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James E. Breck
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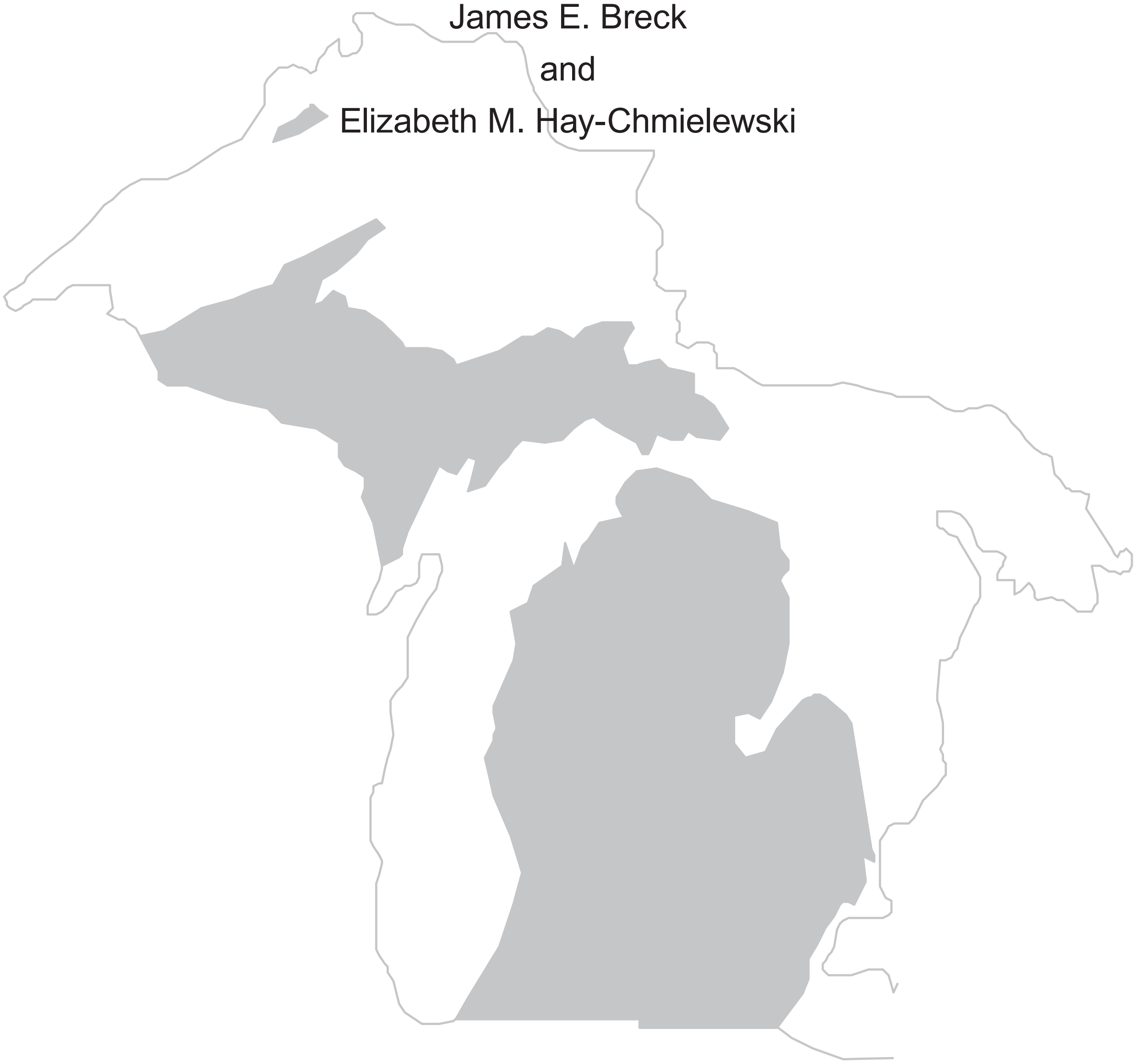
Elizabeth M. Hay-Chmielewski



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Pond Rearing of Juvenile Lake Sturgeon

James E. Breck and Elizabeth M. Hay-Chmielewski

Michigan Department of Natural Resources, Institute for Fisheries Research,
Room 212 Museums Annex Building, 1109 North University Avenue, Ann Arbor, Michigan 48109

Abstract.–Pond rearing of age-0 lake sturgeon could provide an alternative to intensive rearing of juveniles in a hatchery setting. We conducted a series of six pond and raceway experiments and nine laboratory experiments to evaluate factors related to pond rearing. We measured survival and growth of age-0 lake sturgeon stocked at different densities into 0.25-ha earthen ponds and outdoor raceways. In the first pond experiment we observed 100% mortality of the age-0 lake sturgeon. Subsequent experiments were conducted to determine the causes of mortality and improve survival. During summer months, pond water temperatures exceeded 25°C on many days. In several experiments lasting 2-4 months, pond survival of the juvenile lake sturgeon never exceeded 5%. High water temperatures were probably the main cause for the poor survival of juvenile lake sturgeon in these ponds. In one raceway experiment we found 81% mortality during the first 14 d, but water temperatures were only above 20°C for a few hours. We conclude that high water temperature was not the cause of mortality in the raceways. To evaluate the role of predation as a source of mortality observed in our outdoor experiments, we conducted several lab experiments with crayfish and largemouth bass, two main predators in our system. Our observations in both pond and lab experiments confirm that crayfish will attack and can consume juvenile lake sturgeon. Predation by crayfish *Orconectes virilis* was probably the major cause of mortality in the raceways. Crayfish predation may have also contributed to the high mortality of juvenile lake sturgeon in our experimental ponds. Attempts to reduce crayfish predation in ponds by trapping crayfish did not improve lake sturgeon survival. Stocking 50 adult largemouth bass per pond to control crayfish also did not improve sturgeon survival. Several laboratory experiments clearly demonstrated that largemouth bass do not voluntarily consume juvenile lake sturgeon. If a juvenile lake sturgeon is ingested, it is rapidly expelled, with no obvious harm to the lake sturgeon. The natural pattern of dark spots on the head, body, and fins can be used as natural marks to identify individual juvenile lake surgeon using photographic images, at least during the first year of life. We successfully used this method to monitor the growth of several individuals for up to one year. Rearing of juvenile lake sturgeon in earthen ponds or outdoor raceways can result in good growth during the first year, exceeding the typical growth rates for wild juveniles. We measured specific growth rates during summer to fall of 3.0 and 4.8 % body weight/d. The small numbers of survivors often reached 300 mm after 12 months of growth. Rearing age-0 lake sturgeon is not feasible in ponds with high summer temperatures or with abundant crayfish. If survival can be improved by avoiding exposures to high water temperatures and predators, then pond rearing may provide a low-cost method to rear juvenile lake sturgeon.

INTRODUCTION

The Fisheries Division of the Michigan Department of Natural Resources developed a rehabilitation strategy for lake sturgeon *Acipenser fulvescens* (Hay-Chmielewski and Whelan 1997).

This strategy recommended the investigation of potential methods for pond rearing lake sturgeon (Hay-Chmielewski and Whelan 1997). This approach has been successful in formulating methods for extensive culture of walleye *Sander vitreus* in Michigan (Beyerle 1979) and could be useful for lake sturgeon.

Lake sturgeon were cultured in Michigan in the 1980s and 1990s (Anderson 1984). For example, in 1990, 100,000 eggs were obtained from Wisconsin and reared at the Wolf Lake State Fish Hatchery, near Mattawan. Approximately 17,000 juvenile lake sturgeon survived (17% survival) and were stocked into Michigan waters at an average length of 78 mm. Efficient methods of pond rearing may produce larger numbers of lake sturgeon at lower cost.

Some hatcheries in the former Union of Soviet Socialist Republics (USSR) rear sturgeon in ponds, while others use intensive tank culture (Doroshov 1985, Doroshov and Binkowski 1985). "Zaikina (1975) recommends the following parameters of pond ecosystem for best grow-out results: water temperature range 12-27°C; dissolved oxygen – not less than 6 mg/l; biomass of Tendipedidae (= Chironomidae [sic]) larvae in pond benthos – not less than 5 g/m^2. She indicates that at an average stocking density (for three species, beluga [*Huro huro*], Russian sturgeon [*Acipenser guldenstadti*] and sevrjuga [*Acipenser stellatus*]) of 87,000 larvae per hectare and average duration of grow-out of 31 days, fertilized ponds produce fingerlings of 3.3 g mean body weight, with a survival at harvest of 57.1 per cent and yield of 166 kg per hectare" (Doroshov 1985, p. 269).

Water temperature is known to affect growth and survival of fishes, but there appears to be little published information on the growth response of juvenile lake sturgeon to water temperature. Wismer and Christie (1987) summarized thermal criteria for 116 species of Great Lakes fishes, including lake sturgeon, but found no data available on the thermal tolerances, preferred temperature, or optimal growth temperature for lake sturgeon. Buddington (1991) noted that the range of temperatures tolerated by sturgeon was likely to increase with developmental stage, narrowest for spawning, wider for juveniles, and widest for adults. In hatchery rearing experiments described by Anderson (1984), age-0 lake sturgeon were held at 19.4°C, and groups that were fed a natural diet (live zooplankton and an aquatic annelid *Lumbriculus variegatus*) grew from 26 mm and 0.07 g to 84 mm and 2.26 g during the 9-week study. Volkman et al. (2004) reported good growth of 6-g lake sturgeon reared for 10 weeks at 16-18°C. Wehrly (1995) measured the growth of juvenile lake sturgeon fed excess rations in aquaria at four temperatures (7, 10.5, 15, 19, and 23°C) and found the fastest growth at 23°C. However, this was also the temperature with the highest 28-d mortality (45%), primarily among the slowest growing individuals held at that temperature. The pond experiments in this study exceed 23°C during summer.

