. Percent change in initial weight of bowfin after an 86-day feeding experiment (bars) and total diet consumed (♦). Two artificial diets, Purina Mills® Aquamax and Ground Fish, and a control diet of live prey were presented to bowfin. Diet consumed was dry-weight corrected for the artificial diets (7% for Aquamax and 49.5% for Ground Fish, Table 2) but not for the control diet. Fish ID codes correspond to Appendix A. Codes beginning with "X" were females and "Y" were males.

Appendices

Appendix A. Use log of all 55 bowfin captured for this study. Gonadal Somatic Index (GSI) is the percent mass of gonads to whole body. Fish ID codes indicate the sex and season of capture: ‘F’ and ‘X’ were females, ‘M’ and ‘Y’ were males, and ‘F’ and ‘M’ were captured October–November, ‘X’ and ‘Y’ were captured in June.

ID	**Total length** (mm)	**Initial weight** (g)	**Final weight** (g)	**Age** (y)	**Tank/pond**	**Date collected**	**Origin**	**Experiment**	**Treatment**	**Gonad weight** (g)	**GSI** (%)	**Date of perish**	**Days in captivity**
F1	719	3577	3080	7	P1	10/20/2012	Braddock	Breeding	--	--	--	--	295
F2	791	4100	3560	5	P1	10/20/2012	Braddock	Breeding	--	--	--	--	295
F3	724	2893	2860	6	P2	10/27/2012	Long Pond	Breeding	--	115	4.02	5/31/2013	216
F4	771	3912	3330	5	P2	10/20/2012	Braddock	Breeding	--	--	--	--	295
F5	714	3516	2980	5	T1	11/12/2012	Braddock	Breeding	--	123	4.13	5/13/2013	182
F6	708	4002	3240	5	P1	11/12/2012	Braddock	Breeding	--	--	--	--	272
F7	743	4075	3330	5	P2	11/12/2012	Braddock	Breeding	--	--	--	--	272
F8	635	2554	1953	4	T1	11/12/2012	Braddock	Breeding	--	--	--	--	258
F9	647	2580	1994	5	T2	11/12/2012	Braddock	Breeding	--	--	--	--	258
F11	568	1576	1180	4	T3	11/12/2012	Braddock	Breeding	--	113	9.58	6/26/2013	226
F13	684	2889	2401	4	T2	10/20/2012	Braddock	Breeding	--	--	--	--	281
F15	603	1928	1860	4	T4	11/12/2012	Braddock	Breeding	--	185	9.95	5/2/2013	171

ID	Total length (mm)	Initial weight (g)	Final weight (g)	Age (y)	Tank/pond	Date collected	Origin	Experiment	Treatment	Gonad weight (g)	GSI (%)	Date of perish	Days in captivity
F17	589	1842	1432	4	T5	11/12/2012	Braddock	Breeding	--	--	--	--	258
M1	624	2118	1970	5	P1	11/12/2012	Braddock	Breeding	--	--	--	--	272
M2	614	2102	1900	6	P2	11/12/2012	Braddock	Breeding	--	--	--	--	272
M3	540	1363	1480	4	P1	11/12/2012	Braddock	Breeding	--	--	--	--	272
M4	540	1205	1033	4	T2	11/12/2012	Braddock	Breeding	--	--	--	--	258
M5	579	1454	968	4	T1	10/20/2012	Braddock	Breeding	--	--	--	--	281
M6	533	1334	941	4	T3	11/12/2012	Braddock	Breeding	--	--	--	--	258
M9	598	2148	1750	4	P2	10/20/2012	Braddock	Breeding	--	--	--	--	295
M10	531	1418	970	3	T4	11/12/2012	Braddock	Breeding	--	--	--	--	258
M15	529	924	815	3	T5	10/20/2012	Braddock	Breeding	--	72	8.83	8/4/2013	288
X4	656	2694	2694	6	T1	6/14/2013	Braddock	Breeding	--	280	10.39	6/15/2013	1
X5	701	3111	3130	8	T4	6/14/2013	Braddock	Breeding	--	120	3.83	8/1/2013	48
X6	701	3238	3220	7	P2	6/14/2013	Braddock	Breeding	--	350	10.87	6/21/2013	7
X3	692	2975	2720	8	T13R	6/14/2013	Braddock	Feeding	Aquamax	--	--	--	105
Y4	459	526	620	3	T11	6/14/2013	Braddock	Feeding	Aquamax	--	--	--	105
Y6	502	1056	930	4	T14R	6/14/2013	Braddock	Feeding	Aquamax	--	--	--	105
Y9	499	966	860	5	T15L	6/14/2013	Braddock	Feeding	Aquamax	--	--	--	105

ID	Total length (mm)	Initial weight (g)	Final weight (g)	Age (y)	Tank/pond	Date collected	Origin	Experiment	Treatment	Gonad weight (g)	GSI (%)	Date of perish	Days in captivity
Y2	495	902	750	4	T7	6/14/2013	Braddock	Feeding	Backup	--	--	--	105
X2	592	1796	1600	4	T12R	6/14/2013	Braddock	Feeding	Control	--	--	--	105
Y1	481	870	760	4	T6	6/14/2013	Braddock	Feeding	Control	--	--	--	105
Y10	520	1133	1040	5	T12L	6/14/2013	Braddock	Feeding	Control	--	--	--	105
Y7	560	1456	1190	5	T14L	6/14/2013	Braddock	Feeding	Control	--	--	--	105
X1	518	1206	1190	3	T9	6/14/2013	Braddock	Feeding	GF	--	--	--	105
Y11	628	2000	1890	5	T10	6/14/2013	Braddock	Feeding	GF	--	--	--	105
Y3	540	1233	1210	4	T8	6/14/2013	Braddock	Feeding	GF	--	--	--	105
Y5	289	213	220	1	T15R	6/14/2013	Braddock	Feeding	GF	--	--	--	105
Y8	629	1937	1937	5	T15R	6/14/2013	Braddock	Feeding	--	45	2.32	6/17/2013	3
F10	443	803	785	2	T15R	11/12/2012	Braddock	Pilot	Aquamax	--	--	--	209
F12	550	1461	1649	4	T6	11/12/2012	Braddock	Pilot	Aquamax	200	12.13	4/23/2013	162
F14	439	1265	462	2	T14L	10/21/2012	Braddock	Pilot	Aquamax	--	--	--	231
M14	497	1021	1036	3	T7	9/24/2012	Sandy Creek	Pilot	Aquamax	22	2.12	4/16/2013	204
M7	512	1150	816	3	T10	11/12/2012	Braddock	Pilot	Aquamax	--	--	--	209
M13	501	1098	1084	3	T11	10/20/2012	Braddock	Pilot	Backup	18	1.66	4/19/2013	181
F16	539	1466	1383	2	T12L	11/12/2012	Braddock	Pilot	Control	60	4.34	5/2/2013	171

ID	**Total length** (mm)	**Initial weight** (g)	**Final weight** (g)	**Age** (y)	**Tank/pond**	**Date collected**	**Origin**	**Experiment**	**Treatment**	**Gonad weight** (g)	**GSI** (%)	**Date of perish**	**Days in captivity**
F19	567	1680	1511	4	T12R	11/12/2012	Braddock	Pilot	Control	110	7.28	4/22/2013	161
M12	394	516	344	2	T8	10/27/2012	Long Pond	Pilot	Control	--	--	--	225
M16	517	1339	780	4	T15L	11/12/2012	Braddock	Pilot	Control	--	--	--	209
F18	509	1168	1301	3	T13L	11/12/2012	Braddock	Pilot	GF	122	9.38	4/20/2013	159
F20	517	901	802	2	T13R	11/12/2012	Braddock	Pilot	GF	--	--	--	209
M11	462	985	607	3	T9	11/12/2012	Braddock	Pilot	GF	--	--	--	209
M8	512	1248	1191	3	T14R	10/20/2012	Braddock	Pilot	GF	34	2.85	5/3/2013	195
F0	715	3400	3400	4	-	10/20/2012	Braddock	--	--	249	7.32	10/22/2012	2
F00	458	1265	-	4	-	9/24/2012	Sandy Creek	--	--	--	--	9/25/2012	1

Appendix B. Catch data for all overnight fyke-net–sets in coastal wetlands on the south shore of Lake Ontario west of Rochester, New York from 20 October to 12 November 2012. All nets were set in the afternoon and retrieved the following afternoon. The nets were set either solo or in tandem with the leads joined; near a shoreline, open water, or a in a channel; and aligned either perpendicularly (perp) or parallel (parl) to shore (n/a for open water). Two types of nets were used: rectangular (rect), 4.7mm bar mesh with an opening of 1.3 m x 1.0 m and a 4.5 m main lead; and round, 25.4 mm bar mesh with a 1.3 m diameter opening and a 7.6 m main lead. Depth was measured at trap opening. Air temperatures (previous daytime high, overnight low, daytime high on day of retrieval) were obtained from The Weather Channel's online historical weather data for Rochester International Airport (www.wunderground.com).

Net ID	**Date retrieved**	**Location**	**Temp Hi/Low/Hi** (C)	**# Bowfin captured**	**Net set type**	**Net type**	**Depth** (m)	**GPS coordinates**	**Other catch**
1	10/20/2012	Braddock Bay	17.2 7.7 13.8	2	Solo, Shore, Perp	Rect	1.0	43°18'27.23"N 77°42'48.57"W	Bluegill, Brown bullhead, YOY Largemouth bass
2	10/20/2012	Braddock Bay	17.2 7.7 13.8	6	Tand, Open, Perp	Rect	0.7	43°18'27.93"N 77°42'59.19"W	Bluegill, Brown bullhead, Pumpkinseed
3	10/20/2012	Braddock Bay	17.2 7.7 13.8	2	Tand, Shore, Perp	Rect	1.0	43°19'2.23"N 77°43'0.15"W	Bluegill, Brown bullhead, Pumpkinseed, YOY Largemouth bass
4	10/21/2012	Braddock Bay	13.8 7.7 16.6	0	Solo, Shore, Perp	Rect	1.0	43°18'27.23"N 77°42'48.57"W	Bluegill, Pumpkinseed
5	10/21/2012	Braddock Bay	13.8 7.7 16.6	1	Tand, Open, Perp	Rect	0.7	43°18'27.93"N 77°42'59.19"W	None
6	10/21/2012	Braddock Bay	13.8 7.7 16.6	0	Tand, Shore, Perp	Rect	1.0	43°19'2.23"N 77°43'0.15"W	Bluegill, *Notropis* spp.
7	10/21/2012	Braddock Bay	13.8 7.7 16.6	0	Solo, Open, Parl	Rect	1.2	43°18'55.42"N 77°43'28.03"W	None
8	10/27/2012	Long Pond	25 8.8 11.6	1	Solo, Open, n/a	Round	2.0	43°17'18.29"N 77°41'47.82"W	Brown bullhead, Channel catfish, Common carp, Walleye, White perch
9	10/27/2012	Long Pond	25 8.8 11.6	0	Solo, Open, n/a	Round	2.2	43°17'14.27"N 77°42'9.51"W	Brown bullhead, Channel catfish, White perch

Net ID	**Date retrieved**	**Location**	**Temp Hi/Low/Hi** (C)			**# Bowfin captured**	**Net set type**	**Net type**	**Depth** (m)	**GPS coordinates**	**Other catch**
10	10/27/2012	Long Pond	25	8.8	11.6	1	Solo, Shore, Perp	Rect	1.0	43°17'3.04"N 77°41'55.95"W	Brook silverside, Brown bullhead, Channel catfish, Gizzard shad, Golden shiner, Largemouth bass, White perch, Yellow perch
11	10/27/2012	Long Pond	25	8.8	11.6	0	Solo, Shore, Perp	Rect	0.7	43°17'4.10"N 77°41'48.77"W	Brook silverside, Brown bullhead, Channel catfish, Gizzard shad, Largemouth bass, *Notropis* spp., White perch, Yellow perch
12	10/27/2012	Long Pond	25	8.8	11.6	0	Solo, Channel, Perp	Rect	1.0	43°17'10.09"N 77°42'21.18"W	Brown bullhead, Channel catfish, Gizzard shad, YOY *Lepomis* spp.
13	11/2/2012	Buck Pond	7.7	5.5	5.5	0	Solo, Shore, Perp	Rect	0.8	43°16'59.89"N 77°40'2.48"W	Bluegill, Gizzard shad
14	11/2/2012	Buck Pond	7.7	5.5	5.5	0	Solo, Shore, Perp	Rect	0.9	43°16'58.41"N 77°40'19.25"W	Bluegill
15	11/2/2012	Buck Pond	7.7	5.5	5.5	0	Solo, Shore, Perp	Rect	0.9	43°16'52.59"N 77°40'17.29"W	Bluegill, Gizzard shad
16	11/2/2012	Buck Pond	7.7	5.5	5.5	0	Solo, Shore, Perp	Rect	0.7	43°16'44.91"N 77°40'13.56"W	Bluegill, Gizzard shad, Northern pike
17	11/2/2012	Buck Pond	7.7	5.5	5.5	0	Solo, Shore, Perp	Rect	0.5	43°16'44.64"N 77°40'0.84"W	Bluegill, Gizzard shad
18	11/2/2012	Buck Pond	7.7	5.5	5.5	0	Solo, Shore, Perp	Rect	0.5	43°16'47.18"N 77°39'45.14"W	Bluegill, Gizzard shad, Northern pike
19	11/10/2012	Braddock Bay	9.4	-2.7	10.5	0	Solo, Channel, Parl	Rect	0.8	43°18'34.90"N 77°44'38.20"W	YOY *Lepomis* spp.
20	11/10/2012	Braddock Bay	9.4	-2.7	10.5	0	Solo, Channel, Parl	Rect	0.8	43°18'38.74"N 77°44'27.89"W	None
21	11/10/2012	Braddock Bay	9.4	-2.7	10.5	0	Solo, Channel, Parl	Rect	0.9	43°18'39.80"N 77°44'9.30"W	Bluegill, Pumpkinseed
22	11/10/2012	Braddock Bay	9.4	-2.7	10.5	0	Solo, Channel, Parl	Rect	1.0	43°18'47.76"N 77°43'52.76"W	Brown bullhead, Pumpkinseed, YOY *Lepomis* spp.
23	11/10/2012	East Creek	9.4	-2.7	10.5	0	Solo, Channel, Perp	Rect	1.2	43°20'12.52"N 77°47'54.71"W	Brown bullhead, Common carp, Largemouth bass, *Notropis* spp.
24	11/10/2012	Rush Creek	9.4	-2.7	10.5	0	Solo, Channel, Perp	Rect	1.5	43°20'17.35"N 77°48'18.80"W	Bluegill, Channel catfish, Pumpkinseed

Net ID	**Date retrieved**	**Location**	**Temp Hi/Low/Hi** (C)	**# Bowfin captured**	**Net set type**	**Net type**	**Depth** (m)	**GPS coordinates**	**Other catch**
25	11/12/2012	Braddock Bay	22.7 10 20.5	7	Solo, Channel, Perp	Rect	0.7	43°17'50.72"N 77°43'32.97"W	Bluegill, Brown bullhead, Largemouth bass, Northern pike, *Notropis* spp., Pumpkinseed, YOY *Lepomis* spp.
26	11/12/2012	Braddock Bay	22.7 10 20.5	3	Solo, Channel, Perp	Rect	1.0	43°18'16.53"N 77°43'8.42"W	Bluegill, Largemouth bass, Northern pike, YOY *Lepomis* spp.
27	11/12/2012	Braddock Bay	22.7 10 20.5	9	Tand, Open, Perp	Rect	1.0	43°18'31.35"N 77°42'55.90"W	Bluegill, Brown bullhead, Largemouth bass, Pumpkinseed
28	11/12/2012	Braddock Bay	22.7 10 20.5	4	Tand, Open, Perp	Rect	1.0	43°18'36.80"N 77°42'55.73"W	Bluegill, Largemouth bass, Pumpkinseed, YOY *Lepomis* spp.

Appendix C. Feeding log showing the numbers and weight of all eaten and uneaten (UE) food presented to twelve bowfin from three treatments—Ground Fish (GF), Purina Mills® Aquamax, and a control diet of live prey—for 86 days from 2 July to 25 September 2013. Days with multiple pieces eaten indicate that a morsel was consumed during the time that the observer was in the room (minimum of 15 minutes after the last piece was presented). If a piece of feed was found in the tank upon arrival for the daily activities, it was assumed that it was from the previous day and the weight of the morsel was moved to the uneaten column. For the control treatment, however, all feedings were batched together in weight, and therefore any uneaten (i.e. found dead) prey items were weighed and subtracted individually. All weights are in grams. Fish ID codes indicate the sex and season of capture: 'F' and 'X' were females, 'M' and 'Y' were males, and 'F' and 'M' were captured October–November, 'X' and 'Y' were captured in June.

Treatment: GF		**Fish ID:**	**X1**			**Y11**			**Y5**			**Y3**		
Day	**Date**	**Time**	**Eaten**		**UE**	**Eaten**		**UE**	**Eaten**		**UE**	**Eaten**		**UE**
1	7/2/13	19:30	7.6					8.8	4.4			6.2		
2	7/3/13	20:30			4.0			5.8			3.7			4.0
3	7/4/13	19:15	3.4			5.6			6.1			6.6		
4	7/5/13	22:00			3.2	8.2			4.3					1.7
5	7/6/13	13:30	1.1			6.0			5.4			6.7		
6	7/7/13	17:00	3.2			4.2			4.8			7.1		
7	7/8/13	18:00	3.5			6.1			5.3			3.0		
8	7/9/13	19:30	3.6			5.2			5.4			4.2		
9	7/10/13	21:00	3.3			5.7			6.5			8.6		
10	7/11/13	22:00	5.8			4.6			3.1			2.5		
11	7/12/13	21:30	6.0	5.0		6.0			6.0	5.0		6.0		

Treatment: GF		Fish ID:	X1		Y11			Y5		Y3		
Day	**Date**	**Time**	**Eaten**	**UE**	**Eaten**		**UE**	**Eaten**	**UE**	**Eaten**		**UE**
12	7/13/13	19:00	5.9		6.7			3.6		3.6	6.0	
13	7/14/13	19:25	6.0		9.0	8.6		7.0		7.0		
14	7/15/13	20:25	8.0		7.0			8.0		5.0		
15	7/16/13	17:20	6.0		6.0			5.0		5.0		
16	7/17/13	18:30	7.0		6.0			6.0		6.0		
17	7/18/13	15:15	8.0		6.0			8.0		6.0		
18	7/19/13	13:00	8.5		6.6			4.7		6.7		
19	7/20/13	16:00	5.0		6.0				4.0	4.0		
20	7/21/13	17:30		5.0	6.0				6.0	6.0		
21	7/22/13	22:00	6.0		6.0			8.0		6.0		
22	7/23/13	20:30		3.0	2.0			2.0		4.0		
23	7/24/13	13:30	7.0				7.6	4.0				6.0
24	7/25/13	17:30	7.4		4.3			2.9		4.4		
25	7/26/13	12:30	3.8		2.7				5.6	4.7		
26	7/27/13	13:30	7.3		7.0			6.0		1.1		
27	7/28/13	18:00	6.7		7.7			6.3		0.4		
28	7/29/13	18:00	7.6		4.2			4.1		4.1		
29	7/30/13	16:00	5.0		4.0			4.3		5.7		
30	7/31/13	11:30	7.4		5.4				7.9	3.7		
31	8/1/13	17:00	4.4		4.1			4.7		2.8		
32	8/2/13	21:30	3.7		3.4			3.3		3.5		
33	8/3/13	22:00	4.9		6.0				8.3	5.9		
34	8/4/13	21:00	7.7		5.8			7.4				6.1

Treatment: GF		Fish ID:	X1							Y11				Y5				Y3					
Day	**Date**	**Time**	**Eaten**						**UE**	**Eaten**			**UE**	**Eaten**			**UE**	**Eaten**					**UE**
35	8/5/13	22:00	3.8							3.6				7.3				6.6					
36	8/6/13	18:30	5.4							3.0				4.9				4.2					
37	8/7/13	19:30	5.1							4.8				7.6									6.7
38	8/8/13	19:00							7.0	6.0				6.0				5.0					
39	8/9/13	21:00	5.0							3.0				4.0				5.0					
40	8/10/13	19:00	4.8							7.6				3.5				5.3	4.7				
41	8/11/13	22:30	7.0	3.5						3.0				4.0				4.0					
42	8/12/13	19:00	5.0	3.5						5.0				5.0				5.0					
43	8/13/13	18:30	6.1							5.4				3.4				5.8	3.0	6.4			
44	8/14/13	21:00	3.3							6.3				4.1				5.4					
45	8/15/13	19:30	4.0	5.0	2.0	4.0	3.0	4.0		4.0	4.0	4.0		4.0	2.0	4.0		4.0	4.0	3.0	4.0	4.0	
46	8/16/13	13:00	5.0	4.9						4.3				4.3	5.2			3.7					
47	8/17/13	13:00	5.8							5.5				5.5				2.9					
48	8/18/13	17:30	4.4							4.8				3.1				4.5					
49	8/19/13	19:00	3.4	4.3	6.7	6.7	2.8						5.1	4.4				4.5					
50	8/20/13	22:00	3.5							3.5				3.5									3.5
51	8/21/13	21:00	3.5							5.8				5.3				5.5					
52	8/22/13	17:30	3.5	4.0	5.0					3.0				4.0				5.0					
53	8/23/13	13:30	7.1							4.7				5.8				2.6					
54	8/24/13	12:30	3.5							4.5				6.2				5.2					
55	8/25/13	17:00	5.0							4.5				4.2				4.6					
56	8/26/13	18:30	8.0							6.0				6.0				5.0					
57	8/27/13	19:00	6.4	4.2						5.1							4.5	3.8					

Treatment: GF		**Fish ID:**	**X1**		**Y11**		**Y5**		**Y3**	
Day	**Date**	**Time**	**Eaten**	**UE**	**Eaten**	**UE**	**Eaten**	**UE**	**Eaten**	**UE**
58	8/28/13	11:00	6.1		3.8		4.6		4.9	
59	8/29/13	16:00	3.9		3.4		2.6		2.3	
60	8/30/13	13:00		6.1	6.0		5.2		3.6	
61	8/31/13	17:00	4.7 4.9 3.9 5.2		6.3		5.5		4.0	
62	9/1/13	11:00	5.2		4.1		5.6		5.5	
63	9/2/13	18:30	4.8		3.2		4.7		5.6	
64	9/3/13	16:30	5.8		5.7		4.3			5.1
65	9/4/13	11:30	4.6 4.0		4.3		5.8		5.1 8.2	
66	9/5/13	16:15	7.0		4.9		6.6		4.8	
67	9/6/13	12:15	6.9		5.4 4.7		6.2 3.3		4.3	
68	9/7/13	13:00	5.3		7.0		5.8		3.8	
69	9/8/13	19:30	4.6		5.2		2.4		2.5	
70	9/9/13	19:00	5.9		5.4		5.1		4.9	
71	9/10/13	17:00	4.7		3.7		6.9		3.7	
72	9/11/13	12:45	5.2 4.9 3.8		5.9		3.6		4.8	
73	9/12/13	15:00	4.3 4.7		3.2		3.6		4.1 2.0	
74	9/13/13	13:30	3.4		3.0		4.5		3.2	
75	9/14/13	13:45	3.6 6.2		4.2		2.9		3.9	
76	9/15/13	19:00	4.7		3.6		3.0		3.8	
77	9/16/13	18:00	2.4 7.6		2.0		4.3		10.1	
78	9/17/13	19:00	3.0			4.1		6.1	4.7 2.0	
79	9/18/13	12:00	5.0		1.8		3.4		4.9	
80	9/19/13	15:30	5.6		4.6		2.7		3.3	

Treatment: GF		**Fish ID:**	**X1**				**Y11**			**Y5**			**Y3**		
Day	**Date**	**Time**	**Eaten**			**UE**	**Eaten**		**UE**	**Eaten**		**UE**	**Eaten**		**UE**
81	9/20/13	15:00	6.5				6.2			4.3	3.9		1.0		
82	9/21/13	13:15	1.6				2.1			5.8			3.9		
83	9/22/13	19:30	2.5	6.1	4.3		6.1			5.0			5.2	4.2	
84	9/23/13	20:30	5.7				5.8			5.9			4.7		
85	9/24/13	16:45	5.7				5.4	5.2		4.0			4.9		
86	9/25/13	11:00	4.3	4.2			3.9			4.9	5.4		4.2	3.6	
		Sum	*541.0*			*28.4*	*429.7*		*31.4*	*410.9*		*46.1*	*420.7*		*33.1*

Appendix C continued

Treatment: Aquamax		**Fish ID:**	**X3**		**Y9**		**Y4**		**Y6**	
Day	**Date**	**Time**	**Eaten**	**UE**	**Eaten**	**UE**	**Eaten**	**UE**	**Eaten**	**UE**
1	7/2/13	19:30		4.3		4.9		4.8		5.1
2	7/3/13	20:30	3.3			2.7		5.4	3.6	
3	7/4/13	19:15		4.8		4.6		4.6		3.4
4	7/5/13	22:00	4.1		3.0		4.5		4.1	
5	7/6/13	13:30	3.9		4.9			5.0	4.2	
6	7/7/13	17:00	5.1			4.0	4.8		4.4	
7	7/8/13	18:00	4.5			3.9	4.0		4.1	
8	7/9/13	19:30	5.7		4.7			4.6	3.8	
9	7/10/13	21:00	4.7		5.1		4.2		3.6	
10	7/11/13	22:00		4.0		4.4		4.3		5.8
11	7/12/13	21:30		5.0	5.0			3.0		5.0
12	7/13/13	19:00	4.7		3.8		4.9		4.9	
13	7/14/13	19:25		4.0		5.0		5.0	5.0	
14	7/15/13	20:25		4.0		4.0		5.0		4.0
15	7/16/13	17:20	5.0		3.0		4.0			4.0
16	7/17/13	18:30		4.0	4.0		5.0		4.0	
17	7/18/13	15:15	5.0		5.0			5.0	5.0	
18	7/19/13	13:00	5.1		3.9		5.0		4.7	
19	7/20/13	16:00	5.0		6.0		5.0		5.0	
20	7/21/13	17:30		5.0	5.0		4.0		4.0	
21	7/22/13	22:00	4.0		5.0		5.0			4.0
22	7/23/13	20:30	5.0		5.0			5.0	5.0	

Treatment: Aquamax		**Fish ID:**	**X3**		**Y9**		**Y4**		**Y6**	
Day	**Date**	**Time**	**Eaten**	**UE**	**Eaten**	**UE**	**Eaten**	**UE**	**Eaten**	**UE**
23	7/24/13	13:30		4.0		4.0		6.0		5.0
24	7/25/13	17:30	5.0		4.6		4.3		4.6	
25	7/26/13	12:30	4.9		4.1		4.1		4.9	
26	7/27/13	13:30	4.3		5.2		4.2		4.1	
27	7/28/13	18:00		4.6		5.1		3.4		4.4
28	7/29/13	18:00	3.1		5.1		4.9		4.7	
29	7/30/13	16:00	4.1		4.9		3.7			5.3
30	7/31/13	11:30	4.9			3.9	4.6			5.4
31	8/1/13	17:00	3.7		4.5		5.7		5.7	
32	8/2/13	21:30	3.4		3.8		5.7		4.1	
33	8/3/13	22:00	4.2		5.5		4.6		4.8	
34	8/4/13	21:00	3.8		5.0		5.0		4.2	
35	8/5/13	22:00		4.3		4.3	5.1			6.0
36	8/6/13	18:30	4.4		5.5		5.2		4.7	
37	8/7/13	19:30	4.0		4.8			5.0	3.8	
38	8/8/13	19:00		5.0	5.0		5.0		5.0	
39	8/9/13	21:00	4.0		4.0		4.0		4.0	
40	8/10/13	19:00	4.7		4.4			5.2	4.5	
41	8/11/13	22:30	4.0		5.0		5.0		5.0	
42	8/12/13	19:00	4.0		4.0		4.0			4.0
43	8/13/13	18:30	4.2			5.6	3.5		3.6	
44	8/14/13	21:00	4.4		4.6		3.4		5.2	
45	8/15/13	19:30		4.0		4.0		4.0		4.0

Treatment: Aquamax		**Fish ID:**	**X3**		**Y9**		**Y4**		**Y6**	
Day	**Date**	**Time**	**Eaten**	**UE**	**Eaten**	**UE**	**Eaten**	**UE**	**Eaten**	**UE**
46	8/16/13	13:00	4.7		4.6			4.3	3.8	
47	8/17/13	13:00	4.2		4.6		4.1			4.5
48	8/18/13	17:30	4.4			4.7	5.5		4.3	
49	8/19/13	19:00	5.0		4.5		4.7		5.1	
50	8/20/13	22:00	2.0		2.0			3.0	2.0	
51	8/21/13	21:00	4.5			4.0	5.4		4.1	
52	8/22/13	17:30		4.0		4.0		4.0		3.0
53	8/23/13	13:30		4.6		3.7		4.9		4.7
54	8/24/13	12:30		3.3		5.0		4.6		4.7
55	8/25/13	17:00		4.6		4.2		4.4		3.8
56	8/26/13	18:30	4.0		4.0			4.0	4.0	
57	8/27/13	19:00		4.0		3.8	4.8		4.9	
58	8/28/13	11:00	4.8			4.3		3.8	4.2	
59	8/29/13	16:00		5.0		4.5		4.8		4.5
60	8/30/13	13:00		3.2	4.3			3.6	4.8	
61	8/31/13	17:00	4.1			5.0	3.2			3.6
62	9/1/13	11:00		4.0	3.8		4.1			3.1
63	9/2/13	18:30	4.2		5.1		5.8			4.3
64	9/3/13	16:30		5.1		4.4	3.6		4.7	
65	9/4/13	11:30	4.1		3.8			5.1	5.0	
66	9/5/13	16:15		4.8	4.4		5.1			4.1
67	9/6/13	12:15	5.3			4.8	3.9			4.2
68	9/7/13	13:00	5.1		6.2			5.6	5.2	

Treatment: Aquamax		**Fish ID:**	**X3**		**Y9**		**Y4**		**Y6**	
Day	**Date**	**Time**	**Eaten**	**UE**	**Eaten**	**UE**	**Eaten**	**UE**	**Eaten**	**UE**
69	9/8/13	19:30		4.1		4.8		4.6	4.6	
70	9/9/13	19:00	5.0		4.7		4.2		4.6	
71	9/10/13	17:00	5.1			4.1	3.3		4.8	
72	9/11/13	12:45	4.0			4.6	4.4		4.6	
73	9/12/13	15:00	4.2			4.7	4.5		4.1	
74	9/13/13	13:30		4.7		4.0		4.8		4.8
75	9/14/13	13:45		4.1		3.8		4.3		4.2
76	9/15/13	19:00	4.7			5.0	4.9			4.3
77	9/16/13	18:00	4.7		4.1			4.8	5.1	
78	9/17/13	19:00	5.3		4.2		4.2			4.1
79	9/18/13	12:00		5.5	5.0		4.4			4.4
80	9/19/13	15:30	4.0		4.7		4.1		3.9	
81	9/20/13	15:00	4.4		5.7		4.6		4.4	
82	9/21/13	13:15	3.4			3.9		4.5	4.6	
83	9/22/13	19:30		3.7	4.4		4.2		3.5	
84	9/23/13	20:30	4.3		5.3		3.8			4.5
85	9/24/13	16:45	4.3			4.6	4.0		4.7	
86	9/25/13	11:00		5.1	4.0		4.9		4.6	
		Sum	*250.1*	*126.7*	*232.7*	*152.4*	*237.8*	*150.5*	*244.1*	*136.1*

Appendix C continued

Treatment: Control		**Fish ID:**	**X2**			**Y7**				**Y10**				**Y1**		
Day	**Date**	**Time**	**Eaten**		**UE**	**Eaten**			**UE**	**Eaten**			**UE**	**Eaten**		**UE**
1	7/2/13	19:30	2.0			1.9				1.8				1.5		
2	7/3/13	20:30	4.8							3.1				7.8		
3	7/4/13	19:15	2.0		5.9	6.6				3.9				5.4		
4	7/5/13	22:00	7.5			5.5				5.4				4.6		
5	7/6/13	13:30	5.8							6.9				5.9	1.0	
6	7/7/13	17:00	2.6			2.6				11.4				5.3		
7	7/8/13	18:00	6.5			7.8	3.0		6.1	8.2						
8	7/9/13	19:30	5.9			7.2				8.5			6.4	6.8		
9	7/10/13	21:00	6.0			7.2				6.4				9.9		
10	7/11/13	22:00				8.8			2.6	1.7				6.3		
11	7/12/13	21:30	5.3			4.9				6.8				6.0		
12	7/13/13	19:00	3.0	5.0						4.0				3.0		
13	7/14/13	19:25	13.0	6.0		14.0	9.0			12.0	4.0	6.0		11.0	4.0	
14	7/15/13	20:25	6.1							7.8						
15	7/16/13	17:20	7.6			6.7				9.0				9.0		
16	7/17/13	18:30	8.1			5.8				6.1				2.0		
17	7/18/13	15:15												5.4		
18	7/19/13	13:00	3.2	2.0		5.6				6.9				8.3		10.0
19	7/20/13	16:00	4.9							3.1				8.4		
20	7/21/13	17:30	6.5			10.4	2.0			6.8				9.9		
21	7/22/13	22:00	8.7			7.4				1.6				7.6		
22	7/23/13	20:30	15.0	9.0		15.0	9.0	6.0		16.0	9.0			16.0	9.0	

Treatment: Control		Fish ID:	X2			Y7			Y10			Y1		
Day	**Date**	**Time**	**Eaten**		**UE**	**Eaten**		**UE**	**Eaten**		**UE**	**Eaten**		**UE**
23	7/24/13	13:30	4.1			5.2						6.0		
24	7/25/13	17:30	5.4			4.8			5.5			5.5		
25	7/26/13	12:30	7.1			6.7			2.0			6.8		
26	7/27/13	13:30	3.1						6.7	7.0		7.8		
27	7/28/13	18:00	7.4		6.8	4.0			9.0					
28	7/29/13	18:00	7.9			7.8			6.2			7.0		
29	7/30/13	16:00	6.8			8.8			7.4	2.0	4.4	7.9		
30	7/31/13	11:30	4.3			4.5			4.9			7.4		
31	8/1/13	17:00				7.4		6.7	3.5					
32	8/2/13	21:30	7.6	6.0		8.8			5.7			8.4		
33	8/3/13	22:00	5.6			3.1			3.7			6.0		
34	8/4/13	21:00	11.7						5.6					
35	8/5/13	22:00	8.8			7.5			11.0			6.3		
36	8/6/13	18:30	4.8			4.4			7.1			5.5	6.0	
37	8/7/13	19:30	3.6			6.0			4.4			3.5		
38	8/8/13	19:00	3.5			4.0			2.9					
39	8/9/13	21:00	3.0			3.0			5.0			3.0		
40	8/10/13	19:00	4.9			5.9			6.6			5.4		
41	8/11/13	22:30	7.0			2.0			2.0			4.0		
42	8/12/13	19:00	6.0			6.0						8.5		
43	8/13/13	18:30	10.7			9.4			7.3			8.5		
44	8/14/13	21:00				3.6			6.5			6.8		
45	8/15/13	19:30	4.1			4.8			7.6			7.6		

Treatment: Control		**Fish ID:**	**X2**		**Y7**		**Y10**		**Y1**	
Day	**Date**	**Time**	**Eaten**	**UE**	**Eaten**	**UE**	**Eaten**	**UE**	**Eaten**	**UE**
46	8/16/13	13:00	2.9		3.5		5.4		4.2	
47	8/17/13	13:00	4.0				4.0		3.5	
48	8/18/13	17:30			4.4		6.1		9.1	
49	8/19/13	19:00	6.0		5.0		7.0		5.0	
50	8/20/13	22:00			3.4				4.6	5.2
51	8/21/13	21:00	7.0		7.3		6.4	6.6	9.3	
52	8/22/13	17:30	7.0		8.0		6.0	3.2	7.0	
53	8/23/13	13:30	5.6		0.2		6.8		7.9	
54	8/24/13	12:30	4.0		6.4		5.6		8.3	
55	8/25/13	17:00	7.3		9.6		8.6		6.2	
56	8/26/13	18:30	6.0	5.1	6.0		7.0		8.0	
57	8/27/13	19:00	10.7		16.3		14.6			
58	8/28/13	11:00	3.1						4.9	
59	8/29/13	16:00	5.1		5.1		5.6		4.9	
60	8/30/13	13:00	4.2		3.1		7.8		3.2	
61	8/31/13	17:00			9.7		13.9		10.2	
62	9/1/13	11:00	9.0		6.1		4.2		6.3	
63	9/2/13	18:30			4.9		6.2		7.8	
64	9/3/13	16:30	6.7		8.1				6.6	
65	9/4/13	11:30								
66	9/5/13	16:15	6.1		10.6	5.2	5.4		5.7	
67	9/6/13	12:15	8.2		7.3		11.0		12.0	
68	9/7/13	13:00	9.1		11.3				5.1	

Treatment: Control		**Fish ID:**	**X2**		**Y7**		**Y10**		**Y1**	
Day	**Date**	**Time**	**Eaten**	**UE**	**Eaten**	**UE**	**Eaten**	**UE**	**Eaten**	**UE**
69	9/8/13	19:30	11.7		13.1		11.8		13.2	
70	9/9/13	19:00			6.4		6.8		8.2	
71	9/10/13	17:00	7.7		9.3		6.7		4.4	
72	9/11/13	12:45	5.6		11.5		11.8		10.1	
73	9/12/13	15:00	14.3		13.4		11.3		13.6	
74	9/13/13	13:30			10.1		7.1		9.2	7.4
75	9/14/13	13:45	6.2		7.1		4.3		8.1	
76	9/15/13	19:00	2.8		3.1		3.2			
77	9/16/13	18:00	6.4	5.6	9.1		7.5		7.0	
78	9/17/13	19:00	5.6				5.8			
79	9/18/13	12:00			5.6		8.3		3.5	
80	9/19/13	15:30	5.4		6.7		5.8		5.5	
81	9/20/13	15:00			4.5		8.5		7.0	
82	9/21/13	13:15	4.4	4.7	5.4		4.5		9.7	
83	9/22/13	19:30	7.6				4.6		5.8	
84	9/23/13	20:30	7.5		5.3		4.4		6.1	
85	9/24/13	16:45	5.8		8.0	8.9	4.0	6.7	6.7	
86	9/25/13	11:00	10.2		7.7		7.0			
		Sum	*493.5*	*28.0*	*526.6*	*29.6*	*540.9*	*27.3*	*539.9*	*22.6*

Appendix D. Back-calculated length-at-age estimates for bowfin from Braddock Bay, Monroe County, New York 20 October 2012 to 14 June 2013 using sectioned pectoral fin rays. Fish ID codes indicate the sex and season of capture: ‘F’ and ‘X’ were females, ‘M’ and ‘Y’ were males, and ‘F’ and ‘M’ were captured October–November, ‘X’ and ‘Y’ were captured in June.

Fish ID	**Age**	**Total length at capture** (mm)	**Length at age** (mm)							
			I	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**
Y5	1	289	230							
F14	2	439	149	271						
F10	2	443	163	345						
F20	2	517	192	407						
F16	2	539	211	382						
Y4	3	459	182	320	395					
M11	3	462	79	229	373					
M13	3	501	204	317	429					
F18	3	509	247	361	445					
M7	3	512	224	350	453					
M8	3	512	151	227	299					
X1	3	518	153	342	444					
M15	3	529	189	302	464					

Fish ID	**Age**	**Total length at capture** (mm)	**Length at age** (mm)							
			I	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**
M10	3	531	234	361	457					
Y1	4	481	165	268	381	446				
Y2	4	495	142	218	307	418				
Y6	4	502	139	303	397	479				
M16	4	517	196	325	402	471				
M6	4	533	125	265	404	492				
M3	4	540	188	307	386	505				
M4	4	540	199	328	411	479				
Y3	4	540	257	368	430	490				
F12	4	550	154	267	351	456				
F19	4	567	213	335	431	509				
F11	4	568	169	294	392	470				
M5	4	579	200	364	429	505				
F17	4	589	254	358	465	526				
X2	4	592	225	353	460	556				
M9	4	598	230	371	497	564				
F15	4	603	186	331	436	528				

Fish ID	**Age**	**Total length at capture** (mm)	**Length at age** (mm)							
			I	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**
F8	4	635	249	396	488	576				
F13	4	684	213	318	398	560				
F0	4	715	260	412	540	624				
Y9	5	499	104	219	288	398	485			
Y10	5	520	207	269	326	401	492			
Y7	5	560	125	219	323	460	523			
M1	5	624	161	272	381	446	583			
Y11	5	628	228	350	445	528	585			
Y8	5	629	168	284	387	470	575			
F9	5	647	157	230	382	480	571			
F6	5	708	168	325	455	561	631			
F5	5	714	199	322	443	548	650			
F7	5	743	100	272	378	488	634			
F4	5	771	223	331	503	634	711			
F2	5	791	230	334	481	634	726			
M2	6	614	140	241	330	419	514	565		
X4	6	656	98	204	318	442	558	622		

Fish ID	**Age**	**Total length at capture** (mm)	**Length at age** (mm)							
			I	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**
X6	7	701	202	342	428	496	538	609	662	
F1	7	719	205	303	417	492	563	628	687	
X3	8	692	177	270	379	449	523	571	630	662
X5	8	701	138	250	323	402	476	536	593	658
		Mean back-calculated length	184	309	408	497	574	589	643	660
		N	51	50	46	37	18	6	4	2

Chapter 2

Status of the Last Wild Population of Northern Sunfish (*Lepomis peltastes*) in New York State: Changes in the Fish Community and Hybridization with Bluegill (*L. macrochirus*) in Tonawanda Creek, Erie County

Introduction

The northern sunfish (*Lepomis peltastes* Cope, 1870) is a small, ornate centrarchid that inhabits low-gradient streams and rivers scattered throughout the Great Lakes basin and the Upper Mississippi River drainage. It was formerly recognized as one of two subspecies of *L. megalotis*, the longear sunfish, which was divided into *L. m. peltastes*, the northern longear sunfish, and *L. m. megalotis*, the central longear sunfish (Jennings 1991; Bailey *et al.* 2004; Figure 1). The northern sunfish's historical range encompassed eight waters in Western New York: the Oneida Lake outlet, West Creek, Braddock Bay, Johnson Creek, Jeddo Creek, Oak Orchard Creek, and Marsh Creek of the Lake Ontario basin, and Tonawanda Creek of the Lake Erie basin (Wells & Haynes 2007; Figure 2). Local extirpations led to the species being listed as "threatened" in New York State in 1983 (Carlson 2014). As of 2005, wild populations had only been detected in a single 3.7 km segment of lower Tonawanda Creek (Wells 2009; Carlson 2014; Figure 2).

A recovery stocking program was initiated in 2005 by the NYSDEC, in which production ponds were established with northern sunfish from Tonawanda Creek (Lake Erie basin), the Huron River near Detroit, Michigan (Lake Erie basin), and the

Moira River near Tweed, Ontario, Canada (Lake Ontario basin). Several historical watersheds, as well as those identified as having suitable habitat for *L. peltastes* by Wells (2009), were stocked with a total of 19,000 fingerlings from 2006 to 2013. Follow-up sampling showed they could be caught several months post-stocking in Oak Orchard (personal communication, Douglas Carlson, NYSDEC, Watertown, NY), Marsh, Cayuga, Murder, and Ellicott Creeks (Figure 2; Carlson 2014). Recruitment was searched for, but documented only once in Cayuga Creek near Buffalo, NY. Repeated sampling efforts were not successful in detecting recruitment (D. Carlson, personal communication) at any stocking location.

Species description

Several features distinguish northern sunfish from co-occurring sunfishes in Western New York, which include *L. macrochirus* (bluegill), *L. gibbosus* (pumpkinseed), and *L. cyanellus* (green sunfish) which are not native to New York (Carlson & Daniels 2004). Northern sunfish are the smallest of these species, with a maximum total length (TL) of 130 mm, which is less than bluegill (410 mm), pumpkinseed (400 mm), and green sunfish (310 mm). Northern sunfish are deep-bodied with the forehead sloping steeply toward the dorsal fin. The opercular flap is elongate, angled upwards, flexible, and black with a white margin and red center. Bluegills, pumpkinseeds, and green sunfish have a much shorter, stiffer, and straight-angled opercular flap that is plain black, black with a white margin and red highlight, or black with a faint margin and orange highlight, respectively. Northern sunfish and green sunfish have short, rounded pectoral fins, whereas pumpkinseeds and bluegills have long, pointed pectoral fins. Northern sunfish have short, blunt gill rakers numbering 12/5 on the lower and upper limb, as opposed to pumpkinseed with 8/4 short, blunt rakers, and green sunfish and bluegill which have long slender gill rakers. Adults have bright coloration (more-so in males), including distinct wavy streaks of turquoise and orange on the cheeks, a dark-olive dorsal surface blending to a checkerboard pattern of orange, olive, and turquoise on the sides, a yellow belly, and the fins are yellow overall with red spots in the membranes and black margins (Figure 3; Table 1; Scott & Crossman 1973; Page & Burr 1991).

Northern sunfish occupy warm water streams, rivers, ponds, and small lakes with low turbidity (Scott & Crossman 1973), as well as calmer water near currents in streams (Wells 2009). Their diet consists of small insects, fish, and crustaceans. Spawning occurs in the early summer over bowl-shaped nests constructed by males in gravel substrate (Keenleyside 1972; Scott & Crossman 1973).

Hybridization among sunfish

Natural and artificial hybridization have been well studied among *Lepomis* spp. (cf. Hubbs 1920; Hubbs & Hubbs 1932; Childers 1967; Keenleyside *et al.* 1973; Bolnick & Near 2005). Hubbs (1955) found that hybridization can be very common in habitats that are degraded, when a new species is introduced, or when two related sympatric species diverge greatly in abundance. In one stream near Ann Arbor, Michigan, samples of the sunfish community were comprised of 95 percent green sunfish x bluegill hybrids. Hubbs (1955) also demonstrated through laboratory breeding experiments that previously described species of sunfish were in fact hybrids: the species *L. euryorus* Mckay 1881 was a green sunfish x pumpkinseed hybrid, and *L. ischyrus* Jordan & Nelson 1877 was a green sunfish x bluegill hybrid.

Mechanisms for hybridization among sunfish species in nature stem from the complex breeding behavior of the genus. Northern sunfish, like most sunfish species, are colonial nesters. Interspecific colonies of *Lepomis* are common, especially when nesting substrate is limited. Jennings & Philipp (2002) observed frequent interspecific nest intrusions in a nesting colony of longear sunfish and *L. microlophus* (redear sunfish). Both cuckold males, which mimic females with dull coloration in order to sneak past nest guarders, and nesting males were observed intruding on an adjacent nest of another species. Similarly, Garner and Neff (2013) found unidirectional hybridization occurring in a lake in southern Ontario caused by bluegill cuckolds intruding on pumpkinseed nests.

Northern sunfish hybridization in Western New York has been a concern of NYSDEC Fish Biologists Douglas Carlson and Scott Wells, who delivered eight suspected hybrid specimens to the New York State museum from 1999 to 2013. Two of these specimens were confirmed by museum staff to be northern sunfish *x* pumpkinseed hybrids (Wells 2009; Carlson 2014). Earlier assessments of the status of longear sunfish (Bouton 1994) contended that hybridization was a potential cause for the species' decline.

Objectives

The original goal of my study was to determine the status of New York's remaining wild population of northern sunfish in lower Tonawanda Creek. After an intensive season of sampling in 2013, the population could not be detected and as such, the project's focus was expanded in 2014 to attempt to detect the species at other locations stocked by the NYSDEC. Again the species was not detected in lower Tonawanda Creek or elsewhere, and the goal of the project was broadened to become an investigation of the cause(s) of the northern sunfish's decline in lower Tonawanda Creek. The objectives for achieving this goal were to:

- Determine whether the fish community in lower Tonawanda Creek had changed from 2005 to 2013, and
- Investigate whether hybridization of northern sunfish with other *Lepomis* spp. had occurred in lower Tonawanda Creek.

Methods

Study location

I conducted 30 sampling trips during the summers of 2013 and 2014 at 25 sites (Figure 4) within four watersheds of the Niagara River basin in Erie and Genesee Counties, New York. Watersheds sampled included (1) Tonawanda Creek with nine sites, (2) the Erie Canal with five sites, (3) Ellicott Creek with six sites, and (4) Cayuga Creek with five sites. Alphanumeric codes were assigned to each sampling site using the watershed number (1–4) and letters indicating relative position of the site in an upstream order (A–I).

Sampling

Based on sampling in 2005 (Wells 2009) and from 1999–2012 (Carlson, personal communication), several northern sunfish "hotspots" in lower Tonawanda Creek were known at the beginning of my project; they included specific log jams, features in the streambed, and lengths of shoreline. These spots were sampled during most trips to lower Tonawanda Creek in 2013. The remaining effort during each trip was distributed among other potentially desirable habitats (in-stream vegetation, brush piles, shaded pools; Wells 2009) as well as less desirable habitat (bare mud banks, swift waters, etc.).

In lower Tonawanda Creek, the Erie Canal, and lower Ellicott Creek, sampling was performed by boat electroshocking (Type VI-A Pulsator, Smith-Root Inc., Seattle, WA, with a 5,000 W generator mounted to a 5.5 m, 50 hp boat) conducted during runs of ~900 sec of power-on time. Electrical impulses were delivered in bursts while traveling slowly upstream along the shoreline. Sampling in middle Tonawanda Creek (Figure 4: 1G) was conducted by raft-guided backpack electroshocking (HT-2000, Halltech Aquatic Research, Inc., Guelph, Ontario, Canada). Sampling in middle Cayuga Creek at Como Lake (Figure 4: 4D) was conducted by canoe-guided backpack electroshocking. Sampling in upper Tonawanda (Figure 4: 1I), lower Murder (Figure 4: 1H), upper Ellicott (Figure 4: 3F), lower Cayuga and adjacent Slate Bottom Creeks (Figure 4: 4A–4C), and Little Buffalo creeks (Figure 4: 4E) was conducted by backpack electroshocking on foot.

The Erie Canal (Figure 4: 2A–2E) and lower Tonawanda Creek (Figure 4: 1A–1E) were sampled by boat electroshocking in 2005 (Wells 2009) and during my study in 2013 and 2014. Fourteen days of sampling occurred in 2013 in the lower 3.7 km of Tonawanda Creek (Figure 4: 1A–1F), the adjacent Erie Canal (Figure 4: 2A, 2B, 2D, and 2E), and lower Ransom Creek (Figure 4: 2C). One day of sampling occurred in lower Ellicott Creek (Figure 4: 3A–3E). These creeks all enter the Erie Canal; the mouth of Tonawanda Creek is 2.3 km from the mouth of Ransom Creek and 17.4 km upstream from the mouth of Ellicott Creek.