Growth and survival of fish in ponds depends on fish size and density. As total fish biomass increases, limits are reached on the ability of natural prey items to support additional fish biomass, with resulting decreases in growth or survival. This is clear from work on walleye, bluegill *Lepomis macrochirus,* and other species (Dobie 1956, Smith and Moyle 1943, Latta and Merna 1976, Beyerle 1977, Clark and Lockwood 1990, Breck 1993). Efficient uses of rearing ponds requires knowledge of the relationship between stocking size and density, and the resulting growth and survival in order to maximize either numbers or sizes of fish produced and minimize chance of mass mortality (e.g., starvation).

This goal of this project was to address several topics related to pond rearing of age-0 lake sturgeon through specific objectives targeted at potential limiting phases of production. A major objective motivating this study was to estimate the optimal stocking density for age-0 lake sturgeon in these ponds and raceways, by measuring survival and growth at different densities (experiments 1 and 2). Survival was poor, and a series of experiments attempted to determine causes. We deployed temperature loggers each year to discover whether pond or raceway temperatures reached a stressful range. Pond experiment 3 was to evaluate whether intensive trapping to reduce crayfish density would (through decreased predation) increase juvenile lake sturgeon survival. The objective of pond experiment 4 was to evaluate whether adult largemouth bass *Micropterus salmoides* would alter crayfish behavior or density enough to improve lake sturgeon survival. Experiment 5 was conducted to compare the growth rates of juvenile lake sturgeon in the ponds with growth information for wild fish. The goal of experiment 6 was to determine the timing of juvenile lake sturgeon mortality.

Observations and experiments in laboratory aquaria were conducted to address additional issues. Lab experiment 1 was to assess whether crayfish could be predators on juvenile lake sturgeon. Lab experiments 2 and 3 were to evaluate the vulnerability of juvenile lake sturgeon to predation by largemouth bass. Because largemouth bass did not appear to voluntarily consume juvenile lake sturgeon, the goal of lab experiment 4 was to determine whether largemouth bass would eat lake sturgeon if tricked into ingesting them. Lab experiment 5 was to compare growth of largemouth bass force-fed lake sturgeon or bluegill. The objective of lab experiments 6-9 was to test for the possibility of chemical defense by juvenile lake sturgeon.

Methods

Experimental Ponds and Raceways

Experiments were conducted in ponds and outdoor raceways at the Saline Fisheries Research Station, Saline, Michigan. The earthen ponds have a surface area of about 0.25 hectare, mean depth of approximately 1 m, maximum depth of 2 m, and have little vegetation. Adjacent to the ponds are three successive pairs of raceways. Each raceway is approximately 36.7 m long, about 5.0 m wide and 1 m deep at the downstream end. Raceways in each pair are separated by a concrete wall. Additional information on the ponds and raceways is given by Latta and Merna (1976) and Merna and Queener (1977).

These ponds are productive and the food supply was expected to be good. Midge larvae are common in the diets of fish in these ponds (Latta and Merna 1976, Gray 1991, Gray et al. 1998), and midge larvae are a preferred food of juvenile lake sturgeon (Kempinger 1988, 1996; Volkman 2004). In experiments with bluegill the carrying capacity was estimated to be about 392 kg/ha (350 lb/acre), a high level compared to natural lakes (Clark and Lockwood 1990). The ponds contain the virile crayfish *Orconectes virilis*, and crayfish are a food source of adult and large sub-adult sturgeon (Hay-Chmielewski 1987).

Summer water temperatures in the Saline ponds may be near the upper range of temperature tolerance for juvenile lake sturgeon, so water temperatures are especially important for interpreting the results of these experiments. Water temperature in the ponds is typically highest in July; the July monthly average was 24.7°C for 1989-1995 (Appendix Table A1), and turned out to be even higher during several of the experiments. Water temperature is cooler in the raceways than in the ponds. Inflows to the ponds and the raceways are from the same source -- the deeper, cooler waters of a small reservoir on Koch Warner Drain, so cool inflow to the ponds during warm periods might provide a small thermal refuge area for juvenile lake sturgeon. Temperature loggers were deployed in ponds and raceways to record hourly water temperatures. The hourly temperature values were summarized as daily means and monthly statistics that included the minimum and maximum hourly value, the average daily range, and the cumulative degree days (for a base of 0°C).

In 1999 and thereafter, all inflow water passed through a 2-mm nylon net to remove fish and crayfish from water sources.

We conducted a series of six pond and raceway experiments (Table 1) and nine laboratory experiments (Table 2). The pond and raceway experiments are described first.

Pond Experiments on Growth and Survival

Pond and raceway experiments evaluated survival and growth of age-0 lake sturgeon at different stocking densities and under different conditions of potential predators. There was some variation in egg sources, the hatchery or laboratory where larvae and small juveniles were reared, rearing temperature, and the fish size and date of stocking into ponds or raceways (Table 1).

Pond Experiment 1: Lake sturgeon survival in ponds.–Lake sturgeon fry obtained from the Lake St. Clair Fisheries Research Station were in very good condition when stocked, based on visual assessment. Additional lake sturgeon fry obtained from USGS/BRD Great Lakes Science Center were in very poor condition when stocked. This second group of age-0 lake sturgeon was from the same lot of eggs as the first group, but due to cold rearing temperature and lower food ration, they were smaller in size and much thinner on July 24 than their siblings stocked on June 12 (Table 1).

During this first pond experiment we attempted to monitor growth of juvenile lake sturgeon in the ponds by capturing them with tube traps. These traps were made from corrugated, flexible plastic tile cut into tubes 30-40 cm long and about 10 cm in diameter. The traps were open at one end, with 2-mm nylon mesh covering the other end. A cord attached to a float was tied to a hole near the open end, and the tube was sunk to the pond bottom using a large carriage bolt. In theory, juvenile lake sturgeon would seek refuge in these tubes, especially during sunny days, where they could be captured by rapidly lifting the tube off the bottom.

In October 1998, personnel from the USGS/BRD Great Lakes Science Center attempted to capture juvenile sturgeon in the ponds using a diver-operated seine. In addition, two SCUBA divers made a visual search of one pond.

Pond Experiment 2: Lake sturgeon survival in ponds and raceways.–The objective of this experiment was to assess the effect of stocking density on growth and survival. One pond received 160 and another pond received 40 lake sturgeon, a 4-fold difference in number stocked. Because of concern about high water temperatures in the ponds, we also put 97 lake sturgeon into one of the six outdoor raceways where temperatures are typically several degrees cooler than the ponds.

Pond Experiment 3: Crayfish density effect on lake sturgeon survival in ponds.–We conducted an experiment to compare lake sturgeon survival in two control ponds with survival in two ponds where crayfish were trapped intensively. We also evaluated the potential effect on growth and survival of doubling lake sturgeon density from 100 to 200 per pond in two additional ponds where crayfish were trapped daily.

To initially remove crayfish, ponds were drained on July 20 and 21, 2000, which was 12-13 days prior to stocking of lake sturgeon. Many crayfish left the ponds through the drain pipe at draining; others crawled up the bank and walked to another pond, demonstrating overland movement between ponds. Prior to refilling, the ponds were held dry for several days during a hot spell in order to eliminate any remaining crayfish by desiccation or mammalian or avian predation.

Pond Experiment 4: Largemouth bass effect on lake sturgeon survival in ponds.–This experiment was intended to test whether presence of 50 adult largemouth bass per pond would improve survival of age-0 lake sturgeon in ponds containing crayfish. Results of previous experiments, as well as direct observations in the lab and in ponds (described below), indicated that adult crayfish can be predators of age-0 lake sturgeon, reducing their survival. Adult largemouth bass directly reduce the number of crayfish through predation. Presence of largemouth bass is also likely to have an indirect positive effect on lake sturgeon survival by altering the behavior of crayfish. In ponds with predators such as adult largemouth bass, crayfish are expected to be less active and spend more time in burrows, further reducing the encounter rate between crayfish and lake sturgeon. Based on laboratory experiments described later, we did not expect largemouth bass to ingest any lake sturgeon.

Each of four ponds received 100 age-0 lake sturgeon. Two ponds were previously stocked with 50 adult largemouth bass. The other two ponds were controls, with no other fish than the lake sturgeon.

To evaluate the effect of largemouth bass on crayfish density and behavior, we set three crayfish traps in each pond on August 7, 2002, baited with fresh pieces of bluegill. We retrieved the traps the next day, counted the crayfish and measured carapace length and determined sex.

We drained the ponds in spring 2003 and compared lake sturgeon survival in ponds with versus without largemouth bass. We expected much higher survival in ponds containing largemouth bass.

Pond Experiment 5: Monitoring lake sturgeon growth in ponds.–This experiment involved monitoring the growth of juvenile lake sturgeon in ponds where survival was also being evaluated. We measured subsequent growth of the survivors from pond experiments 2, 3, and 4 (Table 1).

Before stocking, fish were photographed individually in a shallow pan containing water to use natural variation in coloration as individual marks. We included a number in the pan with each fish (either on a floating wooden disk or marked on the pan with a wax pencil) so we could associate the measured length and weight with the fish in each photograph.

Raceway Experiment 6: Growth of lake sturgeon and timing of mortality in raceways.–The goals of this experiment were to monitor survival of juvenile lake sturgeon over short time intervals to determine when most mortality occurs and to monitor growth to confirm suitability of the raceways for juvenile lake sturgeon. We also attempted to determine effects of stocking density on growth.

Two raceways each received 10, 20, and 40 lake sturgeon. Raceways were drained every 10-14 days for the first two months, then every 1-4 months for the next 10 months to monitor survival and growth. The juvenile lake sturgeon were taken to the lab, measured for length (nearest 1 mm) and weight (nearest 0.01 g), and individually photographed before restocking.

Each raceway had been stocked earlier with 3 adult largemouth bass to control the abundance and behavior of crayfish. A digital temperature recorder was deployed in early spring 2004 at the downstream end of the raceways.

Laboratory Experiments on Vulnerability to Predators

A series of nine lab experiments was conducted using juvenile lake sturgeon (Table 2). In experiment 1 we observed crayfish and lake sturgeon in the lab to evaluate whether crayfish might be important as predators of age-0 lake sturgeon. Virile crayfish are typically present in the experimental ponds and raceways. In experiments 2 and 3, we tested whether largemouth bass would consume lake sturgeon when there was a choice of alternative prey (bluegill or fathead minnow *Pimephales promelas*). Because the largemouth bass did not appear to voluntarily consume juvenile lake sturgeon, experiment 4 evaluated whether largemouth bass could be tricked into ingesting them. Experiment 5 compared growth of largemouth bass fed either bluegill or age-0 lake sturgeon. The bass were force-fed these food items because the bass would not voluntarily ingest lake sturgeon. This led to four additional experiments (6-9, Table 2) looking for evidence of chemical defense by lake sturgeon.

Lab Experiment 1: Laboratory observations of interactions between crayfish and juvenile lake sturgeon.–Some brief observations of interactions between crayfish and lake sturgeon were made in the laboratory on August 3, 2000. First, two adult female crayfish (52.6 and 45.6 mm carapace length) and two age-0 lake sturgeon (77 and 83 mm) were placed in a gray tub (ca. 41 x 54 cm) filled with water to a depth of about 8 cm. The behavior of crayfish and lake sturgeon was observed for 15 min.

Second, a single large male crayfish (49.1 mm carapace length) was placed in the gray tub with the same two lake sturgeon. The behavior of the crayfish and the two lake sturgeon was observed for 20 min.

Third, the same two lake sturgeon were placed with three crayfish into a 161-liter aquarium (slate bottom, 43.5 cm wide, 90 cm long, filled to 41 cm deep). Both species were observed for several minutes. Then frozen midge larvae were introduced into the tank as food, and the interactions were observed and videotaped over the next 60 min.

Lab Experiment 2: Prey choice by largemouth bass: bluegill versus juvenile lake sturgeon.–Six juvenile largemouth bass in individual 37.8-liter aquaria were presented with equal numbers (two or three) of juvenile bluegill and age-0 lake sturgeon. For three successive days, the number of surviving prey was noted and then dead or consumed prey items were replaced with live prey.

Lab Experiment 3: Prey choice by largemouth bass: fathead minnow versus juvenile lake sturgeon.–We conducted a second prey-choice experiment to use a soft-rayed minnow as alternate prey. Twelve largemouth bass (same fish as used in experiment 9, see below) were held in individual 37.8-liter aquaria. Starting on July 30, 2002, two fathead minnows and two age-0 lake sturgeon were introduced into each aquarium. For three days, prey items that were consumed or found dead were replaced the next day. The average length of fathead minnows was 52±5 mm (N = 72). The average length of lake sturgeon was 79±10 mm (N = 26). For each bass, the larger of the two lake sturgeon was 35-40% of the bass' length. Largemouth bass swallow bluegills, a deep-bodied, spiny-rayed species, that are up to 40% of their length, so the bass would not be expected to have difficulty ingesting lake sturgeon of this relative size (Timmons and Pawaputanon 1980).

Lab Experiment 4: Lake sturgeon ingestion by largemouth bass.–Because largemouth bass did not voluntarily ingest juvenile lake sturgeon, we tried to trick the bass into ingesting them. We continued to hold the largemouth bass from experiment 3 in individual tanks, and each day released 1-5 fathead minnows one at a time by hand into each tank. After five days of such feeding, four bass were capturing each minnow within about 1 s after its entry into the tank. On the sixth day, we fed each of these bass a minnow, which was captured rapidly. Then we offered a lake sturgeon (74, 74, 77, 80 mm) to each of the four bass.

Lab Experiment 5: Growth of largemouth bass force-fed bluegill versus juvenile lake sturgeon.–This experiment attempted to compare growth of largemouth bass fed either bluegill or juvenile lake sturgeon to assess how bass would grow on a diet of lake sturgeon. Bass were held in individual 37.8-liter aquaria. Because largemouth bass would not voluntarily ingest lake sturgeon, we force-fed the prey items to the bass. In this 14-d experiment, four juvenile largemouth bass (initial weight: 28.18±2.71 g; mean±SD) were force-fed one bluegill per day, and four other largemouth bass (initial weight: 29.78±4.91 g) were force-fed one age-0 lake sturgeon each day. Weight of each prey fish was measured (nearest 0.01 g) just before feeding. Of the 56 feedings with bluegill, only one bluegill was regurgitated, and it was digested after being re-fed to the largemouth bass. Of the 56 lake sturgeon feedings, 21 resulted in regurgitation; on several additional occasions largemouth bass behaved as if they were attempting to regurgitate the lake sturgeon, but were not successful. Because the purpose was to evaluate predator growth, regurgitated lake sturgeon were re-fed up to two times to a predator unless regurgitation occurred during the night.

Lab Experiment 6: Testing for chemical defense by juvenile sturgeon.–Because largemouth bass would not voluntarily consume juvenile lake sturgeon in aquaria in lab experiment 2, and because of the regurgitation of lake sturgeon observed in lab experiment 5, we conducted an experiment to test whether chemical defense by juvenile lake sturgeon was influencing their vulnerability to fish predators.

Juvenile lake sturgeon have sharp scutes that could mechanically irritate a predator's mouth, esophagus, or stomach, possibly causing a predator to eject this prey type (Brown 2004). To reduce the possibility of mechanical irritation of the mouth or esophagus by scutes, pieces of juvenile lake sturgeon or fathead minnow were inserted into 10-mg gelatin capsules (ca. 25 mm in length, Fisher Scientific, gelatin capsules #00), and the capsules were force-fed to largemouth bass. If juvenile lake sturgeon have an irritating chemical in the skin or muscle, we expected that the chemical would induce regurgitation shortly after the gelatin capsule dissolved in the stomach. We conducted several experiments in which we force-fed juvenile largemouth bass with gelatin capsules containing either bluegill or lake sturgeon. (In lab experiment 9 we used fathead minnow instead of bluegill as the control food item.) These capsules fit easily into the fish's mouth and stomach.

The following precautions were taken to reduce the chance of transferring a potentially irritating chemical from lake sturgeon skin to other capsules. Capsules containing bluegill were prepared on a wooden board, then scalpel and forceps were washed with soap and water and rinsed thoroughly before preparing capsules containing lake sturgeon on a separate board. Capsules containing lake sturgeon "meat" (carcass excluding skin and head) were prepared on one half of the board, and capsules containing skin were prepared on the other half. In this first gelatin-capsule experiment, capsules contained either (1) pieces of bluegill, (2) lake sturgeon skin including scutes, (3) lake sturgeon meat, or (4) lake sturgeon skin trimmed to exclude scutes. In this experiment we used the same eight largemouth bass from the growth experiment (lab experiment 5). Though kept in individual tanks, the experimental design involved grouping largemouth bass in pairs according to their diet in experiment 3, with one fish that had been force-fed bluegill paired with one that had been force-fed lake sturgeon. Each type of capsule was given to each pair of fish for two consecutive days, for a total of eight days.

Lab Experiment 7: Testing for chemical defense by juvenile sturgeon.–Because previous force-feeding experience appeared to influence the regurgitation behavior of largemouth bass, we repeated the capsule feeding experiment (6) using eight naïve largemouth bass (41.0±6.5 g, 151±6 mm), also from the ponds at the Saline Fisheries Research Station. We used the same four types of capsules as in experiment 6. Individual bass received the same food for four consecutive days.

Lab Experiment 8: Testing for chemical defense by juvenile sturgeon.–We repeated lab experiment 7 with eight new bass. We modified the treatments, replacing capsules containing lake sturgeon skin including scutes with a new control: capsules containing only water. Thus, we used these four types of capsules: (1) pieces of bluegill, (2) water only, (3) lake sturgeon meat, or (4) lake sturgeon skin trimmed to exclude scutes. Individual bass received the same food for four consecutive days.

Lab Experiment 9: Testing for chemical defense by juvenile lake sturgeon.–This experiment was conducted to test whether largemouth bass would regurgitate lake sturgeon more frequently than fathead minnows, consistent with chemical defense by juvenile lake sturgeon. To evaluate whether the presumed defensive chemical was in the skin or the rest of the body, we compared three types of feeding capsules: (1) capsules containing lake sturgeon skin (with dorsal scutes removed, to reduce the possibility of mechanical irritation in the stomach); (2) capsules containing the rest of the body (but not the head); and (3) capsules containing pieces of fathead minnow, known to be a well-accepted prey item for largemouth bass. Each day for six days, four capsules of each type were prepared and one capsule was force-fed to each of twelve largemouth bass. Fathead minnow capsules were prepared first. Following rapid decapitation, a fish was cut into pieces that would fit into a 1-inch long, 0.25-inch diameter gelatin capsule, and the capsule was immediately force-fed to a designated largemouth bass. After the four minnow capsules had been prepared and fed, we thoroughly washed the plastic cutting board, scissors, and scalpel in running tap water, changed latex gloves, and switched to a second set of instruments and cutting board. Following rapid decapitation of a lake sturgeon, the dorsal scutes were dissected out and the skin was separated from the rest of the carcass and placed in one capsule. The carcass (without the head) was placed in another capsule, and then capsules were immediately force-fed to designated largemouth bass. Starting on the second day of the experiment, at the conclusion of the force-feeding, one live fathead minnow was placed in each of the twelve aquaria to provide additional food for the bass. Each day we recorded whether or not regurgitated food was observed in each tank in the 24 h after feeding.

With three types of capsules (skin "S", carcass "C", fathead "F"), there are six ways to give one of each type: SCF, SFC, FSC, FCS, CSF, CFS. Each sequence was randomly assigned to one acclimated and one unacclimated bass in each 3-d period. Thus, each bass received two capsules of each type during the 6-d experiment. For the second 3-d period, each capsule was trimmed prior to filling so that the length was ¾ inch, rather than the original 1 inch.