In 2014, six days of sampling occurred in the lower 3.7 km of Tonawanda Creek (Figure 4: 1A–1E) and the Erie Canal (Figure 4: 2A and 2D), one day of sampling occurred in middle Tonawanda Creek near Rapids, New York (Figure 4: 1G), and eight days of sampling occurred (sometimes split between sites) at locations stocked with northern sunfish by NYSDEC within the Niagara River watershed in western New York: lower Murder Creek near Akron (Figure 4: 1H), upper Tonawanda Creek near Alexander (Figure 4: 1I), upper Ellicott Creek near Bowmansville (Figure 4: 3F), lower Cayuga and adjacent Slate Bottom Creeks in Cheektowaga (Figure 4: 4A–4C), and middle Cayuga Creek at Como Lake in Lancaster (Figure 4: 4D and 4E) (Table 2).

In 2013 all fish were netted, enumerated, and identified to species except for some *Moxostoma* spp. (redhorse suckers). Because my project shifted focus in 2014 to the broader potential range of northern sunfish, I modified methods to allow for greater sampling effort over a wider geographic area. Instead of collecting data for each ~900 sec period of electrofishing, boat and backpack power-on time was accumulated by site per-day, fish were only netted if they could not be identified in the water, and each species captured was recorded per-location, per-day (presence/absence data, not enumerated). In lower Tonawanda Creek (Figure 4: 1A–1E), this allowed for a complete sampling of a shoreline, alternating with each visit, from the mouth (Figure 4: 1A) to the Millersport Riffle (Figure 4: 1E) on most sampling days. At sites sampled by backpack electroshocking unit, this method allowed a much greater distance to be sampled each day (Table 3).

Fish community comparisons

Fish community records from my study in 2013 were compared to those in 2005 (from Wells 2009) for lower Tonawanda Creek and the adjacent Erie Canal. Sampling runs were included in the analysis if they used boat electroshocking and were conducted within 3 weeks of each other in 2013 at locations where northern sunfish were captured in 2005. A total of 52 sampling runs (12 in 2005, 40 in 2013) from six sites (Figure 4: 1A–1E and 2D) met these criteria. Sites 1A–1E are reaches of lower Tonawanda Creek that have distinct physical properties (Figure 4): site 1A is the slow, sluggish confluence of Tonawanda Creek and the Erie Canal; 1B is a swifter, more vegetated area including the Pendleton Riffle; 1C is a slow, deep, winding, sparsely vegetated reach with occasional shallows and woody debris; 1D is the confluence of Mud Creek with Tonawanda Creek (including the downstream area influenced by the confluence); and site 1E is the reach below and up-to the rapids at Transit Road (Rt. 78), the Millersport Riffle. Site 2D is a muck-bottomed, dead-end slough off of the Erie Canal 2.1 km west of the confluence with Tonawanda Creek and 0.2 km east of Ransom Creek.

A few alterations were made in order to make the 2005 and 2013 data sets comparable. First, to represent only the resident fish community, migrating and numerous *Dorosoma cepedianum* (gizzard shad) and *Notropis atherinoides* (emerald shiner) were not included. Second, species were combined for *Esox* spp. (pikes), *Moxostoma* spp. (redhorses), and *Etheostoma* (darters)/*Percina* (logperches) spp. Third, cyprinid (minnow) catches were grouped into the categories "native"—consisting of *Notemigonus crysoleucas* (golden shiner), *Luxilus chrysocephalus* (striped shiner), *Notropis hudsonius* (spottail shiner), *Cyprinella spiloptera* (spotfin shiner), *Lythrurus umbratilis* (redfin shiner), *Notropis volucellus* (mimic shiner), *Pimephales notatus* (bluntnose minnow), *Pimephales promelas* (fathead minnow), and *Semotilus atromaculatus* (creek chub)—and "non-native", consisting of *Carassius auratus* (goldfish), *Cyprinus carpio* (common carp), and *Scardinius erythrophthalmus* (rudd). Lastly, all catch data were transformed into Catch per Unit Effort (CPUE) by dividing the number captured by the number of hours of power-on-time exerted during a sampling run. A two-sample, two-tailed Student's t-test was used to test the hypotheses of whether individual species' and overall fish CPUE differed between 2005 and 2013.

Simpson's index of diversity

Simpson's index of diversity for the fish communities where northern sunfish were caught in 2005 were compared with the fish sampled at the same sites in 2013 using an adapted Student's t-test (Figure 4: 1A–1E, 2D; Brower & Zar 1984). Simpson's index of diversity, D_s, is one minus the probability that two individuals taken in a sample belong to the same taxon; it increases as the number and evenness of taxa increase and is calculated by:

$$D_s = 1 - \frac{\sum n_i(n_i - 1)}{N(N - 1)}$$

where n_i is the number of individuals in the i^{th} species and N is the total number of individuals captured in the sample. A t-test can then be used to test the hypothesis that two samples have equal diversities. The test uses the variance, s^2, of the Simpson's index of diversity, which is calculated by:

$$s^2 = \frac{4[\sum p_i^3 - (\sum p_i^2)^2]}{N}$$

where p_i is the proportion of the total sample, N, comprised of the i^{th} species, or, $\frac{n_i}{N}$. The test statistic, t, is calculated by:

$$t = \frac{D_1 - D_2}{\sqrt{s_1^2 + s_2^2}}$$

and the degrees of freedom, *df*, are calculated as:

$$df = \text{ \# taxa community } 1 + \text{ \# taxa community } 2 - 2$$

Multivariate analyses

Statistical software (Plymouth Routines in Multivariate Ecological Research v.6, PRIMER 6; Clarke & Gorley 2006) was used to evaluate fish community similarities and differences across years. All CPUE data were Log_{10} (x+1)-transformed to counteract the potential for a few highly abundant species to overwhelm the analysis (Hubbell 2001). The data were then used to create a resemblance matrix based on Bray-Curtis similarities between sampling runs. From this matrix, an Analysis of Similarities (ANOSIM) was performed, which compared the variation in the resemblance matrix between years to within years. The analysis gives the test-statistic R that ranges from -1.0 to 1.0, meaning a high amount of differences within- and among groupings, respectively. Next, a Similarity Percentages (SIMPER) analysis was performed on the resemblance matrix to identify the percent contributions of individual taxa to within-year similarities and between-year dissimilarities. Lastly, non-metric Multidimensional Scaling (nMDS) was used to create ordinations showing similarities/dissimilarities between sampling runs based on sampling year. A vector-overlay of the species that contributed a cumulative 60% of the overall dissimilarities between years was included in order to show the relative strengths of their contributions (as indicated by the length of their vectors) and the samples with which they aligned. Non-metric MDS is a technique that treats each sampling run as a point in two-dimensional space by converting the values in the resemblance matrix to relative distances between points and simplifying the number of variables (taxa in this case) into two axes, or ordinations. It then rearranges the points through a selected number of iterations (n = 50 in this case) until it reaches the arrangement that causes the lowest "stress level", or departure of the points from a best-fitting regression line. Ordinations with a stress level of 0.2–0.3 should be interpreted with caution, and those above 0.3 should be interpreted with extreme caution (Clarke & Gorley 2006).

Green sunfish population assessment

A mark-recapture study was conducted to estimate the population abundance of green sunfish in the lower 3.7 km of Tonawanda Creek from 25 July to 26 September 2013. A multiple-census technique, the Schnabel method (Schnabel 1938), was used during sampling dates 25 July, 12 & 22 August, and 26 September 2013. The method uses the formula:

$$\widehat{N} = \frac{\sum_{t=1}^{n} C_t M_t}{\sum_{t=1}^{n} R_t}$$

where $\hat{N}$ is the estimation of the total population, t is an individual sampling period, n is the total number of samplings, C_t is the total number of fish captured during the t^{th} sampling, M_t is the cumulative number of fish marked prior to the t^{th} sampling, and R_t is the number of marked fish recaptured in the t^{th} sampling. This method has the assumptions that the mark is not lost, all marked fish are recognized upon recapture, marked and unmarked fish have equal vulnerability to capture and mortality rates, marked fish will redistribute equally back into the population, and there is no recruitment for the duration of the sampling period. Because the sum of total recaptured sunfish was less than 50, the Poisson distribution was used to estimate the

95% confidence intervals by substituting the denominator of the above equation with values obtained in Appendix II of Ricker (1975; Van Den Avyle & Hayward 1999).

Sampling on each day was conducted with a ~900 sec power-on-time electroshocking run at each of sites 1A–1E. No alterations were made to the overall sampling design or study methods to collect green sunfish for this mini-study, except that green sunfish were held in a live well until being processed and released at the end of an electroshocking run. Only green sunfish >24 mm TL were studied in order to reduce errors in identification and to minimize violations of the assumptions of the method. Fish were marked by removing a pelvic fin.

Hybrid sunfish identification

Following difficulties identifying sub-adult sunfish, a key was developed from the meristics, morphometrics and generalized descriptions of the four western New York sunfish species published in Smith (1985) and Scott and Crossman (1973), and adapted with input from NYSDEC Fish Biologist Douglas Carlson (Table 1). Using this key, even on very small juveniles, several suspected hybrid sunfish were captured, photographed alive, had tissue taken for genetic analysis, and transported frozen to the New York State Museum, Albany, NY for morphometric analysis.

Genetic analysis was performed by Dr. Jose Andres (HeridiTec, Lansing, NY) on 89 sunfish specimens collected in lower Tonawanda Creek in 2013 and 2014 and from a NYSDEC northern sunfish hatchery pond: 27 suspected hybrids, 11 pumpkinseed, 20 bluegill, 15 green sunfish, and 16 northern sunfish. Analysis was attempted on 11 additional specimens but the results were inconclusive. By using microsatellite techniques to analyze the pure bred specimens' nuclear genomes, the alleles of each of the nine genes examined were identified as belonging to one of the four pure species. Each hybrid's parental make-up was then determined by identifying the species to which each set of the nine parental alleles belonged.

Since the mitochondrial genome is inherited from the mother, the direction of each hybrid was determined by identifying the parental origin of the mitochondrial genome. A hybrid index was calculated using STRUCTURE (Pritchard et al. 2000) for each specimen. The index value ranges from 0 to 1 and represents the probability that a specimen's genome resulted from random mating within one of the parental populations. Values close to 0 or 1 indicate a pure-bred specimen, and intermediate values indicate hybridization.

Results

Sampling effort and CPUE

A total of 49.12 hours of electroshocking power-on time (effort) was exerted in 162 sampling runs over 34 days during three years at 25 sites in four watersheds (Table 3), capturing a total of 57 species from 14 families (Appendices A & B). A total of 28.67 hours of effort was exerted in 2013 and 2014 in areas where *L. peltastes* was detected historically and in 2005: lower Tonawanda Creek (Figure 4: 1A-1F) and a near-by dead-end slough adjacent to the Erie Canal (Figure 4: 2D), although only the efforts in 2013, totaling 18.58 hours, were used for the fish community comparisons. Wells (2009) exerted 3.00 hours of effort at the same locations in 2005. In 2013 and 2014, another 12.02 hours of effort were exerted in areas where the northern sunfish has been reintroduced (Tables 2 & 3; Figure 4: 2A, 1H, 1I, 3F, 4A–C, 4E). No non-hybrid northern sunfish were captured at any location in 2013 and 2014 (Appendix B).

From 2005 to 2013, the average CPUE of all fish in lower Tonawanda Creek and the Erie Canal (Figure 4: 1A–1E, 2D) increased significantly ($t = 2.556$, $df = 50$, $P = 0.014$) from 398.0 fish/hour to 610.5 fish/hour, a 53.4% increase (%Δ CPUE; Table 4). The centrarchid community had several shifts in average CPUE ($df = 50$ per test). Green sunfish CPUE increased by 940.8% ($t = 5.801$, $P < 0.001$), bluegills increased by 260.5% ($t = 1.988$, $P = 0.052$), and *Ambloplites rupestris* (rock bass) increased by 123.3% ($t = 1.793$, $P = 0.079$), while pumpkinseeds remained relatively constant, with only a 5.5% decrease ($t = -0.159$, $P = 0.874$). The CPUE of the black bass species *Micropterus dolomieu* (smallmouth bass) and *M. salmoides* (largemouth bass) decreased by -77.8% ($t = -4.496$, $P < 0.001$) and -19.4% ($t = -0.593$, $P = 0.556$), respectively (Table 4).

Non-centrarchid taxa with a decrease in average CPUE >90% included *Hypentelium nigricans* (northern hog sucker; -100%, $t = -1.87$, $P = 0.067$), *Noturus gyrinus* (tadpole madtom; -100%, $t = -1.87$, $P = 0.067$), *Aplodinotus grunniens* (freshwater drum; -100%, $t = -2.774$, $P = 0.008$), *Catostomus commersonii* (white sucker; -95.7%, $t = -3.017$, $P = 0.004$), *Noturus miurus* (brindled madtom; -95.7%, $t = -3.821$, $P < 0.001$), and darters and logperches (-90.2%, $t = -6.28$, $P < 0.001$). Taxa with an increase in average CPUE greater than 200% included *Neogobius melanostomus* (round goby; +200%, t = 1.291, P = 0.203) and pikes (+220.0%, t = 2.247, P = 0.029; Table 4).

Simpson's index of diversity

The fish community in lower Tonawanda Creek (Figure 4: 1A–1E) and the dead-end slough off the Erie Canal (Figure 4: 2D) had significantly higher values of Simpson's index of diversity (D_s) in 2005 (0.790) than 2013 (0.715; t = 3.05, df = 47, P = 0.004). The community richness also decreased from 2005 to 2013 (mean 13.42 to 10.92 species or species groups per sample; Table 5).

Multivariate analyses

There was a significant change in the fish communities of lower Tonawanda Creek and the Erie Canal (Figure 4: 1A–1E, 2D) between 2005 and 2013 (ANOSIM, R = 0.806, P = 0.001). SIMPER showed that taxa contributing >5% to the similarities within the 2005 samples were native (17.8%, NACY) and non-native (10.2%, NNCY) cyprinids, darters and logperches (9.2%, DART), largemouth bass (8.7%, MISA), redhorses (7.8%, MOXO), green sunfish (7.7%, LECY), smallmouth bass (6.7%, MIDO), pumpkinseed (6.5%, LEGI), bluegill (5.7%, LEMA), northern sunfish (5.5%, LEPE), and rockbass (5.2%, AMRU). Taxa contributing >5% to the similarities within the 2013 samples were green sunfish (22.4%, LECY), native cyprinids (17.8%, NACY), bluegill (14.7%, LEMA), rock bass (11.3%, AMRU), redhorse (9.3%, MOXO), pumpkinseed (7.8%, LEGI), and pikes (5.1%, ESOX).

Taxa contributing >5% to the dissimilarities between the 2005 and 2013 samples were green sunfish (9.5%, LECY), darters and logperch (7.8%, DART), bluegill (7.4%, LEMA), non-native cyprinids (7.0%, NNCY), northern sunfish (6.5%, LEPE), pikes (5.4%, ESOX), and smallmouth bass (5.2%, MIDO; Table 6).

The nMDS plot (Figure 5) showed a strong separation between the 2005 and 2013 samples in lower Tonawanda Creek and the Erie Canal combined (Figure 4: 1A–1E, 2D). When the top nine contributing taxa were laid over the nDMS plot, green sunfish, bluegill and rock bass aligned with the 2013 samples. Northern sunfish, darters and logperches, non-native cyprinids, smallmouth bass, pumpkinseed, and pikes aligned with the 2005 samples. The 2-dimensional stress level of the plot was 0.2 which is the lower end of the range needing cautious interpretation.

Green sunfish population assessment

The population of green sunfish in lower Tonawanda Creek (Figure 4: 1A–1E) in 2013 was estimated to be 8,606 (95% CI: 6,297–12,116; Table 7). This stream reach is approximately 3,670 m long, and the density of green sunfish along the shorelines was estimated to be roughly: 8,606 (6,297-12,116) fish ÷ (3,670 m north bank + 3,670 m south bank) = 1.2 (95% CI: 0.9–1.7) green sunfish/meter of shoreline.

Hybrid sunfish identification

From my sample of 27 suspected hybrids, genetic analysis showed that there were eight bluegill x northern sunfish, eight bluegill x pumpkinseed, eight bluegill x green sunfish, and three green sunfish x pumpkinseed hybrids captured in lower Tonawanda Creek in 2013 and 2014 (crosses are in “male x female” order). All crosses were unidirectional, and bluegills were always the male parent of their respective hybrids. Among the “pure bred” specimens identified, two green sunfish, one bluegill, and one northern sunfish (from the NYSDEC hatchery pond) each had a single hybrid allele (Table 8). Selected photographs of juvenile (~5–7 cm), age-at-maturity (~8–12 cm), and mature adult (~14–18 cm) specimens of each pure bred and hybrid group are included in Figures 6–8. Photographs of all specimens examined are provided in Appendix C (http://digitalcommons.brockport.edu/env_theses/101).

Discussion

Sampling methods

I found the methods used for boat and backpack electroshocking very effective for capturing sunfish: unlike larger, strong-swimming fish such as pikes and *Sander vitreus* (walleye) that sensed the electrical current and quickly escaped, sunfish would retreat toward the shoreline and easily succumb to electroshocking. The field methods in 2013 and 2014 did not, however, entirely coincide with the statistical methods and fish community comparisons I ended up using. First, only hard to identify, native minnows collected during the first few trips in 2013 were transported back to the lab for sure identifications, after which identifications were made quickly in the field to permit more sampling time and distance. For the same reason redhorses, juvenile darters and logperches, and juvenile pikes were infrequently identified to species in 2013. This uncertainty about the accuracy of certain field identifications in 2013, as well as some inconsistencies between identifications made in 2005 (Wells 2009) and 2013, led to combining hard-to-identify species from both years into the reliably identified groupings described above. Moreover, by only recording presence/absence data in 2014, an entire field season could not be included in the statistical analysis of this study. However, this method did allow for more sampling to occur and increased the likelihood of capturing any potential northern sunfish occupying the surveyed areas.

Changes in the fish community of lower Tonawanda Creek

In 2013 I found major changes in the fish community at the lower Tonawanda Creek and Erie Canal sites where northern sunfish were last collected in 2005. The overwhelming increase in abundance (+940.8% CPUE) and the high density (1.2 fish per meter shoreline) of green sunfish, which are not native to NY State (Carlson & Daniels 2004), and the large increase in bluegill abundance (+260.5%) indicate that the centrarchid community overall has increased greatly in size. Concurrently, the pike community has also increased in abundance (+220.0%). Northern sunfish are the smallest of the *Lepomis* species occupying this area, and it is likely that they have not fared well during increased interspecific competition and higher abundance of a major centrarchid predator, the pikes (Scott & Crossman 1973). The significant decreases in smallmouth bass (-77.8%) and redhorses (-47.9%), the near disappearances of darters and logperches (-90.2%) and brindled madtoms (-95.7%), and the disappearances of tadpole madtoms and northern hog suckers, may indicate that the fish community has shifted from a cool- to a warm-water stream composition (Page & Burr 1991).

Non-metric Multidimensional Scaling (nMDS) showed a strong separation of the fish communities in 2005 and 2013 at the sites where northern sunfish were captured using the same gear and methods in 2005 (Figure 5). Due to the stress level of the ordination (0.2), as well as the oversimplified grouping of several species, the nMDS plot cannot be interpreted with certainty when viewed by itself. It does, however, support the findings of the CPUE comparisons showing that many species have changed in abundance from 2005 to 2013, which would alter the individual sampling runs' structures and cause the separation.

The decrease in Simpson's index of diversity in LTWC (Figure 4:1A–1E) and the dead-end slough off the Erie Canal (Figure 4: 2D) from 2005 to 2013 supports the fact that the fish communities have changed. Among the sites where northern sunfish were captured in 2005, there is no doubt that the fish community has been altered.

Green sunfish are native to North America, but they were not detected in NY until 1942 and did not reach Lake Erie until 1970 (Carlson & Daniels 2004). Green sunfish have caused problems for other fish communities where they have been introduced, including local extirpations of native centrarchids (Moyle 1976) and cyprinids (Lemly 1985), further declines in threatened species (Karp & Tyus 1990), and declines in other fish species (Dudley & Matter 2000). The major increase in green sunfish abundance, coupled with its ability to disrupt fish communities, is likely to be a major driver in the decline of the northern sunfish in lower Tonawanda Creek.

Competition with green sunfish cannot explain why northern sunfish were not detected at the sites 2A and 2D (Figure 4) which contained few or no green sunfish. Site 2A is a shallow widewater off of the Erie Canal that was stocked in 2011 with 325 adult northern sunfish averaging 63.5 mm TL (Carlson 2014). The site was sampled once in 2013 and four times across three days in 2014 (Table 3). Green sunfish were only sampled in low numbers during two out of the five electroshocking runs (Appendix B).

Lepomis hybridization

The rate of hybridization occurring in lower Tonawanda Creek between northern sunfish females and bluegill males is alarming. There were pure northern sunfish at five sites in lower Tonawanda Creek and one site adjacent to the Erie Canal in 2005, but sampling every meter of the shorelines at the six sites repeatedly for two summers captured eight hybrid and no pure northern sunfish. Roughly equal numbers of other *Lepomis* hybrid crosses were also captured in 2013-2014, which supports the findings of Hubbs (1955) that natural hybridization occurs when one species is scarce among abundant related species. Because of this situation northern sunfish hybridized proportionally at a higher rate than the other *Lepomis* species.

The mechanisms for the hybridization could have been due to female northern sunfish resembling female bluegills and being accepted by a spawning male bluegill, or there were nesting pairs of northern sunfish intruded upon by cuckolding male bluegills, which is not likely given my finding of no pure northern sunfish. Cuckolding would explain, however, the fact that all hybrids with bluegill parentage had bluegill fathers (supporting the findings of Garner & Neff 2014). In either case, northern sunfish likely had major problems in my study area with finding mates due to an extremely low population density, and finding spawning habitat due to high competition for it by other very abundant *Lepomis* species.

Interestingly, my study using genetic analysis of fish sampled in 2013-2014 found only northern sunfish x bluegill hybrids, while morphometric analysis by NY State museum staff identified two northern sunfish x pumpkinseed hybrids in samples provided from sampling between 2005 and 2012 (Wells 2009; Carlson 2014). It is very difficult to identify *Lepomis* hybrids, especially in juvenile form (see Figures 6–8). My results suggest that genetics is a more reliable way.

Other factors potentially contributing to the decline of L. peltastes

The increase in abundance of the non-native round goby (+200%) could have contributed to the northern sunfish’s decline. This species has shown multiple negative impacts in streams of the Great Lakes, including predation on fish eggs and increasing the competition for food (Pennuto *et al.* 2010; Kornis *et al.* 2012). Since this species is small and benthic, boat electroshocking in deep, turbid water such as lower Tonawanda Creek is not an efficient method for capturing round gobies (Kornis *et al.* 2012). Undoubtedly the true population size is larger than what my samples suggest, and the effects of the round goby invasion may be underestimated. The species was first caught in Tonawanda Creek in 2002, and seine samples by NYSDEC in this area have seen an increase in frequency of occurrence (# seines containing round goby ÷ total number of samples) to over 80% by 2011 (D. Carlson, personal communication).

I collected three specimens of the non-indigenous species, *Morone americana* (white perch), in lower Tonawanda Creek which was not collected by Wells (2009). This species is native to Atlantic coast drainages and was introduced to the Great Lakes via the Erie Canal in the 1950s. Like its distant, morphologically-similar relative, *Perca flavescens* (yellow perch), it is an opportunistic feeder (Page & Burr 1991) and would likely consume northern sunfish eggs and juveniles if available.

Northern sunfish were observed spawning at one particular “hotspot” in 2005—a fluvial ledge at the confluence of Mud Creek and Tonawanda Creek (Figure 4: 2D; Wells 2009). Months before my 2013 sampling, a residential property on the north bank of Mud Creek 60 m upstream of the confluence had a landslide that blocked the flow of Mud Creek for several weeks (personal communication, Timothy DePriest, NYSDEC, Buffalo, NY). This event contributed an enormous amount of suspended solids and likely buried the spawning hotspot with sediment.

Conclusion

After massive electroshocking effort, New York State’s remaining wild population of northern sunfish in lower Tonawanda Creek has fallen below detectable levels. The evidence of hybridization I found may be a “vapor trail” left by a native population now lost to our state. The large change in the fish community in the study area indicates that this habitat has been altered and that it is unlikely to be suitable for restocking unless it can be restored to favor the northern sunfish again. Surveys in other streams of the area which had been stocked were also without evidence of established populations. If the LTWC system is changing from a coolwater to warmwater fish community, perhaps due to global warming or changes in the watershed, restoration of the northern sunfish may not be possible in this historical location, and possibly other streams in the area.

Of those waters surveyed in 2013 and 2014, I believe the best candidate sites for developing a population would be ones with low green sunfish and round goby abundance. One such site is Como Lake on Cayuga Creek (Figure 4: 4D)—fish community samples did not detect round goby (nor did any samples in Cayuga Creek) and were rich with sensitive species of suckers and darters, indicating a healthy ecosystem. Ellicott Creek at Bowmansville (Figure 4: 3F) is another candidate site because round goby were not detected. Lastly, the unnamed creek (Figure 4: 2B) west of Ransom Creek (Figure 4: 2C) may be a good candidate locale because neither green sunfish nor round goby were detected (Appendix B). An examination of physical characteristics in streams in Western NY should be conducted as a follow-up to Wells (2009) to aid in identifying new waters potentially suitable for northern sunfish, and future efforts in LTWC should continue to monitor if this remnant historical site could be repopulated.