The experiment used twelve largemouth bass (214±27 mm in length; 132±48 g in weight; mean±SD) kept in individual 37.8-liter aquaria. All bass were obtained from ponds at the Saline Fisheries Research Station. Six of the bass ("acclimated") were held in their aquaria for at least six weeks. They appeared to be well acclimated to the holding conditions and readily fed on fathead minnows placed in their tanks. Six other bass ("unacclimated") were caught by angling 4-5 d before the start of the experiment. These were considered to be unacclimated to the lab conditions at the start of the experiment. Water temperature in each aquarium was measured daily with a digital thermometer; daily average temperature varied between 22.7 and 24.9°C.

Results

Pond Experiments on Growth and Survival

Pond Experiment 1: Lake sturgeon survival in ponds.–No lake sturgeon were captured in the tube traps that had been deployed. No lake sturgeon were caught or seen by SCUBA divers using a diver-operated seine. No lake sturgeon were seen by two SCUBA divers that searched the clearer stocked pond in October 1998 (the other pond was considered too turbid for visual search to be successful).

When the two ponds were drained in late fall, 119 and 123 d after stocking, no juvenile lake sturgeon were recovered (Table 3). However, we found 213 age-0 largemouth bass, with a mean length of 160 mm (range: 112-233 mm). It is not known how these fish got into the pond; it might have been through the inflow pipe. The presence of these bass stimulated us to deploy nets to strain the pond inflow water in subsequent experiments.

At the end of this (1998) experiment we thought that the failed survival of the age-0 lake sturgeon might have been due to high water temperatures. Data from a recording digital thermometer indicated that water temperature in Pond 5 reached a maximum hourly value of 29.2°C on July 17, 1998, and that the average daily temperature ranged from 27.1°C to 28.0°C during July 17-23 (Figure 1, see also Appendix Table A3). The temperature was probably very similar in Pond 6, where the first group of age-0 lake sturgeon had been stocked on June 12. Lake sturgeon were not stocked into Pond 5 until July 24, after the period of highest temperatures. The condition of those lake sturgeon fry at stocking on July 24 was very poor, and they had been raised in cold water, so the high pond water temperatures in mid-July probably caused most of the mortality. It is possible that any lake sturgeon fry surviving the warm temperatures could have been eaten by crayfish (but unlikely they were eaten by the juvenile largemouth bass, as described below).

Pond Experiment 2: Lake sturgeon survival in ponds and raceways.–The two stocked ponds were drained in October 1999, and ten of the 200 lake sturgeon were recovered (Table 4). The day before draining, as the pond water level was being lowered, about twelve lake sturgeon were sighted in Pond 8. Of 40 lake sturgeon fry stocked into Pond 8, only three lake sturgeon were recovered (7.5%

survival; 28.9±6.2 g in weight; mean±SD; 208±19 mm TL, including two fish with caudal fin damage). We observed feces and tracks of a single Great Blue Heron that had walked a distance of about 15 m through the pond (without meandering) as the water level was being lowered for draining. This heron may have captured some lake sturgeon. Of 160 lake sturgeon fry stocked into Pond 7, seven lake sturgeon were recovered (4.4% survival; 25.5±6.9 g in weight; 186±27 mm TL, including four with caudal fin damage). Adult crayfish were present in both ponds.

When the stocked raceway was drained in September, none of the 97 lake sturgeon fry were recovered (Table 4). Present were large numbers of adult crayfish (few juveniles were seen), two juvenile white suckers *Catostomus commersonii*, two mottled sculpins *Cottus bairdii*, three central mudminnows *Umbra limi*, twenty five brook sticklebacks *Culaea inconstans*, and one fathead minnow.

High temperature was a problem in the ponds. During the 10-d period from July 24 to August 2, 1999, the mean daily temperature in Pond 7 was 27.8°C, reaching a high of 30.1°C on July 31 (Figure 2). Similar values were measured in Pond 5 (Table A4). High water temperature was very likely responsible for the low survival in Ponds 7 and 8.

Water temperatures in the raceways tend to be several degrees cooler and to have larger daily fluctuations than in the ponds (Figure 2, Tables A4 and A5). During the 10-d period from July 24 to August 2, 1999, the mean daily temperature in Raceway 1 North was 19.7°C, which was 8.1°C cooler than Pond 7, and the mean daily water temperature did not exceed 22.0°C (Figure 2). During August 1999, the average daily range in the raceway was 5.6°C (Table A5), compared to 1.9°C in Pond 5 (Table A4). Raceway temperatures were cooler after that (Figure 2, Table A5). We conclude that high temperature was not responsible for the zero survival in Raceway 1 North. Some factor other than temperature contributed to the low survival in the cooler raceway.

After measuring the ten surviving lake sturgeon, we released them into Pond 9. Within five minutes, adult crayfish had approached the fish and grabbed the caudal fin or peduncle of three of the lake sturgeon that had been resting on the substrate. All three lake sturgeon struggled to escape. We lifted one attacked lake sturgeon from the water and the crayfish came, too, holding on to the fish's caudal fin. The crayfish was removed and the lake sturgeon was tossed into deeper water. Crayfish are abundant in these ponds and in the outdoor raceways. Predation by crayfish seems likely to have contributed to the poor survival of age-0 lake sturgeon in these experiments.

Pond Experiment 3: Crayfish density effect on survival in ponds.–To try to reduce the abundance of these potential predators, crayfish were intensively trapped from four ponds; two ponds were controls (no crayfish trapping). A total of 16,528 crayfish were trapped and removed during August-November, 2000 (Table 5). Because of various constraints only four of the six ponds were drained in late fall 2000. Six lake sturgeon survivors were recovered (1% survival) (Table 6). The other two ponds were drained in June 2001; no survivors were recovered. Trapping crayfish did not appear to improve survival of the lake sturgeon (Table 6). Water temperatures exceeded 25°C during several days in August and early September (Figure 3, Table A6), and may have been largely responsible for the high mortality rates.

Although the initial pond drying left no crayfish visible in the treatment ponds at the start of this experiment, and although a very large number of crayfish were trapped from the ponds, crayfish were still observed in the ponds at draining. Crayfish could have contributed to the poor survival of the lake sturgeon. Crayfish move over land from pond to pond, especially when the ground is wet after a rain, so our trapping was not as effective as we had hoped in controlling crayfish numbers.

The six survivors from November 2000 were restocked into Pond 6 and Pond 7, three fish into each, and crayfish trapping ceased. One of the three fish was recaptured when Pond 6 was drained June 14, 2001, and two of the other three fish were recaptured when Pond 7 was drained July 3, 2001, for a total of 50% survival over 7-8 months, a much better survival rate for these larger juveniles. The good growth of these fish is described below with pond experiment 5.

Pond Experiment 4: Largemouth bass effect on lake sturgeon survival in ponds.–We attempted to control the abundance and behavior of crayfish by stocking adult largemouth bass before stocking lake sturgeon. Catches from three crayfish traps per pond that were deployed on August 7, 2002, suggested that largemouth bass had influence on the density or behavior of crayfish. The two control ponds averaged 38 and 26 crayfish per trap, with mean±SD carapace length of 40.3±4.2 mm for Pond 5 and 43.4±9.2 mm for Pond 7. (One trap failed in Pond 7; it came open in the pond.) Of two ponds stocked with largemouth bass, one (Pond 6) had no crayfish in any of three traps. The other (Pond 9) averaged 35.7 crayfish per trap, no different than control ponds, but mean±SD carapace length of 28.3±5.8 mm was much smaller than for control ponds, indicating predominance of a younger age-class of crayfish. Bass may have had a dramatic effect on the density or behavior of crayfish in Pond 6, but appear to have had a smaller effect in Pond 9.

We drained the four ponds in April 2003 (Table 7). By that time the adult largemouth bass appeared to have been effective in reducing the number of crayfish. The total weight of crayfish recovered at draining was 100.0 lbs (Pond 5) and 19.8 lbs (Pond 7) in the two ponds without largemouth bass versus 2.2 lbs (Pond 6) and 4.7 lbs (Pond 9) in the two ponds with largemouth bass.

The presence of largemouth bass did not result in a substantially higher survival of juvenile lake sturgeon (Table 7). Of the 100 lake sturgeon stocked into each of four ponds, only one juvenile lake sturgeon survived (0.25%); it was recovered in a pond containing largemouth bass. One probable explanation is that the bass had not had sufficient time in the pond to reduce the numbers of crayfish before lake sturgeon were stocked, so the crayfish caused lake sturgeon mortality before the bass reduced crayfish numbers to low levels. High water temperature may have been responsible for the low survival. There were extended periods in July and August when the water temperature was above 25°C (Figure 4, Table A8).

Of the 50 adult largemouth bass stocked into each of two ponds in May 2002, we recovered 46 (92%) in Pond 6 and 41 (82%) in Pond 9 in April 2003. Reproduction had occurred in 2002 in each of these ponds. We recovered 20.5 pounds of age-1 largemouth bass in Pond 6 and 11 pounds of age-1 largemouth bass in Pond 9.

Pond Experiment 5: Monitoring lake sturgeon growth in ponds.–Although pond survival was poor, growth was very good (Table 8). In pond experiment 2, the ten survivors grew at a specific growth rate of 4.8% body weight per day for the 83-d period. These ten survivors were photographed and released the same day into Pond 9. When this pond was drained again in April 2000 (six months later), we could identify the three survivors, using photographs, based on the natural individual variation in spots and patches of color on the head, back and fins. Over winter, they had doubled in mass, gaining an average of 30±8 g in mass and 29±7 mm in length. This pond was drained again in July 2000, and two lake sturgeon were recovered. Again based on photographs, we were able to identify which individuals survived. From April to July 2000 these two fish increased more than three times in mass and gained an average of 138±10 mm in length. After exactly one year of growth in Saline ponds, these two age-1 lake sturgeon had reached 161 and 249 g in weight and 323 and 376 mm in length.