Although I did not detect them in 2013-2014, northern sunfish were found at some sites where they were reintroduced in the Niagara River watershed in Western New York in the years before my study. Rather than have the recovery program be discontinued, I urge managers to 1) identify additional waters suitable for northern sunfish with low green sunfish, bluegill, pike, and round goby abundance, 2) continue propagating the Tonawanda Creek strain to stock in these waters, and 3) develop a more frequent and systematic sampling schedule to assess restocking success.

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Tables

Table 1. Key used for field identification of the four co-occurring sunfish species in western New York developed from Smith (1985), Scott & Crossman (1973), and from input from Douglas Carlson (NYSDEC Fish Biologist; personal communication).

	L. gibbosus	***L. peltastes***	***L. cyanellus***	***L. macrochirus***
Pectoral fin shape	long and pointed	short and rounded	short and rounded	long and pointed
Lateral line scale #	40	36	43	41
Opercular flap color and angle	dark with white margin; red at middle; angled backward	dark with white margin; red at middle; angled upward	dark with light margin; yellow to red at middle; angled slightly upward	dark through to margin; angled backward
Body shape	2x long as deep	2x long as deep	2.3–2.75x long as deep	2x long as deep
Opercule bone stiffness	firm to margin, smooth edge	flexible throughout, ragged edge	firm to margin, smooth edge	flexible toward edge, ragged edge
Mouth size	small, reaching below front edge of eye	small, not reaching below front edge of pupil	large, reaching below middle of pupil	small, reaching below front edge of eye
Prominent medial fin spots	none	none	dark spot at posterior base of dorsal and anal fins	dark spot at posterior base of dorsal soft rays
Dorsal origin	behind pectoral base	behind pectoral base	over pectoral base	over pectoral base
First dorsal membranes	incised	deeply incised	incised	incised

	L. gibbosus	***L. peltastes***	***L. cyanellus***	***L. macrochirus***
Fin membrane and margin coloration	yellow with black margin	dark with red spots on membranes with black margins	yellow with black margins	clear and dusky
Anal fin insertion	below last dorsal spine	below first dorsal soft ray	below 2nd to last dorsal spine	below last dorsal spine
Pelvic fin insertion	below 2nd dorsal spine	below dorsal origin	below 3rd dorsal spine	below 4th dorsal spine
Last pelvic membrane length	≥ 2/3 last ray length	≥ 2/3 last ray length	1/2 to 2/3 last ray length	2/3 last ray length

Table 2. Descriptions of sites sampled in 2013 and 2014. Sites where *L. peltastes* were detected in 2005 (Wells 2009) and years stocked are denoted by the last two columns. Latitude and longitude coordinates are averages of the starting coordinates of all shocking runs conducted at each site. Information on stocking obtained from Carlson (2014).

Watershed	**Site Code**	**Description**	**Latitude**	**Longitude**	***L. peltastes* Detected in 2005?**	**Years Stocked**
Tonawanda Creek						
	1A	Confluence with Erie Canal	43.08476	-78.7314	Y	
	1B	Pendleton Riffle near New Rd. bridge	43.08512	-78.7247	Y	
	1C	"S" turns	43.08269	-78.7150	Y	
	1D	Confluence with Mud Creek	43.08724	-78.7064	Y	
	1E	Millersport Riffle below Transit Rd. bridge	43.08676	-78.7006	Y	
	1F	Upstream of Millersport Riffle	43.08419	-78.6885		
	1G	Downstream of DEC fishing access near Rapids, NY	43.07233	-78.5961		
	1H	Murder Creek near Tonawanda Creek Rd. bridge	43.08142	-78.5201		2008-09, 2011
	1I	Peaviner Rd. bridge near Alexander, NY	42.92913	-78.2344		2010
Erie Canal						
	2A	Bypass near Veterans Memorial Park, Amherst, NY	43.05699	-78.8061		2011
	2B	Unnamed Creek west of Ransom Creek	43.06889	-78.7534		

Watershed	**Site Code**	**Description**	**Latitude**	**Longitude**	***L. peltastes* Detected in 2005?**	**Years Stocked**
	2C	Ransom Creek	43.06046	-78.7448		
	2D	Dead-end slough east of Ransom Creek	43.06949	-78.7470	Y	
	2E	Erie Canal east of Tonawanda Creek	43.08772	-78.7327		
Ellicott Creek						
	3A	Niagara Falls Blvd. launch through north bypass	43.02610	-78.8161		
	3B	I-990 bridge and 4-way confluence of bypasses	43.02150	-78.7936		
	3C	Upstream of canoe trail bypass	43.02103	-78.7925		
	3D	Audubon Pkwy. bridge to upstream riffle	43.00695	-78.7776		
	3E	Downstream of Audubon Pkwy. bridge	43.00852	-78.7804		
	3F	Stony Rd. bridge upstream	42.93402	-78.6407		2010-11
Cayuga Creek						
	4A	Confluence with Slate Bottom Creek	42.87698	-78.7561		2007-08
	4B	Slate Bottom Creek	42.87560	-78.7577		
	4C	Upstream of Union Rd. bridge	42.88471	-78.7528		2007
	4D	Como Lake	42.89169	-78.6633		
	4E	Little Buffalo Creek	42.88939	-78.6427		2009

Table 3. Summary of all sampling effort in 2005 (Wells 2009), 2013 and 2014. Sampling gears included electroshocking boat (EFB), and backpack electroshocking units (BPS). Data are also given for the number of electroshocking runs and days per-year, per-site. See Table 2 for an explanation of site codes and Appendix B for the raw capture data on each run.

Year	**Site**	**Date Range**	**# Runs**	**# Days**	**Effort (sec)**	**Gear**
2005	1A	6/28–7/22	3	3	2,700	EFB
2005	1B	6/29 & 7/8	2	2	1,800	EFB
2005	1C	7/9 & 7/21	2	2	1,800	EFB
2005	1D	6/24 & 7/20	2	2	1,800	EFB
2005	1E	6/23 & 7/19	2	2	1,800	EFB
		Watershed totals:	*11*	*14*	*9,900*	*2.75 hrs*
2005	2D	27-Jun	1	1	900	EFB
		Watershed total:	*1*	*1*	*900*	*0.25 hrs*
		2005 Total:	*12*	*4*	*10,800*	*3.00 hrs*
2013	1A	5/15–9/26	8	7	7,179	EFB
2013	1B	5/1–11/2	10	9	8,726	EFB
2013	1C	5/15–11/2	17	11	15,913	EFB
2013	1D	5/1–11/2	17	13	14,999	EFB
2013	1E	5/1–9/26	20	13	17,283	EFB
2013	1F	5/30–11/2	2	2	2,647	EFB
		Watershed total:	*74*	*14*	*66,747*	*18.54 hrs*
2013	2A	07/25	1	1	1,001	EFB
2013	2B	08/22	1	1	912	EFB
2013	2C	7/18–8/12	3	2	3,031	EFB
2013	2D	6/5–11/2	3	3	2,792	EFB
2013	2E	08/22	1	1	909	EFB
		Watershed total:	*9*	*7*	*8,645*	*2.40 hrs*
2013	3A	9/14	1	1	907	EFB
2013	3B	9/14	1	1	884	EFB
2013	3C	9/14	1	1	659	EFB
2013	3D	9/14	1	1	1,100	EFB
2013	3E	9/14	1	1	800	EFB
		Watershed total:	*5*	*1*	*4,350*	*1.21 hrs*

Year	Site	Date Range	# Runs	# Days	Effort (sec)	Gear
		2013 Total:	*88*	*15*	*79,742*	*22.15 hrs*
2014	1A	6/1–6/28	5	5	6,617	EFB
2014	1B	6/7 & 7/13	2	2	1,666	EFB
2014	1C	6/1–6/28	7	5	8,042	EFB
2014	1D	6/1–7/13	6	6	7,671	EFB
2014	1E	6/1–7/13	6	6	8,678	EFB
2014	1G	6/27	3	1	3,051	Raft/BPS
2014	1H	6/14–7/11	10	4	16,029	BPS
2014	1I	6/14 & 7/5	2	2	3,582	BPS
		Watershed total:	*41*	*11*	*55,336*	*15.37 hrs*
2014	2A	6/1–7/13	4	3	5,100	EFB
2014	2D	7/13l	1	1	990	EFB
		Watershed total:	*5*	*3*	*6,090*	*1.69 hrs*
2014	3F	6/6–7/10	4	3	7,528	BPS
		Watershed total:	*4*	*3*	*7,528*	*2.09 hrs*
2014	4A	6/6–6/21	4	2	6,334	BPS
2014	4B	7/10	1	1	1,816	BPS
2014	4C	6/6	1	1	1,100	BPS
2014	4D	8/3	5	1	7,292	Canoe/BPS
2014	4E	8/23	1	1	800	BPS
		Watershed total:	*12*	*4*	*17,342*	*4.82 hrs*
		2014 Total:	*62*	*15*	*86,296*	*23.97 hrs*
		Project Total:	*162*	*34*	*176,838*	*49.12 hrs*

Table 4. Average catch per unit effort (CPUE; # captured/hour of power-on electroshocking) and relative abundance (RA) of species and species groups captured in lower Tonawanda Creek and the Erie Canal (Figure 4: 1A–1E, 2D) in 2005 (n = 12 samples) and 2013 (n = 40 samples). A 2-sample, 2-tailed t-test compared the average CPUE between the two years for each taxon as well as the cumulative total, with asterisks indicating a significant difference ($P < 0.05$; $df = 50$ for all tests).

Family	**Scientific name**	**Common name**	**Code**	**CPUE**	**RA** (%)	**CPUE**	**RA** (%)	Δ **CPUE** (%)	***t* value**	***P* value**
				2005		2013				
Cyprinidae										
	n/a	non-native cyprinids	NNCY	25.7	6.40	3.7	0.6	-85.6	-4.845	0.000*
	n/a	native cyprinids	NACY	169.7	42.6	122.3	20.0	-27.9	-1.292	0.202
Catostomidae										
	Moxostoma spp.	redhorse	MOXO	28.0	7.0	14.6	2.4	-47.9	-2.122	0.039*
	Catostomus commersonii	white sucker	CACO	2.3	0.6	0.1	0.0	-95.7	-3.017	0.004*
	Hypentelium nigricans	northern hog sucker	HYNI	0.7	0.2	0.0	0.0	-100.0	-1.870	0.067
Ictaluridae										
	Ameiurus nebulosus	brown bullhead	AMNE	4.7	1.2	0.6	0.1	-87.2	-2.253	0.029*
	Ictalurus punctatus	channel catfish	ICPU	0.3	0.1	0.2	0.0	-33.3	-0.436	0.665
	Noturus gyrinus	tadpole madtom	NOGY	0.3	0.1	0.0	0.0	-100.0	-1.870	0.067
	Noturus miurus	brindled madtom	NOMI	2.3	0.6	0.1	0.0	-95.7	-3.821	0.000*
Esocidae										
	Esox spp.	pikes	ESOX	4.0	1.0	12.8	2.1	+220.0	2.247	0.029*

Family	**Scientific name**	**Common name**	**Code**	**CPUE**	**RA** (%)	**CPUE**	**RA** (%)	**Δ CPUE** (%)	***t* value**	***P* value**
				2005		2013				
Umbridae										
	Umbra limi	central mudminnow	UMLI	1.7	0.4	0.9	0.1	-47.1	-0.975	0.334
Fundulidae										
	Fundulus diaphanus	banded killifish	FUDI	0.0	0.0	1.7	0.3	n/a	1.780	0.081
Atherinopsidae										
	Labidesthes sicculus	brook silverside	LASI	0.0	0.0	4.5	0.7	n/a	2.139	0.037*
Moronidae										
	Morone americana	white perch	MOAM	0.0	0.0	0.3	0.0	n/a	0.967	0.338
Centrarchidae										
	Ambloplites rupestris	rock bass	AMRU	12.0	3.0	26.8	4.4	+123.3	1.793	0.079
	Lepomis cyanellus	green sunfish	LECY	27.7	7.0	288.3	47.2	+940.8	5.081	0.000*
	Lepomis gibbosus	pumpkinseed	LEGI	29.0	7.3	27.4	4.5	-5.5	-0.159	0.874
	Lepomis macrochirus	bluegill	LEMA	22.0	5.5	79.3	13.1	+260.5	1.988	0.052
	Lepomis peltastes	northern sunfish	LEPE	7.7	1.9	0.0	0.0	-100.0	-6.601	0.000*
	Micropterus dolomieu	smallmouth bass	MIDO	11.7	2.9	2.6	0.4	-77.8	-4.496	0.000*
	Micropterus salmoides	largemouth bass	MISA	16.0	4.0	12.9	2.1	-19.4	-0.593	0.556
	Pomoxis annularis	white crappie	POAN	2.0	0.5	1.4	0.2	-30.0	-0.519	0.606
	Pomoxis nigromaculatus	black crappie	PONI	4.0	1.0	2.8	0.5	-30.0	-0.557	0.58
Percidae										
	Etheostoma spp. and Percina spp.	darters and logperch	DART	17.3	4.4	1.7	0.3	-90.2	-6.280	0.000*

Family	**Scientific name**	**Common name**	**Code**	**CPUE**	**RA** (%)	**CPUE**	**RA** (%)	**Δ CPUE** (%)	***t* value**	***P* value**
				2005		2013				
	Perca flavescens	yellow perch	PEFL	5.7	1.4	1.3	0.2	-77.2	-1.914	0.061
	Sander vitreus	walleye	SAVI	1.7	0.4	1.4	0.2	-17.6	-0.204	0.839
Sciaenidae										
	Aplodinotus grunniens	freshwater drum	APGR	0.7	0.2	0.0	0.0	-100.0	-2.774	0.008*
Gobiidae										
	Neogobius melanostomus	round goby	NEME	1.0	0.3	3.0	0.5	+200.0	1.291	0.203
			Total CPUE	398.0		610.5		+53.4	2.556	0.014*

Table 5. Comparison of Simpson's index of diversity (D_s) of lower Tonawanda Creek (Figure 4: 1A–1E) and the Erie Canal (Figure 4: 2D) between 2005 and 2013 using a modified Simpson's t-test (Brower & Zar 1984).

	2005	**2013**
Simpson's index of diversity (D_s)	0.790	0.715
# samples	12	40
Average richness (# spp./sample)	13.42	10.92
Cumulative richness (# spp.)	25	24
Simpson's *t* value	3.05	
Degrees of freedom (*df*)	47	
Significance (*P*)	0.004	

Table 6. Similarity of Percentages (SIMPER) of CPUE catch data was [Log_{10} (x+1) transformed] within (similarities) and between (dissimilarities) the 2005 and 2013 fish communities in lower Tonawanda Creek (Figure 4: 1A–1E) and the Erie Canal (Figure 4: 2D). Values below are the percentage that species or species groups contributed to the similarities or dissimilarities in the samples, with only those that contributed to 90% of either shown. Species abbreviations are in Table 4.

	2005	**2013**	**2005 vs 2013**
	Overall similarity (%)		Overall dissimilarity (%)
	64.4	72.0	42.1
	Species' contributions (%)		
LECY	7.7	22.4	9.5
DART	9.2	-	7.8
LEMA	5.7	14.7	7.4
NNCY	10.2	-	7.0
LEPE	5.5	-	6.5
ESOX	-	5.1	5.4
MIDO	6.7	-	5.2
AMRU	5.2	11.3	4.9
LEGI	6.5	7.8	4.7
MOXO	7.8	9.3	4.1
PONI	-	-	4.1
MISA	8.7	3.9	4.0
NACY	17.8	17.8	3.3
LASI	-	-	3.2
SAVI	-	-	2.6
NOMI	-	-	2.4
NEME	-	-	2.4
PEFL	-	-	2.2
AMNE	-	-	2.1
CACO	-	-	2.1

Table 7. Results of a mark-recapture study (Schnabel1938) on green sunfish in lower Tonawanda Creek from 25 July to 26 September 2013. Confidence intervals for $\sum R_t$ are based on the Poisson probability distribution and were found in Appendix II in Ricker (1975). N̂ is the estimated population size.

Sample date (t)	**Total Captured (C)**	**Recaptured (R)**	**Unmarked (C-R)**	**Cumulative Marked (M)**	**C x M**
7/25/2013	452	0	452	0	0
8/12/2013	353	18	335	452	159,556
8/22/2013	177	21	156	787	139,299
9/26/2013	39	0	39	943	36,777
	$\sum R_t =$	39		$\sum C_t M_t =$	335,632
			$\hat{N} = \frac{\sum_{t=1}^{n} C_t M_t}{\sum_{t=1}^{n} R_t} =$		**8,606.0**
	95% upper $\sum R_t$	27.7	95% upper N̂		**12,116.7**
	95% lower $\sum R_t$	53.3	95% lower N̂		**6,297.0**

Table 8. Summary of the results of nuclear and mitochondrial DNA analysis performed on 27 hybrid sunfish and four phenotypically pure but genotypically mixed specimens collected in lower Tonawanda Creek in 2013 and 2014 and a NYSDEC northern sunfish hatchery pond. Alleles are color-coded by species: red for northern sunfish, blue for bluegill, green for green sunfish, orange for pumpkinseed, and no color indicates the result was inconclusive. The direction of the parental crosses of specimens 23 and 24 could not be determined. See Table 4 for a guide to species abbreviations.

Specimen	**Nuclear (♂ x ♀)**	**Mitochondrial (♀)**	**Hybrid index**	**Allele**																	
				Enc1	Enc1	Glyt	Glyt	Plagl2	Plagl2	ptr	ptr	Sidkey	Sidkey	Tbr1	Tbr1	Cal	Cal	LmegA	LmegA	rag1	rag1
3	LEMA x LEPE	LEPE	0.5	🟥	🟦	🟥	🟦	🟥	🟦	🟥	🟦			🟥	🟦	🟥	🟦	🟦	🟥		
9	LEMA x LEPE	LEPE	0.42	🟦	🟥	🟥	🟦	🟥	🟦	🟦	🟦					🟥	🟦	🟦	🟥		
12	LEMA x LEPE	LEPE	0.44	🟦	🟥	🟥	🟦	🟥	🟦	🟦	🟦			🟦	🟥	🟥	🟦	🟥	🟦	🟦	🟥
13	LEMA x LEPE	LEPE	0.36	🟦	🟥	🟦	🟥	🟥	🟦	🟦	🟦			🟦	🟦	🟥	🟦	🟦	🟥		
14	LEMA x LEPE	LEPE	0.44	🟦	🟥	🟥	🟦	🟦	🟥	🟦	🟦			🟥	🟦	🟥	🟦	🟦	🟥	🟦	🟥
17	LEMA x LEPE	LEPE	0.43	🟦	🟥	🟦	🟥	🟦	🟥	🟦	🟦			🟦	🟥	🟥	🟦	🟦	🟥		
18	LEMA x LEPE	LEPE	0.56	🟥	🟦	🟦	🟥	🟦	🟥	🟦	🟦			🟥	🟦	🟥	🟦	🟥	🟦	🟥	🟦
20	LEMA x LEPE	LEPE	0.44	🟦	🟥	🟥	🟦	🟦	🟥	🟦	🟦			🟦	🟥	🟥	🟦	🟦	🟥	🟥	🟦
7	LEMA x LECY	LECY	0.5	🟦	🟩	🟦	🟩	🟩	🟦	🟩	🟦			🟩	🟦	🟩	🟦	🟦	🟩	🟦	🟩
15	LEMA x LECY	LECY	0.5	🟩	🟦	🟦	🟩	🟩	🟦	🟩	🟦			🟩	🟦	🟩	🟦	🟦	🟩	🟩	🟦
19	LEMA x LECY	LECY	0.5	🟦	🟩	🟩	🟦	🟩	🟦	🟩	🟦					🟩	🟦	🟦	🟩		
22	LEMA x LECY	LECY	0.5	🟩	🟩											🟩	🟦				

Specimen	Nuclear (♂ x ♀)	Mitochondrial (♀)	Hybrid index	Allele																	
				Enc1	Enc1	Glyt	Glyt	Plagl2	Plagl2	ptr	ptr	Sidkey	Sidkey	Tbr1	Tbr1	Cal	Cal	LmegA	LmegA	rag1	rag1
72	LEMA x LECY	LECY	0.5	🟩	🟦	🟦	🟩	🟦	🟩	🟩	🟦					🟩	🟦	🟦	🟩		
79	LEMA x LECY	LECY	0.33	🟦	🟩											🟩	🟦	🟩	🟩		
23	LEMA x LECY	-	0.44	🟦	🟩	🟦	🟩	🟩	🟦	🟩	🟩			🟦	🟦	🟩	🟦	🟦	🟩		
24	LEMA x LECY	-	0.44	🟩	🟦	🟦	🟩	🟦	🟩	🟩	🟩			🟦	🟩	🟩	🟦	🟦	🟩	🟩	🟦
10	LEMA x LEGI	LEGI	0.5	🟦	🟨	🟦	🟨	🟨	🟦	🟨	🟦			🟨	🟦	🟨	🟦	🟨	🟦	🟨	🟦
11	LEMA x LEGI	LEGI	0.5	🟨	🟦	🟦	🟨	🟨	🟦	🟨	🟦			🟦	🟨	🟨	🟦	🟨	🟦		
31	LEMA x LEGI	LEGI	0.57	🟦	🟦	🟨	🟦	🟦	🟨	🟨	🟦			🟨	🟦	🟨	🟦	🟨	🟦	🟦	🟨
55	LEMA x LEGI	LEGI	0.56	🟦	🟨	🟨	🟦	🟨	🟦	🟨	🟦	🟨	🟦	🟦	🟦	🟨	🟦	🟦	🟨		🟦
67	LEMA x LEGI	LEGI	0.42	🟦	🟨	🟨	🟦	🟦	🟨	🟨	🟨					🟨	🟦	🟨	🟦		
71	LEMA x LEGI	LEGI	0.43	🟦	🟨	🟨	🟦	🟨	🟦	🟨	🟨			🟦	🟨	🟨	🟦	🟨	🟦		
74	LEMA x LEGI	LEGI	0.5	🟦	🟨	🟨	🟦	🟦	🟨	🟨	🟦			🟨	🟦	🟨	🟦	🟦	🟨		
75	LEMA x LEGI	LEGI	0.5	🟦	🟨	🟨	🟦	🟨	🟦	🟨	🟦			🟨	🟦	🟨	🟦	🟦	🟨		
6	LECY x LEGI	LEGI	0.5	🟩	🟨	🟨	🟩	🟩	🟨	🟨	🟩			🟩	🟨	🟩	🟨	🟨	🟩		
37	LECY x LEGI	LEGI	0.38	🟩	🟩	🟨	🟩	🟩	🟩	🟨	🟩			🟨	🟩	🟩	🟨	🟨	🟩	🟩	🟨
80	LECY x LEGI	LEGI	0.5	🟨	🟩											🟩	🟨				
27	LECY	LECY	-					🟩	🟩							🟩	🟩	🟩	🟥		
51	LECY	LECY	0.125	🟩	🟩			🟩	🟦							🟩	🟩	🟩	🟩		
34	LEMA	LEMA	0.07	🟦	🟦	🟦	🟦	🟨	🟦	🟦	🟦			🟦	🟦			🟦	🟦	🟦	🟦
95	LEPE	LEPE	-													🟥	🟦				

Figures

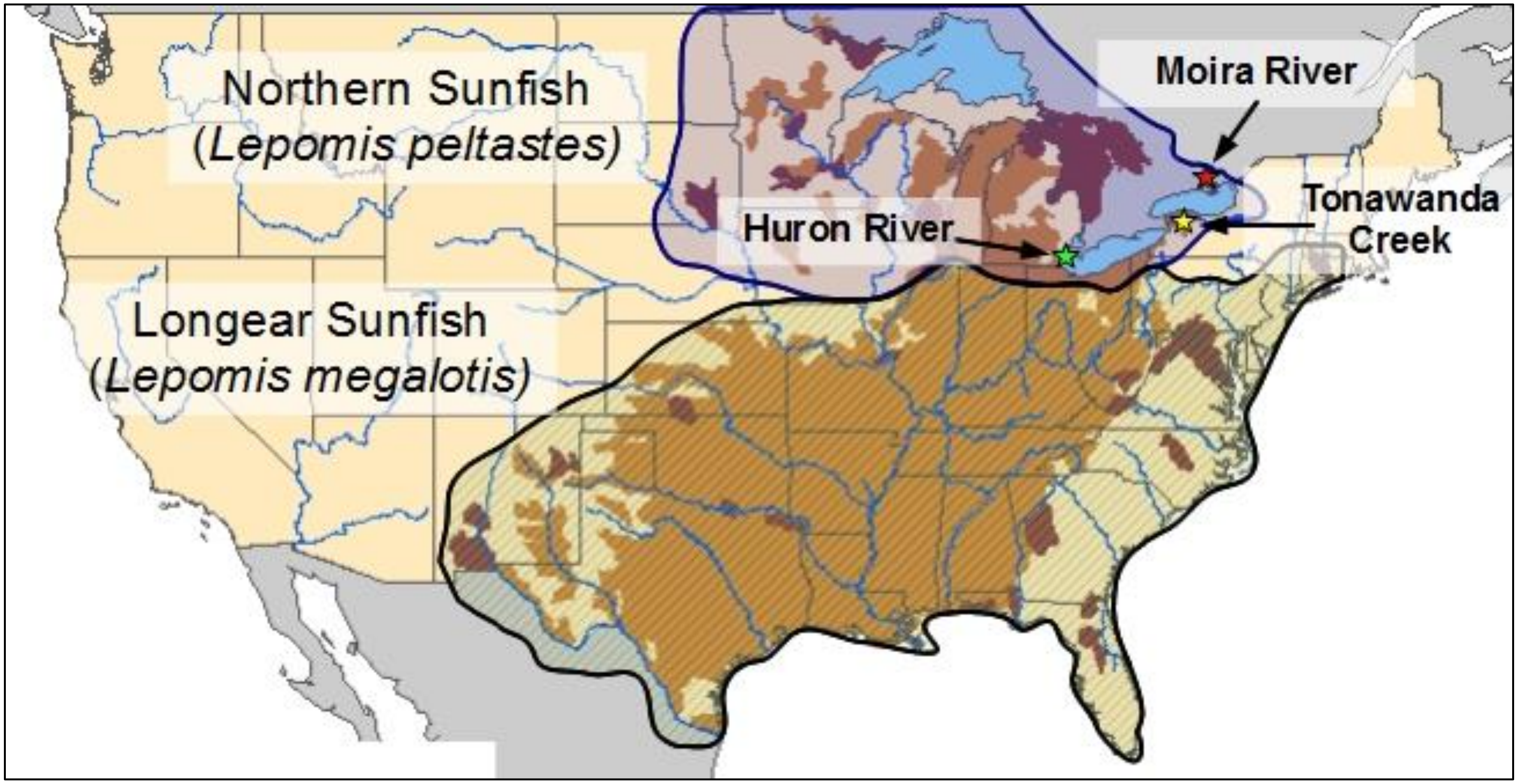

Figure 1. Map showing the native (orange) and introduced (purple) localities of *L. peltastes and L. megalotis*, with stars indicating collection sites of broodstock used for the recovery stocking program. Map adapted from Fuller and Cannister (2012) and Jennings (2013).

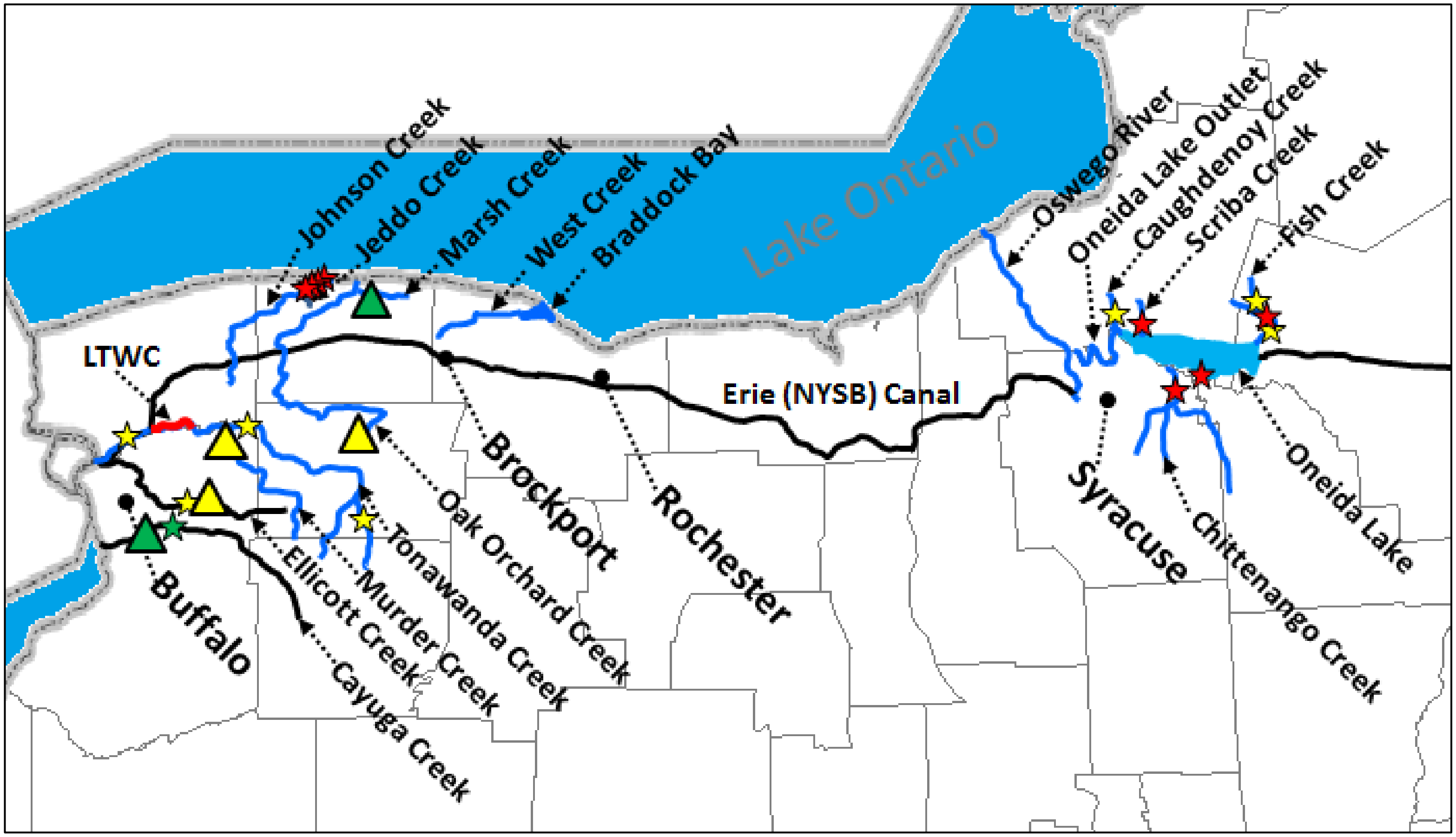

Figure 2. Map of Western and Central New York State showing northern sunfish historic waters (blue lines), stocking sites (stars), and stocked sites where follow-up sampling by NYSDEC 2005–2014 has detected northern sunfish (triangles). The 3.7 km portion of lower Tonawanda Creek (LTWC; sites 1A–1E) is highlighted in red. Stocking symbols are color-coded according to broodstock strain (red = Moira River, yellow = Tonawanda Creek, green = Huron River).

Figure 3. Photographs of adult specimens of the co-occurring species of sunfish (genus *Lepomis*) in Western New York (clockwise from top left): *L. gibossus* (pumpkinseed), *L. peltastes* (Northern sunfish), *L. macrochirus* (bluegill), and *L. cyanellus* (green sunfish). Scale units are centimeters. Photographs by Kelly Owens.

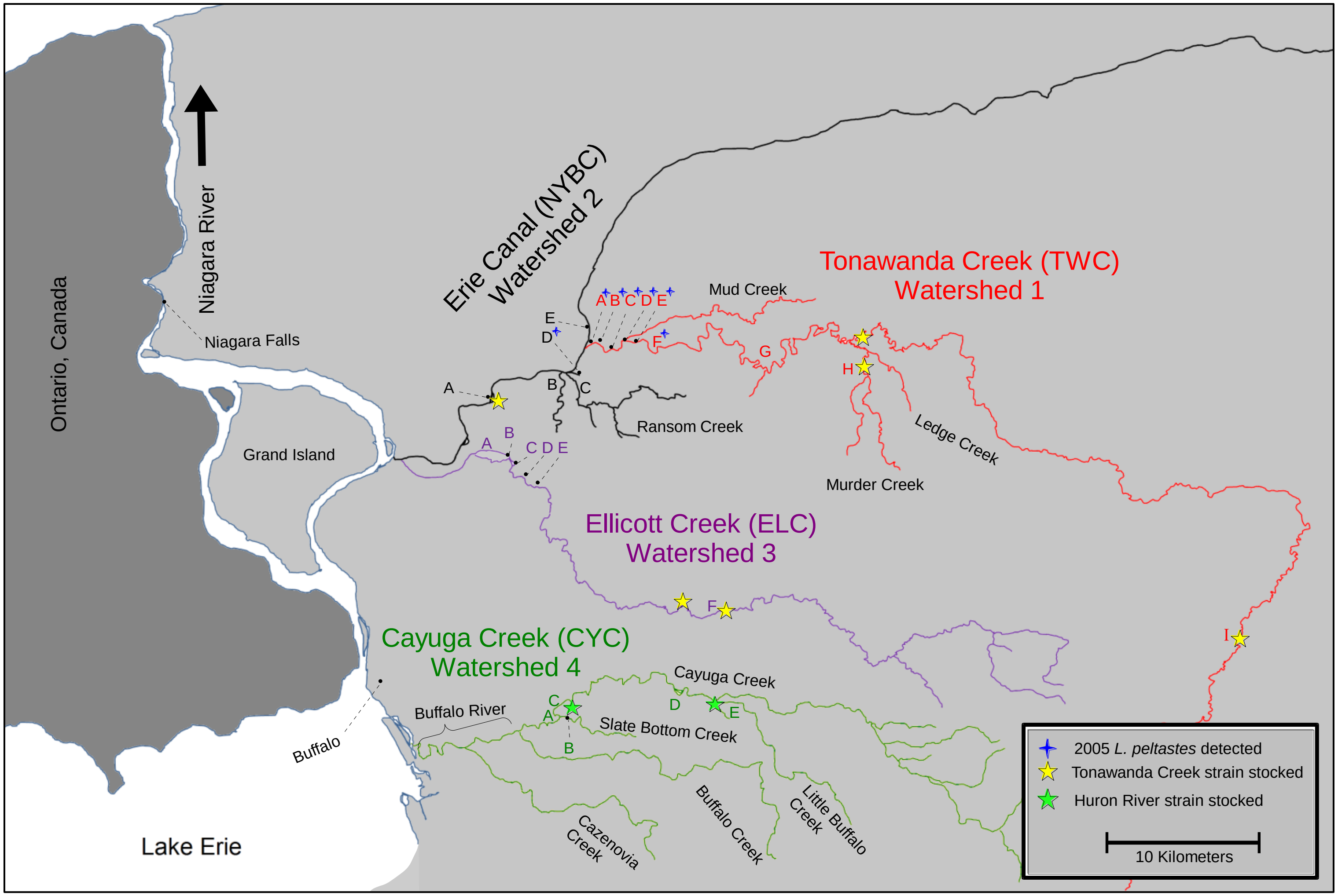

Figure 4. Map of study sites in western New York showing each locality (letters) within the four watersheds sampled. Sites where *L. peltastes* were detected in 2005 are marked with a blue asterisks, and those stocked since 2005 are marked with yellow (Tonawanda strain) or green (Huron River) stars.

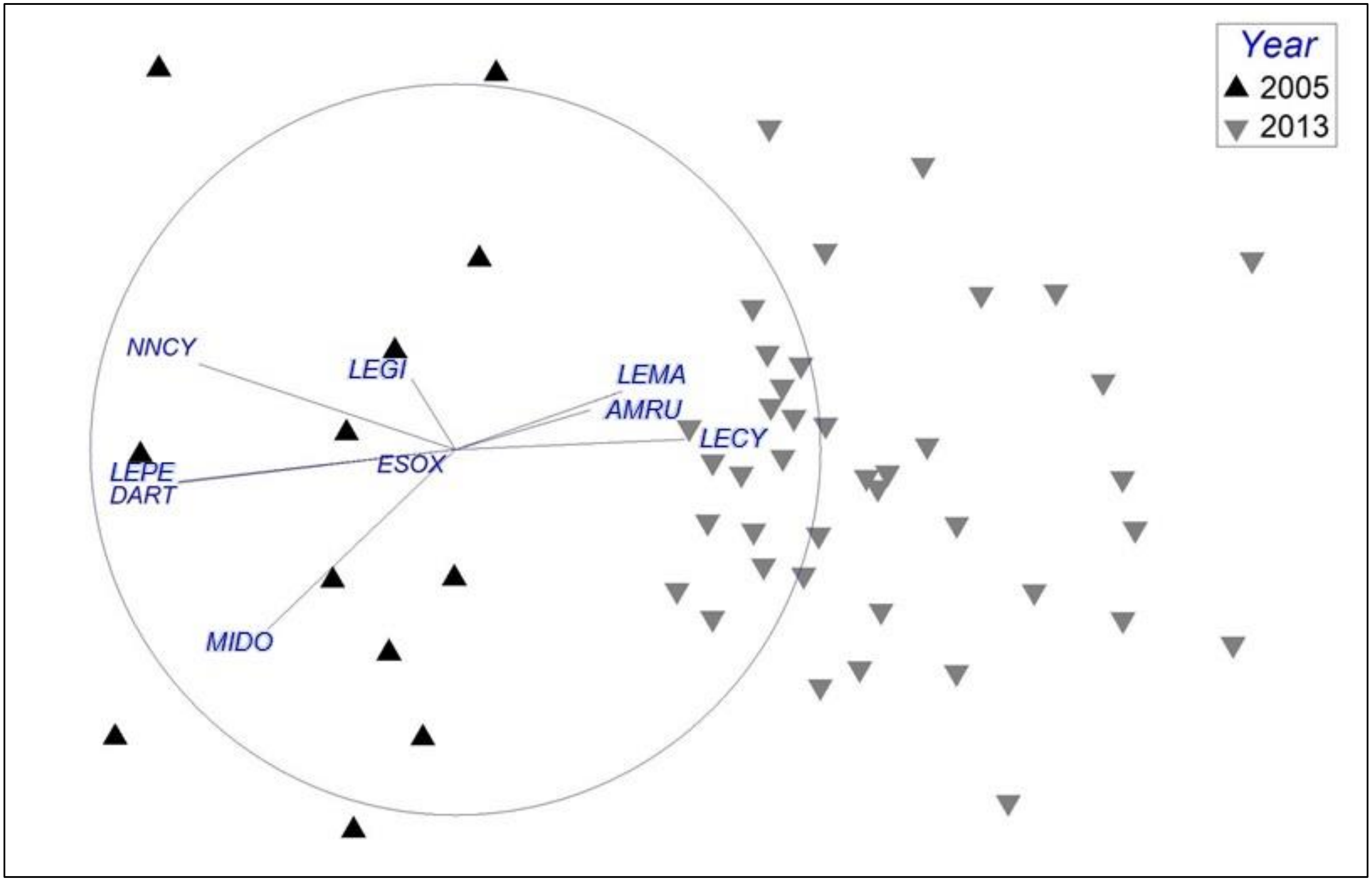

Figure 5. Non-Metric Multidimensional Scaling (nMDS) plot of sampling run CPUE in 2005 and 2013 in lower Tonawanda Creek (Figure 4: 1A–1E) and the Erie Canal (Figure 4: 2D), with vectors of individual species' contributions to differences in the fish communities between years. See Table 4 for species abbreviations.

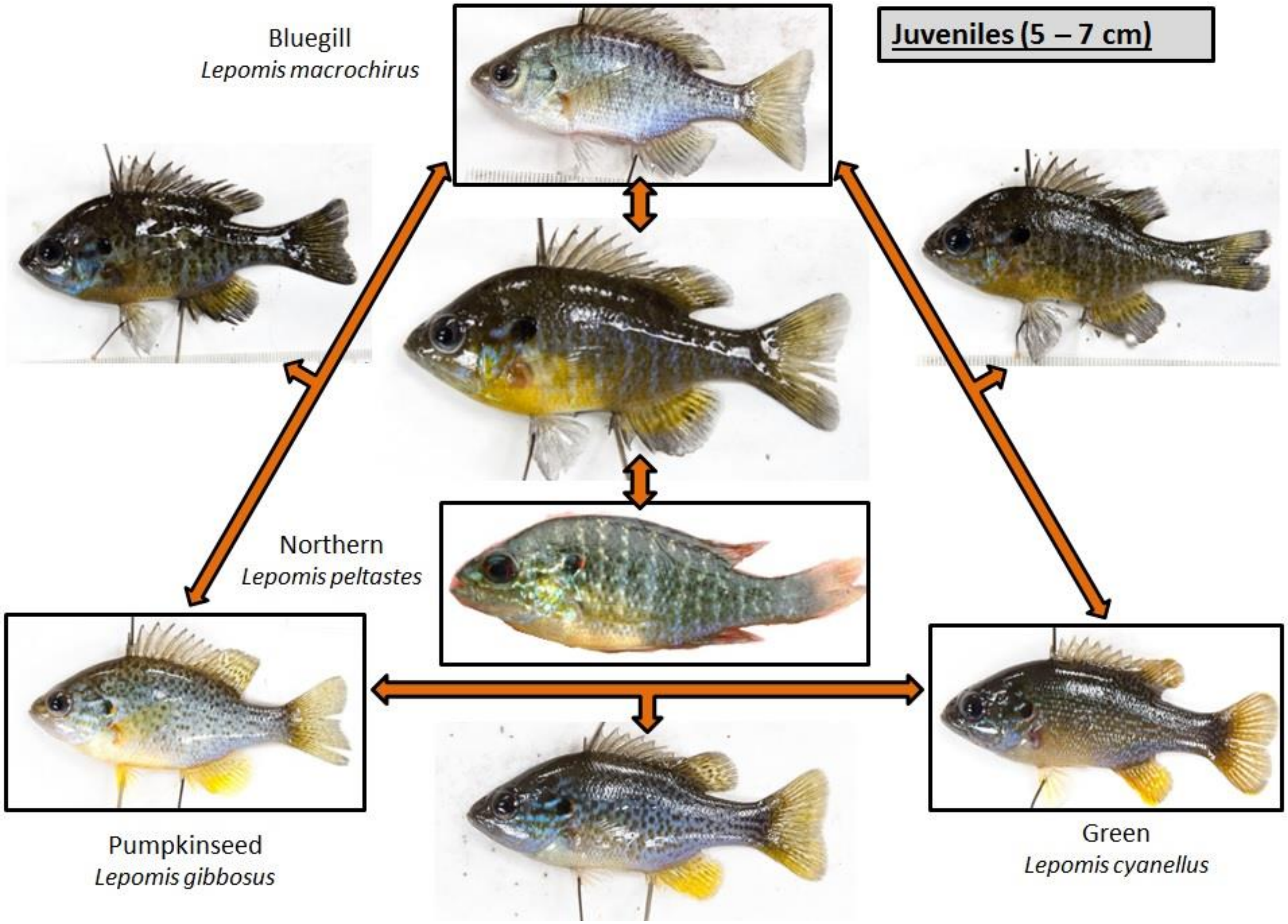

Figure 6. Photographs of juvenile pure bred and hybrid sunfish specimens collected in lower Tonawanda Creek and a NYSDEC Northern sunfish hatchery pond in 2013 and 2014. Photographs by Kelly Owens.

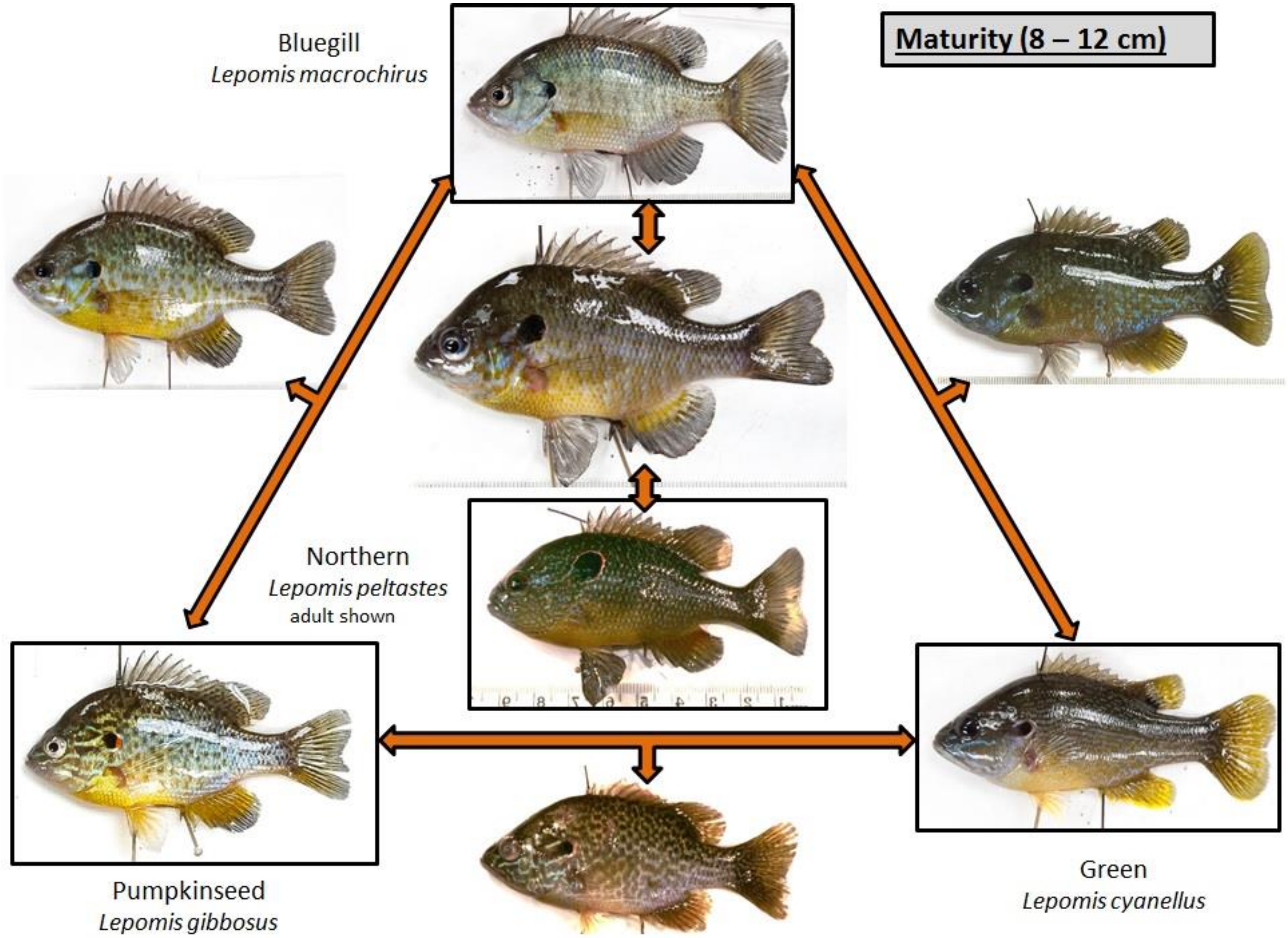

Figure 7. Photographs of mid-sized (age at maturity) pure bred and hybrid sunfish specimens collected in lower Tonawanda Creek and a NYSDEC Northern sunfish hatchery pond in 2013 and 2014. Photographs by Kelly Owens.

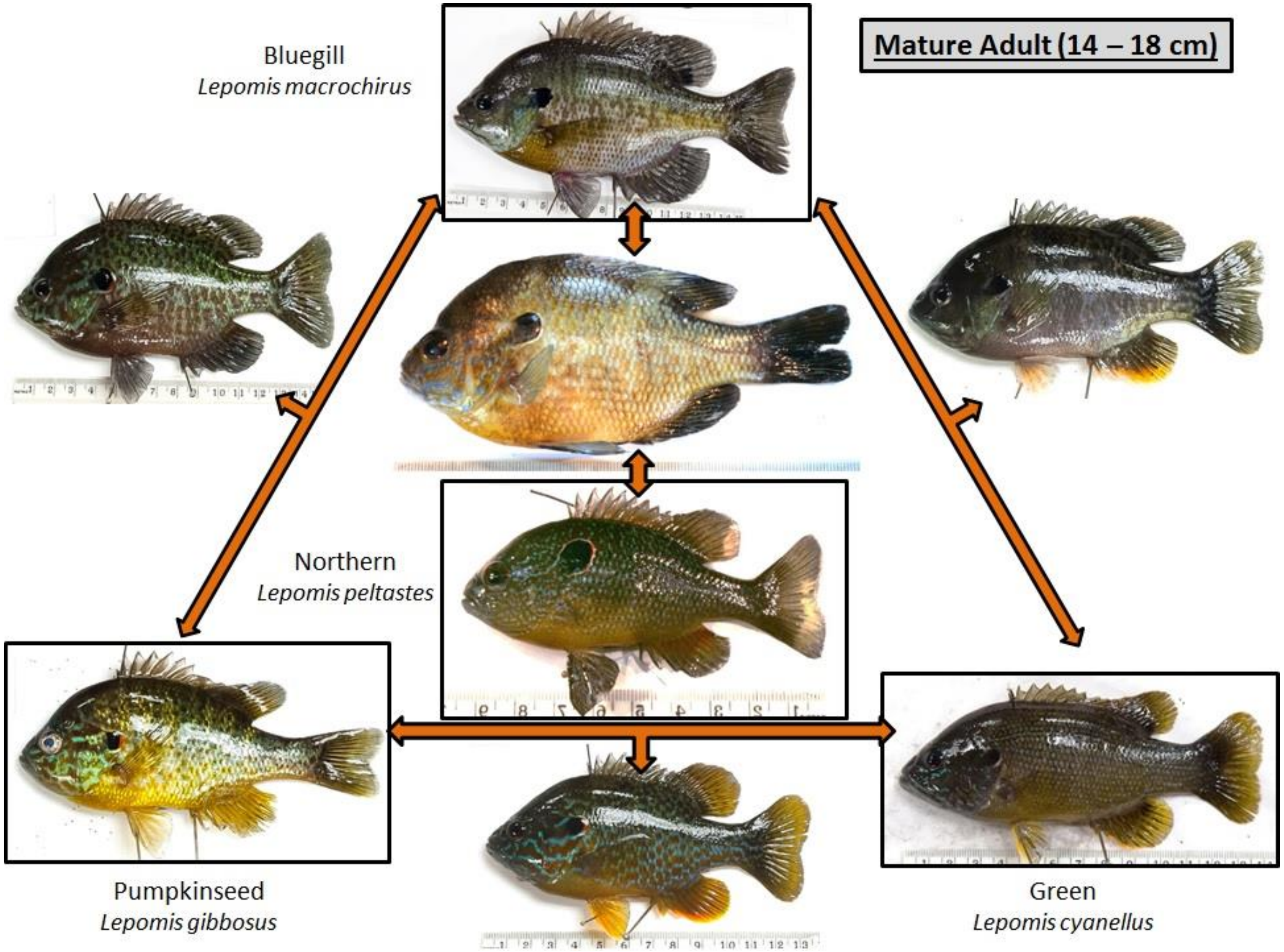

Figure 8. Photographs of full-sized pure bred and hybrid sunfish specimens collected in lower Tonawanda Creek and a NYSDEC Northern sunfish hatchery pond in 2013 and 2014. Photographs by Kelly Owens.