In pond experiment 3, the six survivors grew at a specific growth rate of 3.0% body weight per day for the 119-d period. The survivors were photographed and restocked into two ponds. When these ponds were drained the following summer, significant growth had occurred between November and July. After almost one year of growth in Saline ponds, three age-1 lake sturgeon had reached 295, 370, and 387 mm in length (Table 8).

In pond experiment 4, the single survivor grew at an average rate of 1.5% body weight per day during the 255-d period from July to the following April. From the stocking size (2.0 g mean weight, 81 mm mean length), the single survivor had grown to 97.3 g and 275 mm. The fish appeared to be in excellent condition.

While draining a pond in 2005, we found one lake sturgeon that was a survivor from one of the pond experiments done several years earlier (probably stocked in 1999 or 2000). This individual was 730 mm in length and appeared to be in very good condition. This reflects rapid growth in length, because it exceeds the Michigan average length of an age-8 fish, which is 699 mm, according to Baker (1980). This individual was recaptured in November 2009 and had grown to 1003 mm, close to the average length of an age-14 fish (Baker 1980).

Raceway Experiment 6: Timing of survival and growth of lake sturgeon in raceways.–Rearing lake sturgeon in the raceways allowed us to nearly eliminate high water temperature as a significant cause of mortality (Figure 2). Because the raceways can be more easily and quickly drained and refilled than the ponds, raceway rearing also permitted us to closely monitor survival and growth in length and weight. Most lake sturgeon (81.4%) died during the first 14 days, and 90.7% had died by day 23 (Table 9). Water temperature in the raceways was relatively cool during this period, only going above 20°C for a few hours (Figure 5), so high water temperature is unlikely to have caused mortality. Presence of three adult largemouth bass in each raceway was not sufficient to prevent lake sturgeon mortality.

Growth in length and weight of survivors was rapid in the raceways (Table 9), as it was in the pond studies (Table 8). According to Baker (1980), mean length of wild lake sturgeon at age 1 is 152 mm (6.0 inches), with an estimated weight of 17.3 g. The surviving age-0 lake sturgeon in our experiment had exceeded that average value by the end of September and they continued to grow to December (Table 9). The rapid growth suggests that the mortality in the raceways was not due to low food availability.

After almost exactly 1 year in the raceways, only one fish survived, representing a survival rate of 0.7% of the initial 140 fish. According to Baker (1980), age-2 fish average 279 mm (11.0 inches), with an estimated weight of 116 g. The surviving age-1 lake sturgeon in this experiment had already exceeded that average value for length (293 mm), but was smaller in weight (79 g) than Baker's age-2 fish.

Laboratory Experiments Evaluating Vulnerability to Predators

Lab Experiment 1: Observations of interactions between crayfish and juvenile lake sturgeon.–Given our direct observation in October, 1999, of crayfish attacks on 190-mm age-0 lake sturgeon, crayfish predation on juvenile lake sturgeon may be a factor influencing survival in ponds and raceways. Crayfish were present in all experimental ponds and raceways in all years. Some brief observations of crayfish-lake sturgeon interactions were made in the laboratory in order to explore the potential for predation by crayfish on juvenile lake sturgeon.

On August 3, 2000, two adult female crayfish (52.6 and 45.6 mm carapace length) and two age-0 lake sturgeon (77 and 83 mm) were placed in a gray tub (ca. 41 x 54 cm) filled with water to a depth of about 8 cm. During a 15-min observation period, crayfish did not attack the fish, even when a crayfish walked over the top of the resting lake sturgeon. In a second 20-min observation period with a single large male crayfish (49.1 mm carapace length), the two lake sturgeon were not attacked, although the crayfish touched the fish with its antennae.

When the two lake sturgeon were placed with these three crayfish into a 161-liter aquarium (slate bottom, 43.5 cm wide, 90 cm long, filled to 41 cm deep), both species seemed to ignore each other until frozen midge larvae were introduced into the tank as food. Within a few minutes one lake sturgeon and the large male crayfish moved toward the same aggregation of midge larvae that had sunk to the bottom of the tank. Both individuals started ingesting midge larvae. When a lake sturgeon swam close to the crayfish, the crayfish grabbed it with its two large chelae ("claws"), and then slowly ate the fish over the next 60 min. The capture and ingestion was videotaped.

Lab Experiment 2: Prey choice by largemouth bass: bluegill versus juvenile lake sturgeon.–In this prey choice experiment involving six juvenile largemouth bass followed for three days, almost all bluegill prey were consumed or dead by the next day. No age-0 lake sturgeon died and none were ever observed being ingested by the bass.

Lab Experiment 3: Prey choice by largemouth bass: fathead minnow versus lake sturgeon.–This lab experiment found that largemouth bass in aquaria do not voluntarily ingest age-0 lake sturgeon when given a choice between two lake sturgeon and two fathead minnows. For twelve bass over three days, 63 fathead minnows were consumed and 6 were found dead (presumably killed by the bass, based on apparent injuries). No lake sturgeon were consumed, but two were found dead in one tank (no injuries were obvious). Often, fathead minnows were ingested within a few minutes of being placed in the tanks, and in such cases the only prey items available for the rest of the 24-h period were the two lake sturgeon, yet none were consumed.

Lab Experiment 4: Lake sturgeon ingestion by largemouth bass.–Because the largemouth bass did not voluntarily ingest juvenile lake sturgeon, we tried to trick the bass into ingesting them. Two of the four bass engulfed a lake sturgeon, but spit it out immediately; the other two bass did not ingest the lake sturgeon. All four lake sturgeon, including the two that had been briefly ingested by bass, were still alive in the bass aquaria 48 h later. The next day another lake sturgeon (67 mm) was offered to one of the four bass. The bass engulfed it very quickly and then spit it out very quickly. We then offered three minnows, which were promptly consumed, indicating that the bass was hungry. These observations are further evidence that largemouth bass do not prefer to ingest juvenile lake sturgeon. The reason for this behavior is probably the sharp scutes of juvenile lake sturgeon (Brown 2004).

Lab Experiment 5: Growth of largemouth bass force-fed bluegill versus juvenile lake sturgeon.–This experiment attempted to assess whether bass would grow as well on a diet of juvenile lake sturgeon as on a diet of bluegill. Two groups of largemouth bass were given similar total amounts of food over the 14 days: 16.9±0.1 g bluegill; 17.5±1.1 g lake sturgeon. Bass fed bluegill retained all the food (in one case after one re-feeding). In contrast, fish that were fed lake sturgeon only retained 12.9±2.1 g during the 14 days. This was due to regurgitation, despite the re-feeding that was done when the regurgitation was observed.

Largemouth bass that were force-fed bluegill gained an average of 4.52±0.40 g (mean±SD) over their initial weight of 28.18±2.71 g, an average weight gain of 1.1%/d. In contrast, largemouth bass force-fed lake sturgeon lost an average of 0.21±0.68 g from their initial weight of 29.78±4.91 g, an average change of -0.1%/d. The difference in growth between the two groups of bass is consistent with the difference in the amount of food retained. The regurgitation by the bass of so many juvenile lake sturgeon prevented a direct comparison of growth on these two potential prey items.

Lab Experiment 6: Testing for chemical defense by juvenile sturgeon.–The regurgitation observed in lab experiment 5 prompted us to test for chemical defense by juvenile lake sturgeon. The largemouth bass used in this experiment were the same eight fish used in the force-feeding experiment (lab experiment 3). The results of this 8-d test for chemical defense differed according to previous feeding history of the largemouth bass. During the first two days, the four largemouth bass previously force-fed lake sturgeon regurgitated none of the food from the capsules, whereas largemouth bass previously force-fed bluegill regurgitated neither of the two bluegill capsules, but at least some of the contents of all six lake sturgeon capsules (i.e., both capsules of all three types). Over the entire 8-d experiment, largemouth bass previously force-fed lake sturgeon regurgitated only 3 of 32 capsules (one containing bluegill, one containing lake sturgeon skin with scutes, one containing lake sturgeon skin without scutes), whereas largemouth bass previously force-fed bluegill regurgitated 18 of 32 capsules (six capsules of lake sturgeon skin without scutes, and four capsules each of the other three types). These results show that regurgitation behavior depends on recent feeding experience, that regurgitation can occur in the absence of scutes, and that initial experience with lake sturgeon as food is likely to produce regurgitation behavior.

Lab Experiment 7: Testing for chemical defense by juvenile lake sturgeon.–In order to avoid effects of previous force-feeding experience that were seen in experiment 6, this experiment used bass that had not been force-fed previously. Regurgitation occurred in only 5 of 32 capsule feedings: one with bluegill, two with lake sturgeon skin with scutes, two with lake sturgeon skin without scutes, none with lake sturgeon meat. If there is a chemical in juvenile lake sturgeon skin that causes regurgitation by bass, it does not appear to cause that response consistently. According to these results, such regurgitation might occur in 4 of 16 capsules with lake sturgeon skin. Perhaps the chance is slightly higher if the single bluegill capsule regurgitated indicates a low background chance that any capsule (regardless of contents) will be regurgitated.

Lab Experiment 8: Testing for chemical defense by juvenile lake sturgeon.–In this 4-d experiment, regurgitation occurred in only 6 of 32 capsule feedings, but all involved capsules with juvenile lake sturgeon skin. Bass regurgitated 6 out of 8 capsules with lake sturgeon skin without scutes, 0 of 8 water capsules, 0 of 8 with bluegill, 0 of 8 with lake sturgeon meat. Suppose the chance was 6/32 = 0.1875 that any individual capsule would be regurgitated, regardless of capsule type. Then the probability that 6 of 8 skin capsules would be regurgitated and none of the other 24 non-skin capsules would be regurgitated is $P = 3.62 \cdot 10^{-10}$. So this result is highly unlikely by chance alone. This result is very suggestive of a chemical being present in the skin of juvenile lake sturgeon that causes regurgitation by largemouth bass. However, it is not clear why this result was so much stronger than previous capsule-feeding experiments.