Appendices

Appendix A. List of all 57 species from 14 families captured in 2005 (Wells 2009), 2013, and 2014 in four watersheds in western New York: Tonawanda Creek, Erie Canal, Ellicott Creek, and Cayuga Creek. Species marked with an asterisk are not native to the study area.

Family	**Scientific Name**	**Common Name**	**Abbr.**
Lepisosteidae			
	Lepisosteus osseus	longnose gar	LEOS
Clupeidae			
	Dorosoma cepedianum	gizzard shad	DOCE
Umbridae			
	Umbra limi	central mudminnow	UMLI
Esocidae			
	Esox americanus vermiculatus	grass pickerel	ESAM
	Esox lucius	northern pike	ESLU
	Esox masquinongy	muskellunge	ESMA
	Esox niger	chain pickerel	ESNI
Cyprinidae			
	Campostoma anomalum	central stoneroller	CAAN
	*Carassius auratus**	goldfish*	CAAU
	*Cyprinus carpio**	common carp*	CYCA
	Nocomis biguttatus	hornyhead chub	NOBI
	Nocomis micropogon	river chub	NOMP

Family	Scientific Name	Common Name	Abbr.
	Notemigonus crysoleucas	golden shiner	NOCR
	Notropis atherinoides	emerald shiner	NOAT
	Luxilus chrysocephalus	striped shiner	LUCH
	Luxilus cornutus	common shiner	LUCO
	Notropis hudsonius	spottail shiner	NOHU
	Cyprinella spiloptera	spotfin shiner	CYSP
	Lythrurus umbratilis	redfin shiner	LYUM
	Notropis volucellus	mimic shiner	NOVO
	Pimephales notatus	bluntnose minnow	PINO
	Pimephales promelas	fathead minnow	PIPR
	*Scardinius erythrophthalmus**	rudd*	SCER
	Semotilus atromaculatus	creek chub	SEAT
Catostomidae			
	Catostomus commersonii	white sucker	CACO
	Hypentelium nigricans	northern hog sucker	HYNI
	Moxostoma anisurum	silver redhorse	MOAN
	Moxostoma erythrurum	golden redhorse	MOER
	Moxostoma macrolepidotum	shorthead redhorse	MOMA
	Moxostoma valenciennesi	greater redhorse	MOVA
	Moxostoma spp.	unknown redhorse	MOXO
Ictaluridae			
	Ameiurus nebulosus	brown bullhead	AMNE
	Ictalurus punctatus	channel catfish	ICPU
	Noturus flavus	stonecat	NOFL
	Noturus gyrinus	tadpole madtom	NOGY

Family	**Scientific Name**	**Common Name**	**Abbr.**
	Noturus miurus.	brindled madtom	NOMU
Fundulidae			
	Fundulus diaphanus	banded killifish	FUDI
Atherinopsidae			
	Labidesthes sicculus	brook silverside	LASI
Moronidae			
	*Morone americana**	white perch*	MOAM
Centrarchidae			
	Ambloplites rupestris	rock bass	AMRU
	*Lepomis cyanellus**	green sunfish*	LECY
	Lepomis gibbosus	pumpkinseed	LEGI
	Lepomis macrochirus	bluegill	LEMA
	Lepomis peltastes	northern sunfish	LEPE
	Micropterus dolomieu	smallmouth bass	MIDO
	Micropterus salmoides	largemouth bass	MISA
	Pomoxis annularis	white crappie	POAN
	Pomoxis nigromaculatus	black crappie	PONI
Percidae			
	Etheostoma blennioides	greenside darter	ETBL
	Etheostoma caeruleum	rainbow darter	ETCA
	Etheostoma flabellare	fantail darter	ETFL
	Etheostoma nigrum	johnny darter	ETNI
	Perca flavescens	yellow perch	PEFL
	Percina caprodes	logperch	PECA
	Percina maculata	blackside darter	PEMA

Family	**Scientific Name**	**Common Name**	**Abbr.**
	Sander vitreus	walleye	SAVI
Sciaenidae	*Aplodinotus grunniens*	freshwater drum	APGR
Gobiidae	*Neogobius melanostomus**	round goby*	NEME

Appendix B. Raw capture data of electroshocking runs in western New York in 2005 (Wells 2009), 2013, and 2014. Site codes correspond to Table 2 and species abbreviations are explained in Appendix A. The history of *L. peltastes* at each site is categorized (Catg) as being historic (H), recently detected (RD) in 2005 by Wells (2009), stocked (S) by NYSDEC, or none (-). Whether a run was included in the data analysis (DA) portion of this study is indicated with a Y or N. Effort is in seconds of power-on electroshock time. Gears used included electrofishing boat (EFB), backpack shocking unit (BPS), and raft- and canoe-mounted backpack shocking unit (Raft/BPS and Canoe/BPS).

Date	6/23/05	**Catg**	H/RD	**Lat**	N43.08705	**Effort**	900
Site	1D	**DA?**	Y	**Long**	W078.7072	**Gear**	EFB
UMLI	1	PIPR	3	AMRU	6	MISA	1
CYCA	6	MOAN	1	LECY	34	PONI	6
NOCR	1	MOER	11	LEGI	15	ETNI	7
NOAT	10	MOMA	1	LEMA	1	PEFL	1
CYSP	42	MOVA	1	LEPE	7	PECA	1
NOVO	20	AMNE	1	MIDO	1	PEMA	2
PINO	24						

Date	6/23/05	**Catg**	H/RD	**Lat**	N43.08675	**Effort**	900
Site	1E	**DA?**	Y	**Long**	W078.69927	**Gear**	EFB
ESLU	1	PIPR	5	NOMU	2	MISA	2
CYCA	2	SEAT	1	AMRU	2	PONI	3
NOAT	6	HYNI	2	LECY	3	ETCA	1
LUCH	3	MOER	23	LEGI	1	ETNI	2
CYSP	43	MOMA	2	LEPE	1	PECA	5
NOVO	70	MOVA	1	MIDO	1	SAVI	3
PINO	13	ICPU	1				

Date	6/27/05	**Catg**	H/RD	**Lat**	N43.08392	**Effort**	900
Site	1A	**DA?**	Y	**Long**	W078.7339	**Gear**	EFB
ESLU	3	PINO	15	AMRU	8	PONI	1
CYCA	5	MOER	1	LECY	7	ETNI	1
NOAT	1	MOMA	2	LEGI	4	PEFL	12
LUCH	1	AMNE	1	MIDO	1	NEME	1
CYSP	12	NOGY	1	MISA	3		

Date	6/27/05	**Catg**	H/RD	**Lat**	N43.08483	**Effort**	900
Site	1A	**DA?**	Y	**Long**	W078.7312	**Gear**	EFB
UMLI	1	PINO	16	LEPE	1	PEFL	1
ESLU	1	MOMA	1	MISA	3	PEMA	1
CYCA	26	AMNE	1	POAN	4	APGR	1
CYSP	1	LECY	2	ETNI	1	NEME	2
NOVO	2	LEMA	2				

Date	6/27/05	**Catg**	RD	**Lat**	N43.08558	**Effort**	900
Site	1B	**DA?**	Y	**Long**	W078.7246	**Gear**	EFB
CYCA	5	MOER	5	LEPE	1	ETBL	1
CYSP	3	NOMU	2	MIDO	5	PECA	1
NOVO	2	AMRU	4	MISA	3	APGR	1
PINO	6	LEMA	2	POAN	1		

Date	6/27/05	**Catg**	RD	**Lat**	N43.06914	**Effort**	900
Site	2D	**DA?**	Y	**Long**	W078.7464	**Gear**	EFB
ESLU	4	PIPR	12	MOVA	1	LEPE	1
CYCA	8	SCER	2	AMNE	10	MISA	12
NOCR	24	CACO	1	LECY	3	POAN	1
CYSP	1	MOER	3	LEGI	31	PONI	1
NOVO	2	MOMA	1	LEMA	23	PEFL	3

Date	7/8/05	**Catg**	RD	**Lat**	N43.08407	**Effort**	900
Site	1B	**DA?**	Y	**Long**	W078.722	**Gear**	EFB
CYCA	2	MOAN	1	LEGI	6	MISA	1
NOAT	1	MOMA	2	LEMA	1	ETNI	1
CYSP	47	NOMU	1	LEPE	4	PECA	1
NOVO	24	AMRU	6	MIDO	6	PEMA	4
PINO	20	LECY	2				

Date	7/8/05	**Catg**	RD	**Lat**	N43.08101	**Effort**	900
Site	1C	**DA?**	Y	**Long**	W078.7185	**Gear**	EFB
CYCA	3	PINO	20	AMRU	1	MIDO	3
NOAT	2	PIPR	2	LEGI	4	MISA	1
CYSP	1	CACO	1	LEMA	9	PEMA	1
NOVO	9	MOMA	1	LEPE	2	SAVI	2

Date	7/19/05	**Catg**	H/RD	**Lat**	N43.08537	**Effort**	900
Site	1A	**DA?**	Y	**Long**	W078.7292	**Gear**	EFB
UMLI	1	PINO	4	LEGI	4	MISA	15
CYCA	6	CACO	1	LEMA	14	ETNI	5
CYSP	2	AMRU	7	LEPE	2	PECA	1
NOVO	6	LECY	10	MIDO	9		

Date	7/19/05	**Catg**	RD	**Lat**	N43.0826	**Effort**	900
Site	1C	**DA?**	Y	**Long**	W078.7093	**Gear**	EFB
UMLI	1	NOVO	4	LECY	11	MIDO	4
ESLU	1	PINO	5	LEGI	7	MISA	3
CYCA	7	MOER	6	LEMA	7	ETNI	1
CYSP	6	MOMA	1	LEPE	2	PEMA	2

Date	7/19/05	**Catg**	H/RD	**Lat**	N43.08697	**Effort**	900
Site	1D	**DA?**	Y	**Long**	W078.7052	**Gear**	EFB
UMLI	1	CACO	4	LECY	4	MIDO	3
ESLU	1	MOAN	2	LEGI	8	MISA	3

Date	7/19/05	**Catg**	H/RD	**Lat**	N43.08669	**Effort**	900
Site	1E	**DA?**	Y	**Long**	W078.7013	**Gear**	EFB
ESLU	1	MOAN	5	LECY	7	MISA	1
CYCA	5	MOER	10	LEGI	7	PONI	1

NOVO	9	MOER	1	LEMA	7	ETNI	1
PINO	12	NOMU	2	LEPE	1	PEMA	1

Date	05/01/13	**Catg**	RD	**Lat**	N43.08627	**Effort**	478
Site	1B	**DA?**	N	**Long**	W078.72774	**Gear**	EFB
DOCE	6	AMRU	2	LEMA	1	MISA	1
NOAT	1000	LEGI	1				

Date	05/01/13	**Catg**	H/RD	**Lat**	N43.08679	**Effort**	600
Site	1D	**DA?**	N	**Long**	W07870750	**Gear**	EFB
DOCE	50	MOAN	1	MOXO	1	ETNI	1
NOAT	50	MOER	1				

Date	05/01/13	**Catg**	H/RD	**Lat**	N43.08679	**Effort**	600
Site	1E	**DA?**	N	**Long**	W078.70067	**Gear**	EFB
DOCE	5	PINO	10	MOXO	20	LECY	4
NOAT	1000	MOER	1	LASI	4	MISA	3
CYSP	10	MOMA	2				

Date	05/15/13	**Catg**	RD	**Lat**	N43.08382	**Effort**	910
Site	1B	**DA?**	N	**Long**	W078.72191	**Gear**	EFB
DOCE	6	MOMA	3	LECY	1	LEMA	6
NOAT	400	AMRU	1	LEGI	1	POAN	1
PINO	1						

CYSP	4	MOVA	1	LEPE	1	ETNI	6
NOVO	3	AMNE	1	MIDO	2	PECA	5
PINO	9	AMRU	2				

Date	05/01/13	**Catg**	H/RD	**Lat**	N43.08679	**Effort**	383
Site	1D	**DA?**	N	**Long**	W078.70750	**Gear**	EFB
DOCE	30	MOAN	1	AMRU	1	LEMA	5
NOAT	50	ICPU	1	LECY	5	MISA	1

Date	05/01/13	**Catg**	H/RD	**Lat**	N43.08677	**Effort**	600
Site	1E	**DA?**	N	**Long**	W078.70065	**Gear**	EFB
DOCE	100	MOER	1	MIDO	1	SAVI	2
NOAT	500	MOXO	8	MISA	3	NEME	1
MOAN	1	LEMA	4				

Date	05/15/13	**Catg**	H/RD	**Lat**	N43.08538	**Effort**	920
Site	1A	**DA?**	N	**Long**	W078.72974	**Gear**	EFB
DOCE	5	NOCR	2	MOMA	2	LEMA	9
ESLU	1	NOAT	1000	MOVA	1	MIDO	1
ESMA	1	MOAN	1	AMRU	3	MISA	4
CYCA	17	MOER	1				

Date	05/15/13	**Catg**	RD	**Lat**	N43.08120	**Effort**	900
Site	1C	**DA?**	N	**Long**	W078.71962	**Gear**	EFB
DOCE	4	PINO	20	AMRU	4	LEMA	10
ESLU	1	MOMA	1	LECY	4	MISA	2
CYCA	1	LASI	1	LEGI	5	NEME	1
NOAT	400						

Date	05/15/13	**Catg**	H/RD	**Lat**	N43.08679	**Effort**	1040
Site	1D	**DA?**	N	**Long**	W078.70750	**Gear**	EFB
DOCE	2	PINO	3	LECY	23	LEMA	5
NOAT	300						

Date	05/15/13	**Catg**	H/RD	**Lat**	N43.08677	**Effort**	1125
Site	1E	**DA?**	N	**Long**	W078.70065	**Gear**	EFB
DOCE	8	HYNI	1	AMRU	2	MIDO	1
NOAT	500	MOMA	2	LECY	5	PONI	2
CYSP	1	AMNE	1	LEMA	5		

Date	05/30/13	**Catg**	RD	**Lat**	N43.08266	**Effort**	900
Site	1C	**DA?**	N	**Long**	W078.71283	**Gear**	EFB
DOCE	1	CYSP	14	MOMA	1	LEMA	9
CYCA	1	PINO	4	AMRU	7	MIDO	2
NOAT	100	MOAN	3	LECY	3	SAVI	1
NOHU	10	MOER	14	LEGI	1		

Date	05/30/13	**Catg**	H/RD	**Lat**	N43.08679	**Effort**	801
Site	1D	**DA?**	N	**Long**	W078.70750	**Gear**	EFB
DOCE	8	PINO	1	LASI	1	LEMA	6
NOAT	150	HYNI	1	LECY	7	MISA	1
NOHU	26	MOER	4	LEGI	3	SAVI	2
CYSP	4						

Date	05/30/13	**Catg**	H/RD	**Lat**	N43.08679	**Effort**	918
Site	1D	**DA?**	N	**Long**	W078.70750	**Gear**	EFB
DOCE	1	PINO	7	MOMA	1	LEMA	12
CYCA	1	SCER	1	LASI	5	MIDO	2
NOAT	200	CACO	1	AMRU	3	PECA	2
NOHU	3	MOAN	1	LECY	6	SAVI	1
CYSP	2	MOER	12	LEGI	3		

Date	05/30/13	**Catg**	H/RD	**Lat**	N43.08667	**Effort**	907
Site	1E	**DA?**	N	**Long**	W078.70071	**Gear**	EFB
DOCE	9	MOMA	1	ICPU	1	LEMA	1
NOAT	100	MOXO	1	LECY	1	MIDO	1
MOER	4	AMNE	1				

Date	05/30/13	**Catg**	H/RD	**Lat**	N43.08667	**Effort**	450
Site	1E	**DA?**	N	**Long**	W078.70071	**Gear**	EFB
CYCA	1	MOAN	1	LECY	1	PEFL	1
NOAT	100	MOER	3	MIDO	2	PECA	1
PINO	2						

Date	05/30/13	**Catg**	H	**Lat**	N43.08628	**Effort**	816
Site	1F	**DA?**	N	**Long**	W078.69690	**Gear**	EFB
NOAT	200	MOER	6	LASI	1	LEGI	1
NOHU	11	MOMA	4	AMRU	8	LEMA	3
CYSP	9	MOXO	1	LECY	14	MIDO	3
PINO	9	FUDI	1				

Date	06/05/13	**Catg**	H/RD	**Lat**	N43.08366	**Effort**	914
Site	1A	**DA?**	Y	**Long**	W078.73465	**Gear**	EFB
DOCE	7	PIPR	50	MOAM	1	MIDO	1
NOCR	1	MOER	1	AMRU	32	MISA	4
NOAT	100	MOVA	1	LECY	66	ETNI	1
NOHU	17	AMNE	1	LEGI	3	PEFL	1
CYSP	7	LASI	1	LEMA	9	NEME	5
PINO	11						

Date	06/05/13	**Catg**	H/RD	**Lat**	N43.08679	**Effort**	907
Site	1D	**DA?**	Y	**Long**	W078.70750	**Gear**	EFB
UMLI	1	CYSP	3	AMRU	3	MIDO	1
ESLU	1	PIPR	1	LECY	81	MISA	2
ESNI	1	MOER	1	LEGI	11	PEFL	3
NOAT	100	MOMA	1	LEMA	5	PEMA	3
NOHU	1	LASI	4				

Date	06/05/13	**Catg**	H/RD	**Lat**	N43.08667	**Effort**	871
Site	1E	**DA?**	Y	**Long**	W078.70071	**Gear**	EFB
NOCR	1	PINO	7	FUDI	1	LEGI	3
NOAT	200	PIPR	9	AMRU	5	LEMA	10
NOHU	7	MOER	3	LECY	47	MISA	1
CYSP	9	MOXO	1				

Date	06/05/13	**Catg**	H/RD	**Lat**	N43.08667	**Effort**	912
Site	1E	**DA?**	Y	**Long**	W078.70071	**Gear**	EFB
DOCE	3	CYSP	8	NOMU	1	LEGI	1
ESLU	1	PINO	11	FUDI	1	LEMA	10
ESNI	1	PIPR	30	LASI	2	MISA	1
CYCA	2	MOER	2	AMRU	10	PONI	1
NOAT	100	MOXO	2	LECY	66	PECA	1
NOHU	3						

Date	06/05/13	**Catg**	RD	**Lat**	N43.06953	**Effort**	900
Site	2D	**DA?**	Y	**Long**	W078.74812	**Gear**	EFB
DOCE	2	PIPR	7	AMRU	3	LEMA	55
CYCA	2	MOER	3	LECY	2	MISA	12
NOAT	200	LASI	7	LEGI	26	PONI	7
PINO	13						

Date	06/13/13	**Catg**	RD	**Lat**	N43.08418	**Effort**	906
Site	1B	**DA?**	Y	**Long**	W078.72298	**Gear**	EFB
DOCE	2	PINO	5	LECY	20	PONI	1
CYCA	1	MOER	1	LEGI	8	PEFL	1
NOAT	20	LASI	1	LEMA	16	SAVI	1
CYSP	1	AMRU	4				

Date	06/13/13	**Catg**	RD	**Lat**	N43.08131	**Effort**	976
Site	1C	**DA?**	Y	**Long**	W078.72023	**Gear**	EFB
NOHU	1	PINO	5	AMRU	12	LEGI	1

Date	06/13/13	**Catg**	H/RD	**Lat**	N43.08679	**Effort**	945
Site	1D	**DA?**	Y	**Long**	W078.70750	**Gear**	EFB
NOAT	25	MOAN	2	AMRU	6	POAN	1

CYSP	4	MOER	4	LECY	13	LEMA	13
LYUM	1						

Date	06/13/13	**Catg**	H/RD	**Lat**	N43.08679	**Effort**	917
Site	1D	**DA?**	Y	**Long**	W078.70750	**Gear**	EFB
DOCE	3	CYSP	2	MOER	1	LECY	49
ESAM	3	PINO	5	LASI	1	LEMA	13
NOHU	11	MOAN	1	AMRU	4	POAN	2

Date	06/13/13	**Catg**	H/RD	**Lat**	N43.08677	**Effort**	926
Site	1E	**DA?**	Y	**Long**	W078.70065	**Gear**	EFB
NOHU	4	PINO	6	AMRU	6	LEMA	4
CYSP	3	MOER	1	LECY	32		

Date	06/20/13	**Catg**	RD	**Lat**	N43.08567	**Effort**	913
Site	1C	**DA?**	Y	**Long**	W078.70902	**Gear**	EFB
DOCE	2	PINO	8	AMRU	4	MISA	1
ESLU	1	MOER	7	LECY	70	PONI	1
NOAT	100	MOXO	2	LEMA	4	SAVI	1
NOHU	4	FUDI	1	MIDO	1	NEME	3
CYSP	1	LASI	1				

Date	06/20/13	**Catg**	H/RD	**Lat**	N43.08677	**Effort**	716
Site	1E	**DA?**	Y	**Long**	W078.70065	**Gear**	EFB
ESLU	1	PINO	16	AMRU	5	POAN	3

NOHU	3	MOER	1	LECY	36	PONI	1
CYSP	1	LASI	7	LEMA	7	PEFL	3
PINO	8	MOAM	1				

Date	06/13/13	**Catg**	H/RD	**Lat**	N43.08677	**Effort**	875
Site	1E	**DA?**	Y	**Long**	W078.70065	**Gear**	EFB
DOCE	7	PINO	10	AMRU	3	MIDO	1
UMLI	1	MOER	7	LECY	26	POAN	3
NOHU	4	MOXO	7	LEGI	2	NEME	1
CYSP	1	FUDI	1	LEMA	2		

Date	06/20/13	**Catg**	H/RD	**Lat**	N43.08507	**Effort**	917
Site	1A	**DA?**	Y	**Long**	W078.73016	**Gear**	EFB
DOCE	2	PINO	15	LASI	3	LEMA	25
NOCR	1	MOER	1	AMRU	19	MIDO	2
NOHU	6	MOXO	2	LECY	24	PONI	1
CYSP	1	AMNE	2	LEGI	5	NEME	2

Date	06/20/13	**Catg**	H/RD	**Lat**	N43.08679	**Effort**	1079
Site	1D	**DA?**	Y	**Long**	W078.70750	**Gear**	EFB
UMLI	1	PINO	11	FUDI	2	LEMA	34
ESLU	7	PIPR	1	AMRU	2	MISA	12
NOAT	100	MOER	3	LECY	140	PONI	7
NOHU	5	MOXO	2	LEGI	4		

Date	06/20/13	**Catg**	H/RD	**Lat**	N43.08677	**Effort**	1071
Site	1E	**DA?**	Y	**Long**	W078.70065	**Gear**	EFB
NOAT	50	PINO	5	LASI	1	LEGI	7

NOAT	75	MOXO	5	LECY	87	PONI	3
NOHU	3	FUDI	1	LEGI	3	SAVI	3
CYSP	4	LASI	3	LEMA	4		

Date	06/27/13	**Catg**	RD	**Lat**	N43.08412	**Effort**	928
Site	1C	**DA?**	Y	**Long**	W078.70806	**Gear**	EFB
DOCE	4	PINO	1	LECY	28	MISA	1
NOAT	20	MOAN	1	LEGI	4	PONI	2
NOHU	3	MOXO	4	LEMA	15	SAVI	3
CYSP	1	AMRU	2	MIDO	1	NEME	1

Date	06/27/13	**Catg**	H/RD	**Lat**	N43.08679	**Effort**	908
Site	1D	**DA?**	Y	**Long**	W078.70750	**Gear**	EFB
DOCE	1	CYSP	4	AMRU	3	MISA	3
ESLU	7	PINO	5	LECY	158	PEMA	2
NOAT	3	MOXO	4	LEGI	2	NEME	1
NOHU	5	ICPU	1	LEMA	9		

Date	06/27/13	**Catg**	H/RD	**Lat**	N43.08677	**Effort**	908
Site	1E	**DA?**	Y	**Long**	W078.70065	**Gear**	EFB
DOCE	4	CYSP	9	LASI	1	MISA	4
ESLU	1	PINO	57	AMRU	9	POAN	1
CYCA	3	MOAN	1	LECY	75	PONI	1
NOAT	1	MOXO	18	LEGI	2	PEMA	1
NOHU	7	FUDI	2	LEMA	27	SAVI	2

NOHU	5	MOXO	2	AMRU	2	LEMA	10
CYSP	8	FUDI	5	LECY	76	SAVI	2

Date	06/27/13	**Catg**	RD	**Lat**	N43.08208	**Effort**	990
Site	1C	**DA?**	Y	**Long**	W078.73016	**Gear**	EFB
ESLU	5	PINO	11	LEGI	17	PONI	1
CYCA	2	MOXO	2	LEMA	24	PEFL	1
NOAT	6	AMRU	8	MIDO	1	PEMA	2
NOHU	9	LECY	47	MISA	4	NEME	2
CYSP	6						

Date	06/27/13	**Catg**	H/RD	**Lat**	N43.08677	**Effort**	900
Site	1E	**DA?**	Y	**Long**	W078.70065	**Gear**	EFB
DOCE	2	NOHU	7	MOER	1	LECY	70
ESLU	3	CYSP	5	MOXO	1	LEGI	1
CYCA	4	PINO	9	LASI	1	LEMA	12
NOAT	1	MOAN	1	AMRU	12	MISA	7