Lab Experiment 9: Testing for chemical defense by juvenile lake sturgeon.–We attempted to confirm the intriguing results observed in lab experiment 8. But in this next capsule-feeding experiment we did not find evidence for chemical defense by juvenile lake sturgeon. Out of a total of 72 capsules fed to 12 largemouth bass, the bass regurgitated 11 capsules (15%): 5 of 24 fathead minnow capsules, 4 of 24 carcass capsules, and 2 of 24 skin capsules. (A twelfth capsule, containing sturgeon skin, was regurgitated within 10 s of force-feeding. The capsule was still intact, and it was immediately re-fed to the bass. Because of the extremely short interval before regurgitation, because the capsule was intact, and because the re-fed capsule was not regurgitated, this event was not included in the total number of regurgitations.) The bass did not regurgitate capsules containing lake sturgeon more frequently than capsules with fathead minnows: 5 of 24 or 21% of fathead minnow capsules, versus 6 of 48 or 12.5% of lake sturgeon capsules. These results are not consistent with a hypothesis of a chemical defense by juvenile lake sturgeon.

Of the 11 regurgitations, 10 were by acclimated bass and 1 (a skin capsule) was by an unacclimated bass. The pattern of regurgitations was influenced more by the acclimation state of the bass than by the type of capsule. Perhaps unacclimated bass were hungrier and thus less likely to regurgitate items in their stomach.

It is conceivable (but seems unlikely) that juvenile lake sturgeon have a chemical defense that acts only on the mouth or esophagus and is less effective or rapidly deactivated in the stomach of fish predators. Perhaps a defensive chemical is associated with the head, which was removed in this experiment. In such cases our experiment would not have detected a chemical defense. Although this experiment does not completely exclude the possibility of a chemical defense by juvenile lake sturgeon, it does not provide support for such a hypothesis.

Discussion

In order for pond rearing to be a useful method for growing juvenile lake sturgeon, growth must be good and survival must be acceptable. In the initial pond and raceway experiments, survival of age-0 lake sturgeon was very poor, so we sought to determine the factor or factors responsible for high mortality. We considered several hypotheses to be unlikely: insufficient food quantity or quality; poor water quality; and stocking-related mortality, such as rapid change in water temperature. Based on our experiments, we consider fish predation to be unlikely as a cause of poor survival, at least for this size of juvenile lake sturgeon and largemouth bass as the potential predator (fish predation may be an important mortality source for larval lake sturgeon). We considered two hypotheses to be more likely responsible for mortality: predation by crayfish and high water temperatures.

We did not directly measure food quantity or quality in the pond experiments, and juvenile lake sturgeon are known to use large quantities of food. For example, Volkman et al. (2004) fed various diets of bloodworms and brine shrimp to juvenile lake sturgeon at a rate of 30% of their wet body weight per day, resulting in a specific growth rate of 2.6% BW/d for the group fed bloodworms. However, the hypothesis of insufficient food quantity or quality would mean that lake sturgeon died due to starvation, which is contradicted by the good growth of the survivors (see results for pond and raceway experiments, Tables 8 and 9). In previous studies, other fish species have grown quite well in these ponds and raceways (Schneider 1975; Clark and Lockwood 1990; Breck 1993). In pond experiment 3 we let the ponds stand dry for a few days of hot weather in order to eliminate crayfish, so this probably reduced the density of some invertebrate prey. However, the observation of many midge exuviates shortly after stocking the ponds with lake sturgeon indicates that many invertebrate prey survived the drying, with some later emerging and leaving exuviates behind. It is known that midge larvae (and probably other invertebrates) burrow into the sediment, and that larger instars tend to burrow deeper (Shiozawa and Barnes 1977); this probably reduces their vulnerability to temporary drying of the pond.

We consider it very unlikely that poor water quality caused the high mortality of juvenile lake sturgeon. Water for all the ponds and raceways at the Saline Fisheries Research Station comes from a common source and we did not observe mortality of other species (e.g., bluegill, largemouth bass, fathead minnow) in other ponds and raceways.

We minimized stocking mortality due to rapid temperature change. At the time of stocking fish from the hatchery, we allowed the temperature to slowly become adjusted to the temperature of the receiving water. When released to the receiving water, fish appeared to swim normally and no unusual behavior was noted. We do not believe that the large mortality was due to stress at stocking.

We believe that predation by crayfish was at least partly responsible for the high mortality of juvenile lake sturgeon in our experimental ponds and raceways. Observations in the lab (lab experiment 1) provide direct evidence that crayfish (*O. virilis*) can capture and consume juvenile lake sturgeon (about 80 mm in length). Following re-stocking of some larger individuals in pond experiment 2, we observed adult crayfish approach and grab three juvenile lake sturgeon (193±26 mm) that were resting in the shallow water of the pond. This observation confirms that crayfish will attack juvenile lake sturgeon in ponds. Crayfish are common in ponds and raceways at the Saline Fisheries Research Station and are a plausible cause of the high lake sturgeon mortality we observed. Even in those experiments where we attempted to reduce crayfish density by drying the ponds and trapping (pond experiment 3) or by stocking adult largemouth bass (experiment 4 in the ponds and experiment 6 in the raceways), the remaining number of crayfish may have been high enough to cause the observed mortality. Future attempts to rear juvenile lake sturgeon in ponds should include minimizing the number of crayfish.

High water temperature may have been the major cause of mortality of juvenile lake sturgeon in our pond experiments. Juvenile lake sturgeon grew well at 16-18°C in the lab experiments of

Volkman et al. (2004), with no mortality during their 10-week experiments (Trent Sutton, University of Alaska Fairbanks, personal communication). In contrast, Wehrly (1995) observed about 30% mortality in 28 days in groups of juvenile lake sturgeon held at 15 and 19°C. Wehrly (1995) found the most rapid growth at 23°C, but also the highest 28-d mortality: 45% (55% survival). If mortality continued at a similar rate, there would be 70% mortality (0.3025 survival = 0.55·0.55) after 56 days, and so on. Therefore, low survival at water temperatures of 23°C and higher would be consistent with Wehrly's lab findings for 23°C. The Saline ponds typically average 24.7°C in July (*N* = 7 years, Table A1), but temperature was even higher in the years of our experiments: 26.1°C in 1998 (Table A3), 28.0°C in 1999 (Table A4), 27.1°C in 2001 (Table A7), and 27.4°C in 2002 (Table A8). Based on Wehrly (1995), some high-temperature mortality would be expected.

Other species of sturgeon can at least tolerate water temperatures near 25°C, and some can survive and grow well at this temperature. Secor and Gunderson (1998) conducted several 10-d experiments with juvenile Atlantic sturgeon *Acipenser oxyrinchus* (8-30 g wet weight) at 19°C and 26°C. They observed no mortality with normal levels of dissolved oxygen (~7 mg/L), though mortality did occur in their hypoxic treatments (~3 mg/L). Building on a previous study at 20°C with juvenile white sturgeon *Acipenser transmontanus* (Hung and Lutes 1987), Hung et al. (1993) conducted 8-week experiments at 23°C and 26°C. They reported no mortality during their study, and the white sturgeon at 26°C grew from 30 g to an average of 88 to 125 g, depending on feeding rate. They concluded that the optimal temperature for growth of white sturgeon was closer to 23°C than to 20 or 26°C. Allen et al. (2006) reared juvenile (0.1 g) green sturgeon *Acipenser medirostris* at 19 and 24°C at ad libitum rations for 50 days, and found faster growth at the higher temperature. Survival was generally good, although one tank at 24°C had an unexplained die-off that left only 6 survivors. Mayfield and Cech 2004) reported that bioenergetics performance of green sturgeon peaked between 15 and 19°C. They observed significant handling mortality of age-1 green sturgeon at 24-25°C. They used a regression equation to estimate 27°C as the lethal temperature for green sturgeon (Mayfield and Cech 2004). Ziegeweid et al. (2008) acclimated juvenile (0.6 to 35.0 g) shortnose sturgeon *Acipenser brevirostrum* to 19.5 and 24.1°C and estimated the critical thermal maxima as 33.7 and 35.1°C, respectively, for these two groups, and lethal thermal maxima as 34.8 and 36.1°C, respectively. It would be worthwhile to conduct additional laboratory experiments with juvenile lake sturgeon to determine upper thermal limits for this species and to resolve differences between previous studies in survival and growth at high temperatures (Wehrly 1995; Volkman et al. 2004; Ziegeweid et al. 2008).

The upper thermal limits for lake sturgeon may increase with size or age. Although we observed poor survival of age-0 lake sturgeon in the ponds, there was one individual that survived for several years. This fish was 730 mm in 2005 and was 1003 mm when recaptured in late 2009, after surviving four more years in one of the ponds. This individual, at least, was able to tolerate the high summer water temperatures in the ponds.

Not all the mortality in our experiments can be attributed to high temperature. In experiment 2, Raceway 1 North had a mean daily water temperature of 22°C on July 24, 1999, and was cooler than that for the rest of the experiment (Figure 2, Table A5), yet the juvenile lake sturgeon suffered 100% mortality; crayfish were present. In raceway experiment 6, where crayfish were also present, we found 81% mortality during the first 14 d, but water temperature was only above 20°C for a few hours (Figure 5). We conclude that high water temperature was not the cause of mortality in the raceways.

Predation by Great Blue Heron and Kingfisher may also have contributed to lake sturgeon mortality, especially when the ponds were being lowered prior to draining (see results for pond experiment 2). However, we do not believe that birds were responsible for the majority of the mortality.