Date	07/10/13	**Catg**	RD	**Lat**	N43.08627	**Effort**	930
Site	1B	**DA?**	Y	**Long**	W078.72774	**Gear**	EFB
DOCE	3	CYSP	5	AMRU	34	MIDO	3
ESLU	1	PINO	63	LECY	48	MISA	5
CYCA	1	MOMA	1	LEGI	4	PONI	1
NOAT	40	MOXO	2	LEMA	20	NEME	2
NOHU	4	LASI	5				

Date	07/10/13	**Catg**	H/RD	**Lat**	N43.08679	**Effort**	940
Site	1D	**DA?**	Y	**Long**	W078.70750	**Gear**	EFB
ESLU	10	MOER	1	LECY	117	MISA	2
NOAT	20	MOXO	6	LEGI	11	POAN	1
CYSP	2	FUDI	1	LEMA	24	PEFL	1
MOAN	1	AMRU	4	MIDO	3		

Date	07/10/13	**Catg**	H/RD	**Lat**	N43.08677	**Effort**	938
Site	1E	**DA?**	Y	**Long**	W078.70065	**Gear**	EFB
DOCE	2	NOHU	1	MOXO	3	LECY	163
ESLU	3	CYSP	32	AMNE	1	LEGI	10
CYCA	2	LYUM	1	LASI	1	LEMA	10
NOAT	20	PINO	72	AMRU	4	MISA	7

Date	07/10/13	**Catg**	H/RD	**Lat**	N43.08677	**Effort**	910
Site	1E	**DA?**	Y	**Long**	W078.70065	**Gear**	EFB
DOCE	15	CYSP	15	FUDI	1	LEGI	4
ESLU	13	PINO	21	LASI	1	LEMA	3
CAAU	1	MOXO	3	AMRU	4	MIDO	1
CYCA	6	ICPU	1	LECY	106	NEME	5
NOHU	1						

Date	07/10/13	**Catg**	RD	**Lat**	N43.06975	**Effort**	917
Site	2D	**DA?**	Y	**Long**	W078.74543	**Gear**	EFB
DOCE	3	MOXO	2	AMRU	6	MISA	15
NOCR	2	AMNE	1	LECY	22	POAN	1
NOAT	38	FUDI	1	LEGI	32	PEFL	2
CYSP	2	LASI	2	LEMA	158	NEME	1
PINO	60						

Date	07/18/13	**Catg**	RD	**Lat**	N43.08167	**Effort**	909
Site	1C	**DA?**	Y	**Long**	W078.71695	**Gear**	EFB
DOCE	3	CYSP	7	AMRU	2	MIDO	4
ESLU	3	PINO	8	LECY	30	MISA	3
NOAT	4	MOXO	1	LEGI	2	PEMA	1
NOHU	1	LASI	2	LEMA	21		

Date	07/18/13	**Catg**	RD	**Lat**	N43.08507	**Effort**	938
Site	1C	**DA?**	Y	**Long**	W078.70801	**Gear**	EFB
ESLU	3	CYSP	2	AMRU	1	LEMA	20
CYCA	1	PINO	16	LECY	52	MIDO	2
NOAT	19	MOXO	3	LEGI	1	SAVI	1

Date	07/18/13	**Catg**	H/RD	**Lat**	N43.08677	**Effort**	888
Site	1E	**DA?**	Y	**Long**	W078.70065	**Gear**	EFB
DOCE	4	PINO	39	LEGI	2	PONI	1
ESLU	3	MOXO	3	LEMA	22	PEFL	1
NOAT	9	AMRU	7	MIDO	1	PECA	1

Date	07/18/13	**Catg**	RD	**Lat**	N43.08285	**Effort**	999
Site	1C	**DA?**	Y	**Long**	W078.71298	**Gear**	EFB
DOCE	3	NOAT	13	PINO	24	LECY	65
ESLU	5	MOXO	3	MOXO	1	LEGI	9
CYCA	2	LYUM	1	AMRU	3	LEMA	32

NOHU	3	LECY	104	MISA	4	PEMA	1
CYSP	2						

Date	07/18/13	**Catg**	-	**Lat**	N43.06097	**Effort**	1017
Site	2C	**DA?**	N	**Long**	W078.73974	**Gear**	EFB
DOCE	22	NOHU	1	AMRU	2	LEMA	27
ESLU	1	PINO	9	LECY	18	MISA	9
CYCA	2	MOXO	3	LEGI	14		

Date	07/25/13	**Catg**	RD	**Lat**	N43.08418	**Effort**	899
Site	1B	**DA?**	Y	**Long**	W078.72245	**Gear**	EFB
ESLU	6	PINO	12	LECY	41	MIDO	1
NOAT	10	MOXO	2	LEGI	5	MISA	3
CYSP	8	AMRU	4	LEMA	11		

Date	07/25/13	**Catg**	H/RD	**Lat**	N43.08679	**Effort**	954
Site	1D	**DA?**	Y	**Long**	W078.70750	**Gear**	EFB
UMLI	3	NOAT	2	MOXO	3	LEMA	2
ESLU	6	NOHU	6	AMRU	3	MIDO	1
ESNI	1	CYSP	6	LECY	211	MISA	1
CAAU	6	PINO	15	LEGI	5		

Date	07/25/13	**Catg**	S	**Lat**	N43.05797	**Effort**	1001
Site	2A	**DA?**	N	**Long**	W078.80581	**Gear**	EFB
DOCE	16	CYSP	1	MOAN	1	LEGI	56

MIDO	1	MISA	1	PEMA	1		

Date	07/18/13	**Catg**	-	**Lat**	N43.05945	**Effort**	722
Site	2C	**DA?**	N	**Long**	W078.75494	**Gear**	EFB
DOCE	14	NOHU	2	LECY	42	MIDO	5
ESLU	3	PINO	95	LEGI	50	MISA	4
CYCA	2	LASI	1	LEMA	34	NEME	3
NOCR	4	AMRU	5				

Date	07/25/13	**Catg**	H/RD	**Lat**	N43.08469	**Effort**	929
Site	1A	**DA?**	Y	**Long**	W078.73151	**Gear**	EFB
DOCE	7	CYSP	9	LECY	87	MISA	10
ESLU	4	PINO	38	LEGI	18	ETNI	1
CYCA	1	MOXO	1	LEMA	25	NEME	1
NOAT	2	AMRU	12	MIDO	1		

Date	07/25/13	**Catg**	RD	**Lat**	N43.08108	**Effort**	907
Site	1C	**DA?**	Y	**Long**	W078.71954	**Gear**	EFB
DOCE	5	NOHU	3	AMRU	3	MISA	3
ESLU	10	CYSP	14	LECY	101	PONI	1
CYCA	2	PINO	27	LEGI	19	NEME	2
NOAT	2	MOXO	2	LEMA	30		

Date	07/25/13	**Catg**	H/RD	**Lat**	N43.08677	**Effort**	917
Site	1E	**DA?**	Y	**Long**	W078.70065	**Gear**	EFB
DOCE	1	PINO	43	LECY	111	MISA	3

ESLU	2	PINO	205	MOXO	10	LEMA	86
CYCA	2	SCER	2	AMNE	1	MISA	22
NOCR	8	CACO	2	AMRU	15	POAN	3
Date	08/12/13	**Catg**	H/RD	**Lat**	N43.08563	**Effort**	767
Site	1A	**DA?**	Y	**Long**	W078.729167	**Gear**	EFB
DOCE	4	CYSP	4	LECY	93	MISA	1
ESLU	2	PINO	6	LEGI	8	ETNI	1
NOCR	2	MOXO	2	LEMA	17	PEMA	1
NOHU	8	AMRU	9	MIDO	1		
Date	08/12/13	**Catg**	RD	**Lat**	N43.08108	**Effort**	923
Site	1C	**DA?**	Y	**Long**	W078.71954	**Gear**	EFB
DOCE	6	NOAT	22	MOXO	2	LEGI	20
ESLU	4	NOHU	56	AMRU	5	LEMA	42
ESNI	1	CYSP	4	LECY	134	MISA	2
CYCA	1	CACO	1				
Date	08/12/13	**Catg**	H/RD	**Lat**	N43.08677	**Effort**	877
Site	1E	**DA?**	Y	**Long**	W078.70065	**Gear**	EFB
DOCE	4	CYSP	2	AMRU	3	LEMA	20
ESLU	8	PINO	28	LECY	94	MISA	5
NOAT	3	MOXO	3	LEGI	6	NEME	2
NOHU	7	FUDI	1				
Date	08/12/13	**Catg**	-	**Lat**	N43.06097	**Effort**	1292
Site	2C	**DA?**	N	**Long**	W078.73974	**Gear**	EFB
DOCE	19	NOAT	1	MOAN	2	LECY	31
ESAM	1	CYSP	3	MOER	6	LEGI	15

ESLU	1	MOXO	1	LEGI	6	POAN	1
ESNI	2	AMRU	3	LEMA	19	NEME	1
CYSP	6						
Date	08/12/13	**Catg**	H/RD	**Lat**	N43.08469	**Effort**	900
Site	1A	**DA?**	Y	**Long**	W078.73151	**Gear**	EFB
DOCE	9	NOHU	15	AMNE	1	LEMA	18
ESLU	5	CYSP	5	AMRU	7	MISA	11
CYCA	1	PINO	6	LECY	67	SAVI	1
NOAT	1	MOXO	6	LEGI	11	NEME	1
Date	08/12/13	**Catg**	RD	**Lat**	N43.08418	**Effort**	941
Site	1B	**DA?**	N	**Long**	W078.72245	**Gear**	EFB
DOCE	3	NOAT	10	MOXO	4	LEMA	28
ESLU	4	NOHU	5	AMRU	2	MISA	6
CYCA	3	CYSP	2	LECY	69	PECA	1
NOCR	3	PINO	6	LEGI	7		
Date	08/12/13	**Catg**	H/RD	**Lat**	N43.08679	**Effort**	944
Site	1D	**DA?**	Y	**Long**	W078.70750	**Gear**	EFB
DOCE	2	NOAT	6	MOXO	1	LEGI	7
UMLI	3	NOHU	9	LASI	1	LEMA	11
ESAM	1	CYSP	2	AMRU	4	MISA	5
ESLU	7	PINO	12	LECY	78		
Date	08/22/13	**Catg**	H/RD	**Lat**	N43.08469	**Effort**	911
Site	1A	**DA?**	N	**Long**	W078.73151	**Gear**	EFB
DOCE	8	NOCR	9	AMRU	10	MIDO	4
ESAM	1	PINO	57	LECY	27	MISA	11

ESLU	4	PINO	8	MOMA	1	LEMA	19
CYCA	3	CACO	2	AMRU	1	MISA	2
NOCR	1						

Date	08/22/13	**Catg**	RD	**Lat**	N43.08108	**Effort**	906
Site	1C	**DA?**	N	**Long**	W078.71954	**Gear**	EFB
DOCE	6	NOHU	3	MOXO	5	LEGI	6
CYCA	1	CYSP	6	AMRU	5	LEMA	16
NOAT	9	PINO	16	LECY	42	MISA	7

Date	08/22/13	**Catg**	H/RD	**Lat**	N43.08677	**Effort**	913
Site	1E	**DA?**	N	**Long**	W078.70065	**Gear**	EFB
DOCE	15	NOHU	2	LECY	70	POAN	1
ESLU	2	PINO	5	LEGI	8	PEFL	1
CYCA	4	MOXO	4	LEMA	15	SAVI	1
NOCR	1	ICPU	1	MISA	14	NEME	1
NOAT	5	AMRU	3				

Date	08/22/13	**Catg**	-	**Lat**	N43.08772	**Effort**	909
Site	2E	**DA?**	N	**Long**	W078.73273	**Gear**	EFB
DOCE	10	NOAT	14	FUDI	1	MIDO	3
ESAM	1	CYSP	1	AMRU	9	MISA	10
ESLU	2	PINO	49	LECY	11	POAN	1
CYCA	8	MOXO	2	LEGI	3	PEMA	5
NOCR	72	AMNE	1	LEMA	17		

ESLU	4	CACO	1	LEGI	13	PEMA	1
CYCA	3	MOXO	5	LEMA	21		

Date	08/22/13	**Catg**	RD	**Lat**	N43.08418	**Effort**	900
Site	1B	**DA?**	N	**Long**	W078.72245	**Gear**	EFB
DOCE	6	CYSP	6	LECY	32	ETNI	1
ESLU	2	PINO	34	LEGI	3	PECA	1
CYCA	2	MOXO	5	LEMA	16	SAVI	1
NOAT	13	AMRU	6	MISA	4		

Date	08/22/13	**Catg**	H/RD	**Lat**	N43.08679	**Effort**	917
Site	1D	**DA?**	N	**Long**	W078.70750	**Gear**	EFB
DOCE	9	NOHU	8	LEGI	6	ETNI	1
UMLI	1	PINO	9	LEMA	11	PEFL	1
ESAM	2	MOXO	5	MIDO	4	PECA	1
ESLU	2	AMRU	3	MISA	5	PEMA	1
NOAT	10	LECY	16	POAN	1	SAVI	1

Date	08/22/13	**Catg**	-	**Lat**	N43.06889	**Effort**	912
Site	2B	**DA?**	N	**Long**	W078.75343	**Gear**	EFB
DOCE	25	NOAT	1	AMRU	7	LEMA	45
ESAM	4	MOXO	1	LECY	0	MIDO	1
CYCA	2	AMNE	1	LEGI	46	MISA	18

Date	09/14/13	**Catg**	-	**Lat**	N43.02150	**Effort**	884
Site	3B	**DA?**	N	**Long**	W078.79360	**Gear**	EFB
DOCE	1	PINO	9	AMRU	9	LEMA	15
CAAU	1	CACO	4	LECY	2	MISA	14
CYCA	1	AMNE	1	LEGI	32	NEME	1
NOAT	6	FUDI	2				

Date	09/14/13	**Catg**	-	**Lat**	N43.02610	**Effort**	907
Site	3A	**DA?**	N	**Long**	W078.81606	**Gear**	EFB
DOCE	7	NOHU	5	MOXO	1	LEMA	61
CYCA	3	PINO	61	AMRU	2	MISA	6
NOAT	10	CACO	1	LEGI	38	NEME	6

Date	09/14/13	**Catg**	-	**Lat**	N43.00695	**Effort**	1100
Site	3D	**DA?**	N	**Long**	W078.77756	**Gear**	EFB
DOCE	450	LUCO	8	MOER	6	LEMA	18
ESLU	2	PINO	811	MOXO	5	MIDO	7
CYCA	5	HYNI	10	AMRU	49	MISA	7
NOAT	1						

Date	09/14/13	**Catg**	-	**Lat**	N43.02103	**Effort**	659
Site	3C	**DA?**	N	**Long**	W078.79248	**Gear**	EFB
DOCE	10	NOAT	7	MOAN	1	LEMA	32
ESLU	2	PINO	10	AMRU	8	MIDO	1
CAAU	1	SCER	1	LECY	6	MISA	8
CYCA	4	CACO	3	LEGI	53	PEFL	1
NOCR	1						

Date	09/14/13	**Catg**	-	**Lat**	N43.00852	**Effort**	800
Site	3E	**DA?**	N	**Long**	W078.78040	**Gear**	EFB
CYCA	2	PINO	750	LECY	2	MIDO	1
NOAT	3	HYNI	1	LEGI	5	MISA	15
LUCO	40	AMRU	8	LEMA	12	NEME	3
NOHU	7						

Date	09/26/13	**Catg**	H/RD	**Lat**	N43.08469	**Effort**	921
Site	1A	**DA?**	N	**Long**	W078.73151	**Gear**	EFB
DOCE	3	CYSP	2	MOER	2	LEMA	4
ESLU	3	PINO	1	AMRU	5	MISA	7
CYCA	2	CACO	1	LECY	4	PONI	1
NOAT	6	MOAN	1	LEGI	4	SAVI	1

Date	09/26/13	**Catg**	RD	**Lat**	N43.08587	**Effort**	900
Site	1B	**DA?**	N	**Long**	W078.72521	**Gear**	EFB
DOCE	33	NOHU	40	MOXO	1	LEGI	11
ESLU	1	PINO	11	FUDI	1	LEMA	12
CYCA	1	MOER	1	AMRU	14	MIDO	1
NOAT	16	MOMA	1	LECY	24	MISA	2

Date	09/26/13	**Catg**	RD	**Lat**	N43.08418	**Effort**	900
Site	1B	**DA?**	N	**Long**	W078.72245	**Gear**	EFB
DOCE	3	CYSP	2	AMRU	1	LEMA	7
ESLU	1	PINO	1	LECY	8	MISA	2
NOAT	6	MOXO	1	LEGI	1	POAN	1
NOHU	8	NOMU	1				

Date	09/26/13	**Catg**	RD	**Lat**	N43.08477	**Effort**	949
Site	1C	**DA?**	N	**Long**	W078.70799	**Gear**	EFB
DOCE	3	NOHU	2	AMRU	4	MISA	1
ESLU	2	MOAN	1	LECY	13	PEMA	1
NOAT	2	MOER	1	LEMA	2	SAVI	1

Date	09/26/13	**Catg**	RD	**Lat**	N43.08587	**Effort**	928
Site	1C	**DA?**	N	**Long**	W078.71959	**Gear**	EFB
ESLU	2	NOHU	1	LECY	14	SAVI	2
NOAT	11	AMRU	4	LEMA	4		

Date	09/26/13	**Catg**	H/RD	**Lat**	N43.08677	**Effort**	979
Site	1E	**DA?**	N	**Long**	W078.70065	**Gear**	EFB
DOCE	8	NOAT	25	AMRU	7	LEMA	8
ESLU	3	NOHU	15	LECY	16	MISA	14
CAAU	1	MOAN	1	LEGI	1	SAVI	1
CYCA	5	NOMU	1				

Date	11/02/13	**Catg**	RD	**Lat**	N43.08276	**Effort**	1024
Site	1C	**DA?**	N	**Long**	W078.71329	**Gear**	EFB
PINO	9	AMRU	1	LEMA	7	POAN	1
MOXO	7	LECY	1	MIDO	1	PONI	3
LASI	1						

Date	09/26/13	**Catg**	RD	**Lat**	N43.08108	**Effort**	915
Site	1C	**DA?**	N	**Long**	W078.71954	**Gear**	EFB
DOCE	5	NOHU	3	AMRU	2	LEMA	15
CYCA	2	MOER	1	LECY	6	MISA	3
NOAT	6	MOXO	1	LEGI	7	PEFL	3

Date	09/26/13	**Catg**	RD	**Lat**	N43.08237	**Effort**	908
Site	1C	**DA?**	N	**Long**	W078.71188	**Gear**	EFB
DOCE	2	MOER	2	AMRU	2	LEMA	4
NOAT	5	MOMA	1	LECY	6	MISA	1
NOHU	3	MOXO	1	LEGI	3		

Date	09/26/13	**Catg**	H/RD	**Lat**	N43.08679	**Effort**	923
Site	1D	**DA?**	N	**Long**	W078.70750	**Gear**	EFB
DOCE	3	CYSP	1	LEGI	4	MISA	2
NOAT	14	AMRU	3	LEMA	5	PEMA	1
NOHU	12	LECY	30				

Date	11/02/13	**Catg**	RD	**Lat**	N43.08627	**Effort**	962
Site	1B	**DA?**	N	**Long**	W078.72774	**Gear**	EFB
CYCA	1	MOMA	1	AMRU	83	LEMA	3
NOCR	8	MOXO	1	LECY	4	MISA	1
CYSP	1	LASI	3	LEGI	2	PEFL	1
PINO	45						

Date	11/02/13	**Catg**	H/RD	**Lat**	N43.08829	**Effort**	923
Site	1D	**DA?**	N	**Long**	W078.70400	**Gear**	EFB
ESLU	1	PINO	11	AMRU	2	LEMA	1
CYCA	3	MOXO	2	LEGI	1	SAVI	1

Date	11/02/13	**Catg**	H/RD	**Lat**	N43.08679	**Effort**	900
Site	1D	**DA?**	N	**Long**	W078.70750	**Gear**	EFB
CYCA	2	PINO	6	LECY	1	SAVI	3
NOCR	3	MOXO	3	ETNI	1		

Date	11/02/13	**Catg**	RD	**Lat**	N43.06953	**Effort**	975
Site	2D	**DA?**	N	**Long**	W078.74812	**Gear**	EFB
DOCE	1	PINO	29	LASI	1	LEMA	87
CYCA	1	MOMA	1	AMRU	7	MISA	7
NOCR	1	MOXO	5	LECY	11	PONI	1
NOHU	1	AMNE	1	LEGI	7	PEFL	2

Date	11/02/13	**Catg**	H	**Lat**	N43.08210	**Effort**	1831
Site	1F	**DA?**	N	**Long**	W078.68002	**Gear**	EFB
ESLU	1	PINO	1	LEGI	1	PONI	1
CYCA	3	MOXO	50	LEMA	1	SAVI	3
NOAT	10	AMRU	8				

Date	06/01/14	**Catg**	RD	**Lat**	N43.08277	**Effort**	939
Site	1C	**DA?**	N	**Long**	W078.71330	**Gear**	EFB
CYCA	X	MOXO	X	LECY	X	LEMA	X
NOAT	X	AMRU	X				

Date	6/1/14	**Catg**	H/RD	**Lat**	N43.08470	**Effort**	950
Site	1A	**DA?**	N	**Long**	W078.73152	**Gear**	EFB
CYCA	X	MOXO	X	LECY	X	LEMA	X
NOCR	X	ICPU	X	LEGI	X	MIDO	X
PINO	X	AMRU	X				

Date	6/1/14	**Catg**	H/RD	**Lat**	N43.08678	**Effort**	1049
Site	1E	**DA?**	N	**Long**	W078.70066	**Gear**	EFB
LUCH	X	AMNE	X	LECY	X	LEMA	X
HYNI	X	ICPU	X	LEGI	X	NEME	X
MOXO	X	AMRU	X				

Date	6/1/14	**Catg**	H/RD	**Lat**	N43.08830	**Effort**	793
Site	1D	**DA?**	N	**Long**	W078.70401	**Gear**	EFB
UMLI	X	CYCA	X	AMRU	X	LEGI	X
ESLU	X	MOXO	X	LECY	X	LEMA	X

Date	6/1/14	**Catg**	S	**Lat**	N43.053657	**Effort**	989
Site	2A	**DA?**	N	**Long**	W078.806997	**Gear**	EFB
CYCA	X	MOXO	X	LEMA	X	PONI	X

Date	6/1/14	**Catg**	S	**Lat**	N43.057766	**Effort**	1142
Site	2A	**DA?**	N	**Long**	W078.805902	**Gear**	EFB
ESLU	X	MOXO	X	LECY	X	MISA	X

SCER	X	LEGI	X				
Date	6/6/14	**Catg**	S	**Lat**	N42.934029	**Effort**	625
Site	3F	**DA?**	N	**Long**	W078.641345	**Gear**	BPS
ESLU	X	CYCA	X	AMRU	X		
Date	6/6/14	**Catg**	S	**Lat**	N42.878077	**Effort**	750
Site	4A	**DA?**	N	**Long**	W078.756803	**Gear**	BPS
NOAT	X	PINO	X	LEGI	X	LEMA	X
LUCH	X	LECY	X				
Date	6/6/14	**Catg**	S	**Lat**	N42.884714	**Effort**	1100
Site	4C	**DA?**	N	**Long**	W078.752799	**Gear**	BPS
UMLI	X	LUCH	X	AMRU	X	MIDO	X
CYCA	X	CACO	X	LECY	X	PECA	X
NOAT	X	HYNI	X	LEMA	X		
Date	6/7/14	**Catg**	RD	**Lat**	N43.08278	**Effort**	1581
Site	1C	**DA?**	N	**Long**	W078.71331	**Gear**	EFB
CYCA	X	MOXO	X	LECY	X	LEMA	X
NOAT	X	AMNE	X	LEGI	X	MISA	X
PINO	X	AMRU	X				
Date	6/7/14	**Catg**	H/RD	**Lat**	N43.08831	**Effort**	1783
Site	1D	**DA?**	N	**Long**	W078.70402	**Gear**	EFB

SCER	X	AMNE	X	LEGI	X	APGR	X
CACO	X	AMRU	X	MIDO	X	NEME	X
Date	6/6/14	**Catg**	S	**Lat**	N42.933778	**Effort**	1800
Site	3F	**DA?**	N	**Long**	W078.642612	**Gear**	BPS
ESLU	X	CACO	X	LECY	X	LEMA	X
LUCH	X	AMRU	X	LEGI	X	MIDO	X
Date	6/6/14	**Catg**	S	**Lat**	N42.877704	**Effort**	805
Site	4A	**DA?**	N	**Long**	W078.754679	**Gear**	BPS
LUCH	X	CACO	X	AMRU	X	LEGI	X
CYSP	X	HYNI	X	LECY	X	LEMA	X
PINO	X	AMNE	X				
Date	6/7/14	**Catg**	H/RD	**Lat**	N43.08471	**Effort**	900
Site	1A	**DA?**	N	**Long**	W078.73153	**Gear**	EFB
LEOS	X	CYCA	X	PINO	X	MIDO	X
UMLI	X	NOAT	X	AMRU	X	MISA	X
ESAM	X	CYSP	X	LEMA	X	POAN	X
Date	6/7/14	**Catg**	RD	**Lat**	N43.08628	**Effort**	816
Site	1B	**DA?**	N	**Long**	W078.72775	**Gear**	EFB
ESLU	X	PINO	X	AMRU	X	LEMA	X
CYCA	X	MOXO	X	LECY	X	MIDO	X
NOAT	X	ICPU	X	LEGI	X	MISA	X
Date	6/7/14	**Catg**	RD	**Lat**	N43.08279	**Effort**	863
Site	1C	**DA?**	N	**Long**	W078.71332	**Gear**	EFB