This study demonstrates good growth by surviving juvenile lake sturgeon in our ponds and raceways. As noted in the results for pond experiment 5, the 83-d growth rate of 4.8% BW/d is higher than the 2.6% BW/d observed by Volkman et al. (2004) in their lab experiments, where fish were fed 30% of their body weight per day. By the following April the age-1 survivors in our study had grown to 59±16 g in weight and 219±24 mm in length. After almost exactly one year of growth in the ponds, two age-1 fish were 161 and 249 g in weight and 323 and 376 mm in length. A similar rapid specific growth rate of 3.0% BW/d was observed in 2000. Survivors reached 73.4±14.3 g in weight and 243±21 mm in length by late November, and after almost one year of growth three survivors had reached 295, 370 and 387 mm in length. According to Baker (1980), Michigan lake sturgeon reach a mean length of 152 mm by age 1 and 279 mm by age 2. The survivors in our experiments grew faster than these average values for wild lake sturgeon.

Chemical defenses against predators have been demonstrated not only in many species of terrestrial arthropods (Eisner 1970), but also in aquatic organisms (Hay 1996), including beetles (Gerhart et al. 1991), water mites (Kerfoot 1982), and fish (Tachibana et al. 1984). In fact, skin secretions toxic to fish have been reported in 60 species of fish from 18 different families (Kalmanzon et al. 1999). Based on pond experiments and observations from previous years, we hypothesized that age-0 lake sturgeon might have a chemical defense, possibly in the skin, that would cause fish predators to regurgitate them if they were ingested. Despite one result that was very suggestive of a chemical defense in lake sturgeon (lab experiment 8), the combined results of our experiments do not support the existence of a chemical defense by juvenile lake sturgeon against fish predators.

Largemouth bass reject juvenile lake sturgeon as prey, at least juveniles larger than about 75 mm (lab experiments 2, 8 & 9). Larval lake sturgeon were not tested in the experiments described here, but recent research at Michigan State University suggests that larval lake sturgeon are ingested by fish predators (Kim Scribner, Michigan State University, personal communication). The rejection of juvenile lake sturgeon by largemouth bass seems to be due to the sharp scutes, which are present on the back and sides (Brown 2004). The scutes do not deter predation by crayfish.

Management Implications

Water temperature is important for successful rearing of juvenile lake sturgeon. The experimental ponds at the Saline Fisheries Research Station get too warm during summer months for good survival of age-0 lake sturgeon, based on measured water temperatures (Figures 1-4) and the laboratory growth experiments of Wehrly (1995). The Saline outdoor raceways have better temperatures for sturgeon growth and survival, with mean daily temperatures rarely getting above 20°C.

Crayfish appear to be capable of causing high mortality of age-0 lake sturgeon as we documented in pond and aquarium conditions. Crayfish may be an important cause of mortality of age-0 lake sturgeon in rivers and lakes when crayfish are abundant.

Largemouth bass are not likely to prey on juvenile lake sturgeon. Largemouth bass may be useful in controlling the density and behavior of crayfish or other fishes in lake sturgeon rearing ponds if introduced one week or more before lake sturgeon are introduced.

Natural spots on the body, head, and fins can be used as natural marks to identify individual lake sturgeon during the first year of life. Individuals can be recognized from dorsal photographs. The spots and marks tend to increase in number and size during the first year, so identification is easier the more frequently the photographs are taken.

Rearing of juvenile lake sturgeon in earthen ponds or outdoor raceways can result in good growth during the first year, exceeding the typical growth rates for wild juveniles.

If survival can be improved, pond rearing could be a low-cost method to grow juvenile lake sturgeon. But if survival cannot be improved, pond rearing is not feasible.

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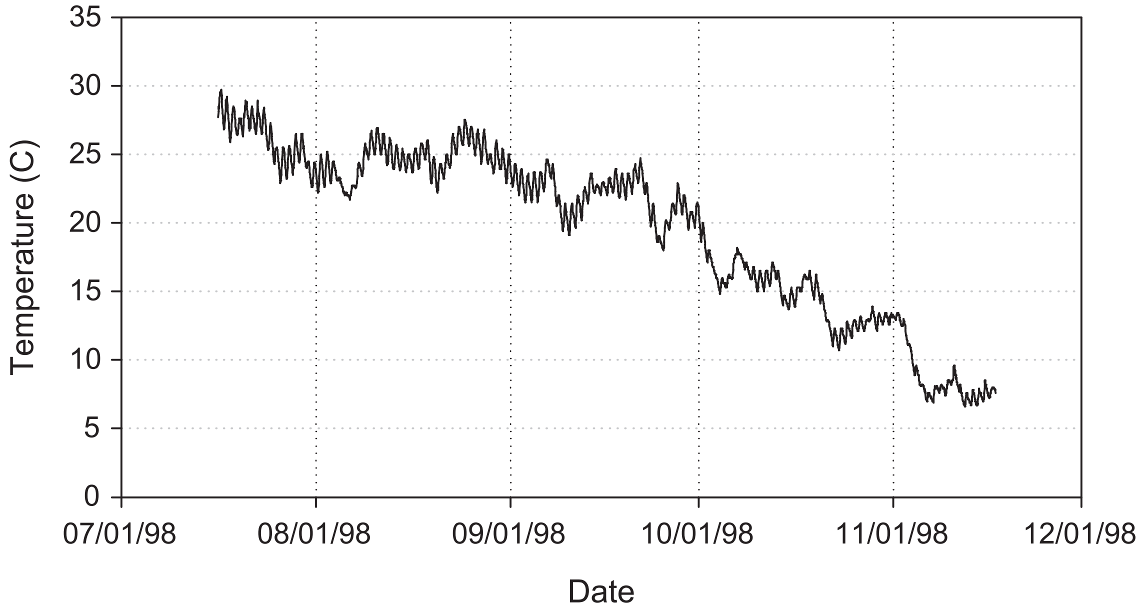

Figure 1.–Hourly water temperature (°C) for experiment 1 in Pond 5 from July 16 (8 d before stocking) until November 17 (3 d before draining), recorded with a digital temperature logger.

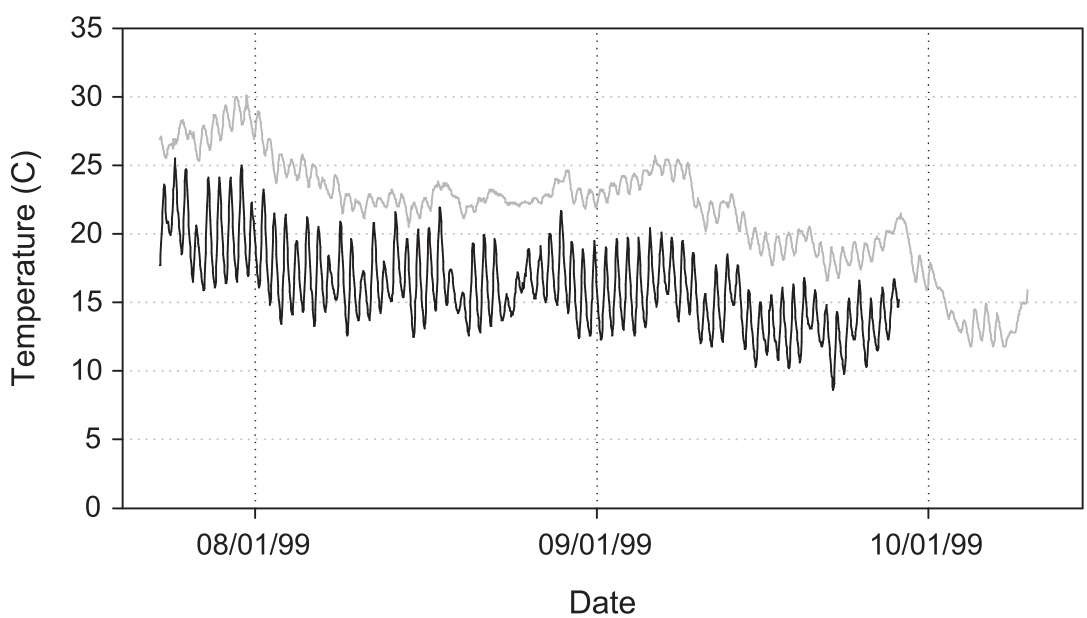

Figure 2.–Hourly water temperature (°C) for experiment 2 in Pond 7 (top line) and Raceway 1 North (bottom line) from July 23 (2 d after stocking) until draining on September 28 (raceway) and October 9, 1999 (3 d before draining; pond), recorded with digital temperature loggers.

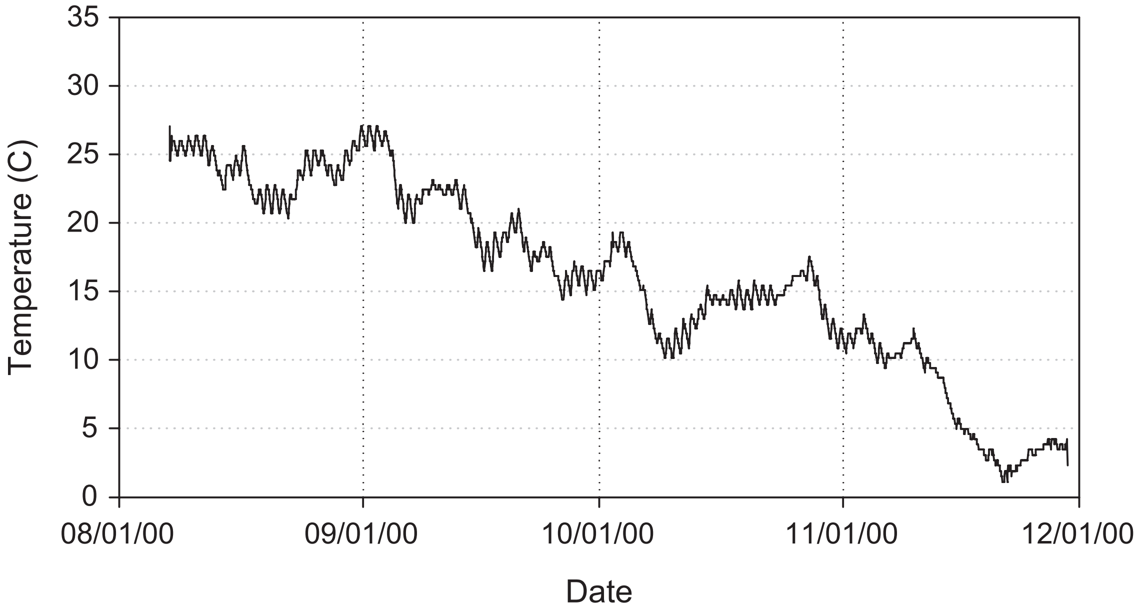

Figure 3.–Hourly water temperature (°C) for experiment 3 in Pond 7 from August 7 (5 d after stocking) until draining on November 29, 2000, recorded with a digital temperature logger.