DOCE	X	PINO	X	LEGI	X	SAVI	X
ESLU	X	AMRU	X	LEMA	X	NEME	X
NOAT	X	LECY	X				

Date	6/7/14	**Catg**	H/RD	**Lat**	N43.08679	**Effort**	1772
Site	1E	**DA?**	N	**Long**	W078.70067	**Gear**	EFB
ESLU	X	CYSP	X	MIDO	X	SAVI	X
CYCA	X	CACO	X	MISA	X		

Date	6/14/14	**Catg**	S	**Lat**	N42.928418	**Effort**	1634
Site	1I	**DA?**	N	**Long**	W078.233902	**Gear**	BPS
NOBI	X	CACO	X	LECY	X	ETCA	X
LUCH	X	AMRU	X	LEGI	X	ETNI	X

Date	6/15/14	**Catg**	H/RD	**Lat**	N43.08832	**Effort**	1091
Site	1D	**DA?**	N	**Long**	W078.70403	**Gear**	EFB
ESAM	X	PINO	X	LECY	X	MISA	X
CYCA	X	CACO	X	LEGI	X	SAVI	X
CYSP	X	MOXO	X	LEMA	X		

Date	6/15/14	**Catg**	H/RD	**Lat**	N43.08680	**Effort**	1652
Site	1E	**DA?**	N	**Long**	W078.70068	**Gear**	EFB
CYCA	X	MOXO	X	AMRU	X	LEGI	X
CYSP	X	NOMU	X	LECY	X	PEMA	X
PINO	X						

NOAT	X	AMRU	X	LEMA	X	SAVI	X
PINO	X	LECY	X	PEMA	X		

Date	6/14/14	**Catg**	S	**Lat**	N43.080195	**Effort**	833
Site	1H	**DA?**	N	**Long**	W078.519074	**Gear**	BPS

No catches--flood stage

Date	6/15/14	**Catg**	H/RD	**Lat**	N43.08472	**Effort**	1432
Site	1A	**DA?**	N	**Long**	W078.73154	**Gear**	EFB
NOAT	X	SCER	X	LECY	X	MISA	X
CYSP	X	MOXO	X	LEGI	X	PONI	X
PINO	X	AMRU	X	LEMA	X		

Date	6/15/14	**Catg**	RD	**Lat**	N43.08280	**Effort**	1135
Site	1C	**DA?**	N	**Long**	W078.71333	**Gear**	EFB
ESAM	X	PINO	X	LEGI	X	PONI	X
NOHU	X	MOXO	X	LEMA	X	SAVI	X
CYSP	X	LECY	X				

Date	6/21/14	**Catg**	S	**Lat**	N42.934069	**Effort**	3100
Site	3F	**DA?**	N	**Long**	W078.6401	**Gear**	BPS
LUCH	X	LECY	X	LEGI	X	LEMA	X
MOXO	X						

Date	6/21/14	**Catg**	S	**Lat**	N42.8756	**Effort**	2108
Site	4A	**DA?**	N	**Long**	W078.757651	**Gear**	BPS
NOAT	X	AMRU	X	LEMA	X	ETNI	X
PINO	X	LECY	X	MISA	X	PEMA	X
MOAN	X	LEGI	X	ETCA	X		

Date	6/21/14	**Catg**	S	**Lat**	N42.87654	**Effort**	2671
Site	4A	**DA?**	N	**Long**	W078.755226	**Gear**	BPS
CYCA	X	PINO	X	LECY	X	ETBL	X
NOAT	X	ICPU	X	LEGI	X	ETCA	X
LUCH	X	AMRU	X	LEMA	X		

Date	6/22/14	**Catg**	RD	**Lat**	N43.08281	**Effort**	2345
Site	1C	**DA?**	N	**Long**	W078.71334	**Gear**	EFB
ESLU	X	MOXO	X	LEGI	X	MISA	X
NOAT	X	AMRU	X	LEMA	X	SAVI	X
CYSP	X	LECY	X	MIDO	X	NEME	X
PINO	X						

Date	6/22/14	**Catg**	H/RD	**Lat**	N43.08473	**Effort**	2211
Site	1A	**DA?**	N	**Long**	W078.73155	**Gear**	EFB
ESAM	X	NOHU	X	AMRU	X	MIDO	X
ESLU	X	CYSP	X	LECY	X	MISA	X
CYCA	X	PINO	X	LEGI	X	POAN	X
NOAT	X	MOXO	X	LEMA	X		

Date	6/22/14	**Catg**	H/RD	**Lat**	N43.08681	**Effort**	1911
Site	1E	**DA?**	N	**Long**	W078.70069	**Gear**	EFB
ESLU	X	PINO	X	AMRU	X	MISA	X
CYCA	X	MOXO	X	LECY	X	SAVI	X
NOAT	X	NOMU	X	LEMA	X	NEME	X
CYSP	X						

Date	6/22/14	**Catg**	H/RD	**Lat**	N43.08833	**Effort**	2089
Site	1D	**DA?**	N	**Long**	W078.70404	**Gear**	EFB
ESAM	X	NOAT	X	ICPU	X	LEMA	X
ESLU	X	PINO	X	LECY	X	MISA	X
CYCA	X	MOXO	X	LEGI	X	NEME	X

Date	6/24/14	**Catg**	S	**Lat**	N43.081786	**Effort**	1489
Site	1H	**DA?**	N	**Long**	W078.518367	**Gear**	BPS
ESAM	X	AMNE	X	LEGI	X	ETNI	X
CAAU	X	AMRU	X	LEMA	X	PEMA	X
PINO	X	LECY	X	MISA	X	NEME	X
MOXO	X						

Date	6/24/14	**Catg**	S	**Lat**	N43.080893	**Effort**	1355
Site	1H	**DA?**	N	**Long**	W078.518503	**Gear**	BPS
UMLI	X	CAAU	X	LEGI	X	ETNI	X
ESAM	X	LECY	X	LEMA	X	PEMA	X
ESLU	X						

Date	6/24/14	**Catg**	S	**Lat**	N43.082196	**Effort**	724
Site	1H	**DA?**	N	**Long**	W078.520046	**Gear**	BPS
CAAU	X	AMRU	X	LECY	X	LEGI	X
NOFL	X						

Date	6/24/14	**Catg**	S	**Lat**	N43.082195	**Effort**	2098
Site	1H	**DA?**	N	**Long**	W078.518968	**Gear**	BPS
CAAU	X	AMRU	X	LEMA	X	PEMA	X
PINO	X	LECY	X	ETNI	X	NEME	X
MOXO	X	LEGI	X				

Date	6/27/14	**Catg**	-	**Lat**	N43.069666	**Effort**	744
Site	1G	**DA?**	N	**Long**	W078.595355	**Gear**	Raft/BPS
ESAM	X	CYCA	X	CYSP	X	LECY	X
CAAU	X	NOHU	X	PINO	X	LEGI	X

Date	6/27/14	**Catg**	-	**Lat**	N43.073835	**Effort**	1089
Site	1G	**DA?**	N	**Long**	W078.591607	**Gear**	Raft/BPS
ESAM	X	CAAU	X	CYSP	X	LECY	X
ESLU	X	NOAT	X	PINO	X	LEGI	X

Date	6/27/14	**Catg**	-	**Lat**	N43.073493	**Effort**	1218
Site	1G	**DA?**	N	**Long**	W078.601193	**Gear**	Raft/BPS
ESAM	X	NOAT	X	PINO	X	LEGI	X
CAAU	X	CYSP	X	LECY	X	LEMA	X

Date	6/28/14	**Catg**	H/RD	**Lat**	N43.08474	**Effort**	1124
Site	1A	**DA?**	N	**Long**	W078.73156	**Gear**	EFB
ESLU	X	PINO	X	AMRU	X	LEMA	X
NOCR	X	MOVA	X	LEGI	X	MISA	X
NOAT	X	AMNE	X				

Date	6/28/14	**Catg**	RD	**Lat**	N43.08283	**Effort**	554
Site	1C	**DA?**	N	**Long**	W078.71336	**Gear**	EFB
ESAM	X	CYSP	X	LECY	X	LEMA	X
CAAU	X	PINO	X	LEGI	X	MISA	X
NOAT	X	AMRU	X				

Date	6/28/14	**Catg**	RD	**Lat**	N43.08282	**Effort**	625
Site	1C	**DA?**	N	**Long**	W078.71335	**Gear**	EFB
CAAU	X	CYSP	X	LEGI	X	MISA	X
NOAT	X	MOVA	X	LEMA	X	SAVI	X
NOHU	X	LECY	X				

Date	6/28/14	**Catg**	H/RD	**Lat**	N43.08682	**Effort**	999
Site	1E	**DA?**	N	**Long**	W078.70070	**Gear**	EFB
CAAU	X	MOXO	X	LEGI	X	ETNI	X

Date	6/28/14	**Catg**	H/RD	**Lat**	N43.08834	**Effort**	977
Site	1D	**DA?**	N	**Long**	W078.70405	**Gear**	EFB
UMLI	X	NOAT	X	PINO	X	LECY	X

CYCA	X	ICPU	X	LEMA	X	PEMA	X
NOAT	X	AMRU	X	MISA	X	NEME	X
NOHU	X	LECY	X				

Date	6/28/14	**Catg**	S	**Lat**	N43.057766	**Effort**	1057
Site	2A	**DA?**	N	**Long**	W078.805902	**Gear**	EFB
CYCA	X	PINO	X	LEGI	X	PEFL	X
NOAT	X	MOXO	X	LEMA	X	APGR	X
CYSP	X	AMNE	X	MISA	X		

Date	7/5/14	**Catg**	S	**Lat**	N43.083432	**Effort**	1152
Site	1H	**DA?**	N	**Long**	W078.523004	**Gear**	BPS
UMLI	X	ESLU	X	AMRU	X	LEGI	X
ESAM	X	CYCA	X	LECY	X	LEMA	X

Date	7/5/14	**Catg**	S	**Lat**	N42.929836	**Effort**	1948
Site	1I	**DA?**	N	**Long**	W078.234814	**Gear**	BPS
CACO	X	AMRU	X	LECY	X	MIDO	X
HYNI	X						
CACO	X						

Date	7/10/14	**Catg**	S	**Lat**	N42.8756	**Effort**	1816
Site	4B	**DA?**	N	**Long**	W078.757651	**Gear**	BPS
CAAN	X	NOFL	X	LEGI	X	ETCA	X
NOMP	X	AMRU	X	LEMA	X	ETNI	X
NOCR	X	LECY	X	MIDO	X	PECA	X
NOHU	X						

ESAM	X	NOHU	X	ICPU	X	LEGI	X
CAAU	X	LYUM	X	AMRU	X	LEMA	X
NOCR	X						

Date	7/5/14	**Catg**	S	**Lat**	N43.082391	**Effort**	1084
Site	1H	**DA?**	N	**Long**	W078.522119	**Gear**	BPS
UMLI	X	CYCA	X	LECY	X	MISA	X
ESAM	X	AMNE	X	LEGI	X	ETNI	X
ESLU	X	AMRU	X	LEMA	X	PEMA	X

Date	7/5/14	**Catg**	S	**Lat**	N43.082993	**Effort**	1027
Site	1H	**DA?**	N	**Long**	W078.522368	**Gear**	BPS
UMLI	X	CYCA	X	LECY	X	LEMA	X
ESAM	X	AMNE	X	LEGI	X	PEMA	X
ESLU	X	AMRU	X				

Date	7/10/14	**Catg**	S	**Lat**	N42.934197	**Effort**	2003
Site	3F	**DA?**	N	**Long**	W078.638859	**Gear**	BPS
NOMP	X	HYNI	X	LEGI	X	MISA	X
NOCR	X	AMRU	X	LEMA	X	ETCA	X
NOHU	X	LECY	X	MIDO	X	ETNI	X

Date	7/11/14	**Catg**	S	**Lat**	N43.078699	**Effort**	3815
Site	1H	**DA?**	N	**Long**	W078.518647	**Gear**	BPS
CAAN	X	CACO	X	LECY	X	MISA	X
CAAU	X	AMNE	X	LEGI	X	ETNI	X
CYCA	X	AMRU	X	LEMA	X	PEMA	X

Date	7/11/14	**Catg**	S	**Lat**	N43.079423	**Effort**	2452
Site	1H	**DA?**	N	**Long**	W078.519739	**Gear**	BPS
ESAM	X	AMNE	X	LEMA	X	ETCA	X
CAAN	X	AMRU	X	MIDO	X	ETNI	X
CAAU	X	LECY	X	MISA	X	PEMA	X
CYCA	X	LEGI	X				

Date	7/13/14	**Catg**	RD	**Lat**	N43.08629	**Effort**	850
Site	1B	**DA?**	N	**Long**	W078.72776	**Gear**	EFB
ESLU	X	NOHU	X	AMRU	X	LEMA	X
CAAU	X	PINO	X	LECY	X	MISA	X
CYCA	X	MOXO	X	LEGI	X	PEMA	X
NOAT	X	ICPU	X				

Date	7/13/14	**Catg**	H/RD	**Lat**	N43.08683	**Effort**	1295
Site	1E	**DA?**	N	**Long**	W078.70071	**Gear**	EFB
CAAU	X	HYNI	X	AMRU	X	MIDO	X
NOAT	X	MOER	X	LECY	X	MISA	X
NOHU	X	ICPU	X	LEGI	X	PONI	X
CYSP	X	LASI	X	LEMA	X	SAVI	X

Date	7/13/14	**Catg**	H/RD	**Lat**	N43.08835	**Effort**	938
Site	1D	**DA?**	N	**Long**	W078.70406	**Gear**	EFB
UMLI	X	NOHU	X	AMRU	X	LEGI	X
ESAM	X	MOXO	X	LECY	X	MISA	X
NOAT	X	FUDI	X				

Date	7/13/14	**Catg**	RD	**Lat**	N43.069494	**Effort**	990
Site	2D	**DA?**	N	**Long**	W078.746851	**Gear**	EFB
ESAM	X	NOHU	X	LECY	X	MISA	X
CYCA	X	MOXO	X	LEGI	X	PEFL	X
NOCR	X	AMNE	X	LEMA	X	NEME	X
NOAT	X	AMRU	X				

Date	7/13/14	**Catg**	S	**Lat**	N43.057766	**Effort**	1912
Site	2A	**DA?**	N	**Long**	W078.805902	**Gear**	EFB
DOCE	X	NOCR	X	AMNE	X	LEMA	X
ESLU	X	NOHU	X	LASI	X	MISA	X
CAAU	X	SCER	X	LECY	X	POAN	X
CYCA	X	MOXO	X	LEGI	X	PEFL	X

Date	8/3/14	**Catg**	-	**Lat**	N42.892238	**Effort**	1300
Site	4D	**DA?**	N	**Long**	W078.66201	**Gear**	Canoe/BPS
CAAN	35	PINO	50	LECY	15	ETBL	10
NOMP	30	CACO	6	LEGI	3	ETFL	5
NOAT	20	HYNI	4	LEMA	7	ETNI	50
LUCH	20	MOER	1	MIDO	80	PECA	3
NOHU	50	AMRU	15	MISA	1	PEMA	5

Date	8/3/14	**Catg**	-	**Lat**	N42.891354	**Effort**	1914
Site	4D	**DA?**	N	**Long**	W078.660519	**Gear**	Canoe/BPS
CAAN	10	PINO	30	AMRU	17	MISA	5
NOMP	35	CACO	150	LECY	6	ETCA	5
NOAT	50	HYNI	8	LEGI	4	ETFL	2
LUCH	50	MOXO	2	LEMA	9	ETNI	10
NOHU	100	AMNE	1	MIDO	90	PEMA	10

Date	8/3/14	**Catg**	-	**Lat**	N42.891452	**Effort**	1616
Site	4D	**DA?**	N	**Long**	W078.664584	**Gear**	Canoe/BPS
CAAN	23	PINO	50	AMRU	27	MISA	5
NOMP	40	CACO	29	LECY	11	ETCA	10
NOCR	2	HYNI	4	LEGI	14	ETNI	10
NOAT	15	MOAN	2	LEMA	34	PEFL	23
LUCH	30	AMNE	1	MIDO	60	PEMA	2
NOHU	30						

Date	8/3/14	**Catg**	-	**Lat**	N42.893295	**Effort**	1225
Site	4D	**DA?**	N	**Long**	W078.666226	**Gear**	Canoe/BPS
CAAN	22	PINO	100	LEGI	5	ETFL	5
NOMP	12	MOAN	1	LEMA	15	ETNI	20
NOCR	1	MOXO	1	MIDO	100	PEFL	20
NOAT	15	AMNE	2	MISA	10	PECA	2
LUCH	15	AMRU	10	ETBL	10	PEMA	2
NOHU	50	LECY	5				

Date	8/3/14	**Catg**	S	**Lat**	N42.889387	**Effort**	800
Site	4E	**DA?**	N	**Long**	W078.642661	**Gear**	BPS
CAAN	10	PINO	15	LECY	15	ETBL	2
NOMP	20	CACO	2	LEGI	3	ETCA	3
NOAT	5	HYNI	1	LEMA	2	ETNI	12
LUCH	15	MOXO	3	MIDO	5	PEMA	1
NOHU	20	AMRU	20				

Date	8/3/14	**Catg**	-	**Lat**	N42.890088	**Effort**	1237
Site	4D	**DA?**	N	**Long**	W078.663103	**Gear**	Canoe/BPS
CAAN	15	PINO	30	LECY	2	ETCA	20
NOMP	5	CACO	40	LEGI	5	ETFL	10
NOCR	1	HYNI	6	LEMA	12	ETNI	50
NOAT	30	MOAN	1	MIDO	30	PEFL	5
LUCH	10	MOXO	1	ETBL	30	PEMA	10
NOHU	100	AMRU	19				

Appendix C. Images of genetically-confirmed hybrid (bluegill x northern sunfish, C–1; bluegill x pumpkinseed, C–2; bluegill x green sunfish, C–3; green sunfish x pumpkinseed, C–4) and pure sunfish (northern sunfish, C–5; bluegill, C–6; pumpkinseed, C–7; green sunfish, C–8) specimens collected in lower Tonawanda Creek 2013–2014. Photographs by Kelly Owens. Below is a bluegill (*L. macrochirus*) x northern sunfish (*L. peltastes*) hybrid. Specimen #3.

Appendix C–1. Bluegill (*L. macrochirus*) x northern sunfish (*L. peltastes*) hybrid. Specimen #9.

Appendix C–1. Bluegill (*L. macrochirus*) x northern sunfish (*L. peltastes*) hybrid. Specimen #12.

Appendix C–1. Bluegill (*L. macrochirus*) x northern sunfish (*L. peltastes*) hybrid. Specimen #13.

Appendix C–1. Bluegill (*L. macrochirus*) x northern sunfish (*L. peltastes*) hybrid. Specimen #14.

Appendix C–1. Bluegill (*L. macrochirus*) x northern sunfish (*L. peltastes*) hybrid. Specimen #17.

Appendix C–1. Bluegill (*L. macrochirus*) x northern sunfish (*L. peltastes*) hybrid. Specimen #18.

Appendix C–1. Bluegill (*L. macrochirus*) x northern sunfish (*L. peltastes*) hybrid. Specimen #20.

Appendix C–2. Bluegill (*L. macrochirus*) x pumpkinseed (*L. gibbosus*) hybrid. Specimen #10.

Appendix C–2. Bluegill (*L. macrochirus*) x pumpkinseed (*L. gibbosus*) hybrid. Specimen #11.

Appendix C–2. Bluegill (*L. macrochirus*) x pumpkinseed (*L. gibbosus*) hybrid. Specimen #31.

Appendix C–2. Bluegill (*L. macrochirus*) x pumpkinseed (*L. gibbosus*) hybrid. Specimen #55.

Appendix C–2. Bluegill (*L. macrochirus*) x pumpkinseed (*L. gibbosus*) hybrid. Specimen #67.

Appendix C–2. Bluegill (*L. macrochirus*) x pumpkinseed (*L. gibbosus*) hybrid. Specimen #71. Notch in upper caudal lobe was made in the laboratory and was not natural.

Appendix C–2. Bluegill (*L. macrochirus*) x pumpkinseed (*L. gibbosus*) hybrid. Specimen #74.

Appendix C–2. Bluegill (*L. macrochirus*) x pumpkinseed (*L. gibbosus*) hybrid. Specimen #75.

Appendix C–3. Bluegill (*L. macrochirus*) x green sunfish (*L. cyanellus*) hybrid. Specimen #7.

Appendix C–3. Bluegill (*L. macrochirus*) x green sunfish (*L. cyanellus*) hybrid. Specimen #15.

Appendix C–3. Bluegill (*L. macrochirus*) x green sunfish (*L. cyanellus*) hybrid. Specimen #19.

Appendix C–3. Bluegill (*L. macrochirus*) x green sunfish (*L. cyanellus*) hybrid. Specimen #22.

Appendix C–3. Bluegill (*L. macrochirus*) x green sunfish (*L. cyanellus*) hybrid. Specimen #23.

Appendix C–3. Bluegill (*L. macrochirus*) x green sunfish (*L. cyanellus*) hybrid. Specimen #24.

Appendix C–3. Bluegill (*L. macrochirus*) x green sunfish (*L. cyanellus*) hybrid. Specimen #72.

Appendix C–3. Bluegill (*L. macrochirus*) x green sunfish (*L. cyanellus*) hybrid. Specimen #79.

Appendix C–4. Green sunfish (*L. gibbosus*) x pumpkinseed (*L.* gibbosus) hybrid. Specimen #6.

Appendix C–4. Green sunfish (*L. gibbosus*) x pumpkinseed (*L.* gibbosus) hybrid. Specimen #37. Note that units are in inches for this specimen's photograph.

Appendix C–4. Green sunfish (*L. gibbosus*) x pumpkinseed (*L.* gibbosus) hybrid. Specimen #80.

Appendix C–5. Northern sunfish (*L. peltastes*). Specimen #2.

Appendix C–6. Bluegill (*L. macrochirus*). Specimen #28.

Appendix C–6. Bluegill (*L. macrochirus*). Specimen #30.

Appendix C–6. Bluegill (*L. macrochirus*). Specimen #33.

Appendix C–6. Bluegill (*L. macrochirus*). Specimen #34.

Appendix C–6. Bluegill (*L. macrochirus*). Specimen #40.

Appendix C–6. Bluegill (*L. macrochirus*). Specimen #42.

Appendix C–6. Bluegill (*L. macrochirus*). Specimen #44.

Appendix C–6. Bluegill (*L. macrochirus*). Specimen #45.

Appendix C–6. Bluegill (*L. macrochirus*). Specimen #50.

Appendix C–6. Bluegill (*L. macrochirus*). Specimen #54.

Appendix C–6. Bluegill (*L. macrochirus*). Specimen #56.

Appendix C–6. Bluegill (*L. macrochirus*). Specimen #57.

Appendix C–6. Bluegill (*L. macrochirus*). Specimen #58.

Appendix C–6. Bluegill (*L. macrochirus*). Specimen #60.

Appendix C–6. Bluegill (*L. macrochirus*). Specimen #61.

Appendix C–6. Bluegill (*L. macrochirus*). Specimen #62.

Appendix C–6. Bluegill (*L. macrochirus*). Specimen #63.

Appendix C–6. Bluegill (*L. macrochirus*). Specimen #64.

Appendix C–6. Bluegill (*L. macrochirus*). Specimen #65.

Appendix C–7. Pumpkinseed (*L. gibbosus*). Specimen #4.

Appendix C–7. Pumpkinseed (*L. gibbosus*). Specimen #8.

Appendix C–7. Pumpkinseed (*L. gibbosus*). Specimen #16.

Appendix C–7. Pumpkinseed (*L. gibbosus*). Specimen #21.

Appendix C–7. Pumpkinseed (*L. gibbosus*). Specimen #29.

Appendix C–7. Pumpkinseed (*L. gibbosus*). Specimen #35.

Appendix C–7. Pumpkinseed (*L. gibbosus*). Specimen #38.

Appendix C–7. Pumpkinseed (*L. gibbosus*). Specimen #47.

Appendix C–7. Pumpkinseed (*L. gibbosus*). Specimen #59.

Appendix C–7. Pumpkinseed (*L. gibbosus*). Specimen #68.

Appendix C–7. Pumpkinseed (*L. gibbosus*). Specimen #76.

Appendix C–8. Green sunfish (*L. cyanellus*). Specimen #25.

Appendix C–8. Green sunfish (*L. cyanellus*). Specimen #26.

Appendix C–8. Green sunfish (*L. cyanellus*). Specimen #27.

Appendix C–8. Green sunfish (*L. cyanellus*). Specimen #32.

Appendix C–8. Green sunfish (*L. cyanellus*). Specimen #36. Note that units are in inches for this specimen’s photograph.

Appendix C–8. Green sunfish (*L. cyanellus*). Specimen #39.

Appendix C–8. Green sunfish (*L. cyanellus*). Specimen #41.

Appendix C–8. Green sunfish (*L. cyanellus*). Specimen #43.

Appendix C–8. Green sunfish (*L. cyanellus*). Specimen #46.

Appendix C–8. Green sunfish (*L. cyanellus*). Specimen #48.

Appendix C–8. Green sunfish (*L. cyanellus*). Specimen #51.

Appendix C–8. Green sunfish (*L. cyanellus*). Specimen #52.

Appendix C–8. Green sunfish (*L. cyanellus*). Specimen #53.

Appendix C–8. Green sunfish (*L. cyanellus*). Specimen #66.

Appendix C–8. Green sunfish (*L. cyanellus*). Specimen #70.