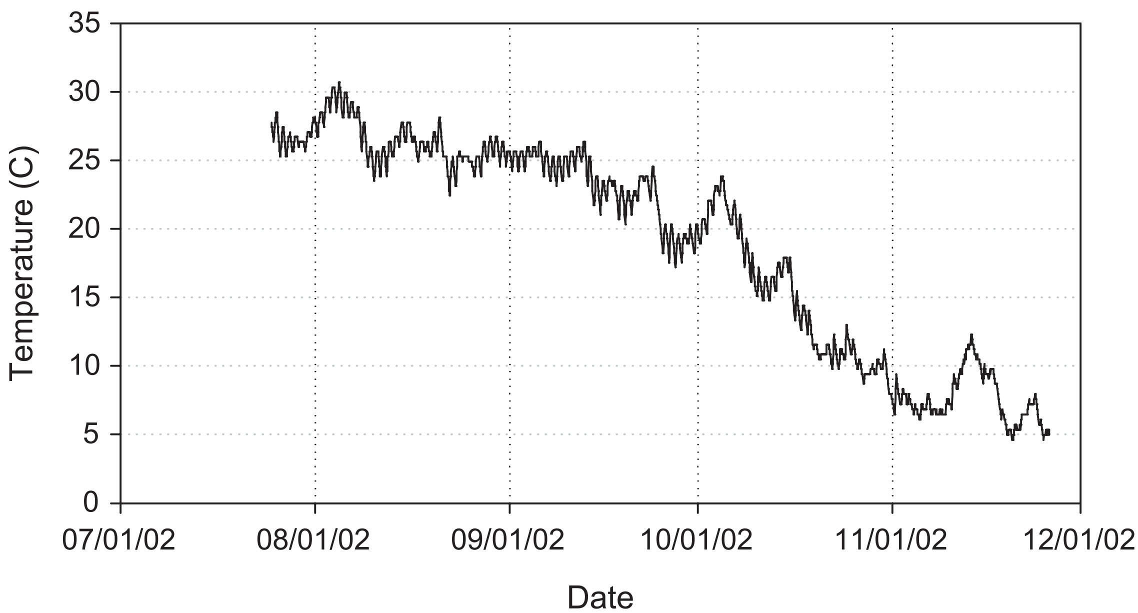

Figure 4.–Hourly water temperature (°C) every hour in Pond 3, from July 23 to November 24, 2002, representing the warm temperatures during experiment 4, recorded with a digital temperature logger (ONSET Optic StowAway S/N 264669).

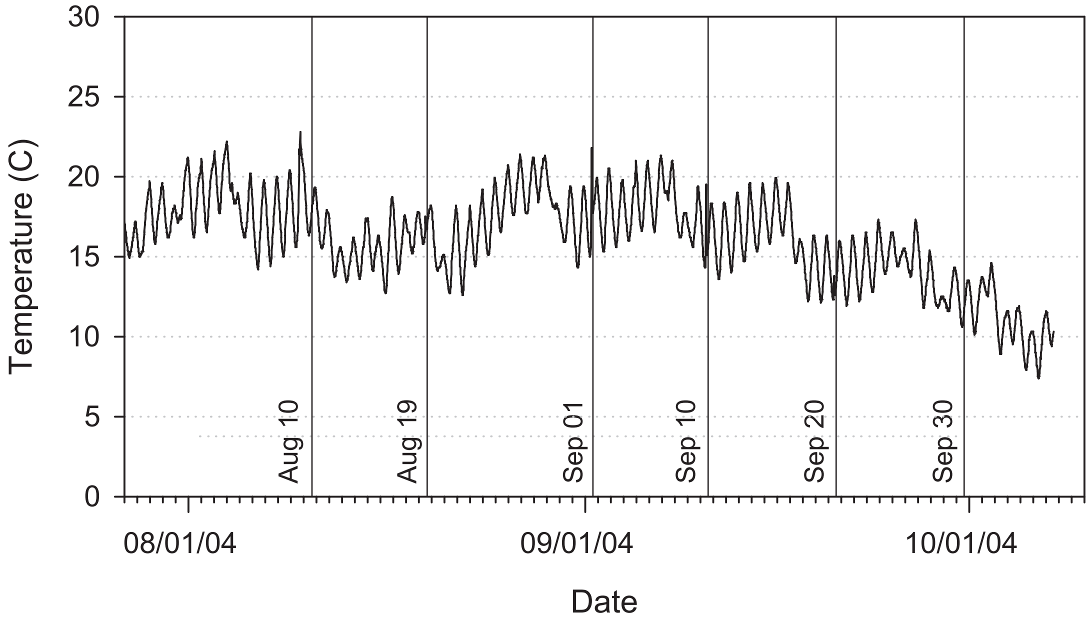

Figure 5.–Water temperature (°C) measured every 30 min in Raceway 3 North for experiment 6, from stocking on July 27 until October 6, 2004, recorded with a digital temperature logger. Vertical lines indicate dates of draining to monitor growth and survival of juvenile lake sturgeon.

Table 1.–Sources, sizes, and numbers of juvenile lake sturgeon used in pond and raceway experiments conducted at the Saline Fisheries Research Station.

Pond/raceway experiment	Egg source	Prior rearing location	Rearing temperature (°C)	Size at stocking		N	Transport mortality	Date stocked
				L±SD (mm)	W±SD (g)			
1. Sturgeon survival in ponds	St. Clair River	Lake St. Clair Fisheries Station	Ambient room temperature	35		76	0	6/12/1998
	St. Clair River	USGS Great Lakes Science Center	~14	<35		458	0	7/24/1998
2. Sturgeon survival in ponds and raceways	St. Clair River	Wolf Lake State Fish Hatchery	25.6	51.3±5.7	0.48	300	3	7/21/1999
3. Crayfish density effect on sturgeon survival in ponds	Sturgeon River, Upper Peninsula	Wolf Lake State Fish Hatchery	?	80±10	2.04±0.71	1,000	61 [a]	8/2/2000
4. Largemouth bass effect on sturgeon survival in ponds	Sturgeon River, Upper Peninsula	Wolf Lake State Fish Hatchery	?	81	2.0	400	0	7/23/2002
5. Monitoring lake sturgeon growth in ponds	Juveniles from previous experiments	Saline Fisheries Research Station	–	–	–	–	–	–
6. Growth of lake sturgeon and timing of mortality in raceways	Sturgeon River, Upper Peninsula	Wolf Lake State Fish Hatchery	18-20	78±10	1.60±0.66	140	0	7/27/2004

[a] Of the 61 that died during transport, 53 lodged themselves in the draining hose attached to the side of the transport tank.

Table 2.–Nine laboratory experiments on juvenile lake sturgeon conducted at the Saline Fisheries Research Station.

Lab experiment	Question	Approach
1. Lab observations of interactions between crayfish and juvenile lake sturgeon	Might crayfish be important as predators of age-0 lake sturgeon?	Observe behavioral interactions between crayfish and juvenile lake sturgeon in a large container or aquarium.
2. Prey choice by largemouth bass. bluegill versus juvenile lake sturgeon	Will largemouth bass choose bluegill or age-0 lake sturgeon when both are offered as prey?	For three successive days, offer equal numbers (2 or 3) of each prey type to largemouth bass held in individual aquaria.
3. Prey choice by largemouth bass. fathead minnows versus juvenile lake sturgeon	Will largemouth bass choose fathead minnows or age-0 lake sturgeon when both are offered as prey?	For three successive days, offer two of each prey type to 12 largemouth bass (from expt. 9) held in individual aquaria.
4. Lake sturgeon ingestion by largemouth bass	Will largemouth bass ingest age-0 lake sturgeon if we trick them?	Train largemouth bass to rapidly take fathead minnows offered as food. Then offer a sturgeon instead.
5. Growth of largemouth bass force-fed bluegill versus juvenile lake sturgeon	Will largemouth bass grow as well when fed lake sturgeon as when fed bluegill?	Because largemouth bass do not voluntarily ingest lake sturgeon, force-feed bass either bluegill or lake sturgeon for 14 d, and measure change in weight.
6. Testing for chemical defense by juvenile lake sturgeon	Might juvenile lake sturgeon have a chemical defense against fish predators?	Force-feed largemouth bass from experiment 5 with gelatin capsules containing pieces of bluegill or lake sturgeon meat or sturgeon skin with scutes or sturgeon skin without scutes. Capsules reduce mechanical irritation.
7. Testing for chemical defense by juvenile lake sturgeon	Might juvenile lake sturgeon have a chemical defense against fish predators?	Force-feed gelatin capsules (pieces of bluegill versus sturgeon meat versus sturgeon skin with scutes versus sturgeon skin without scutes) to eight naïve bass; previous feeding experience appears to influence regurgitation behavior of bass.
8. Testing for chemical defense by juvenile lake sturgeon	Might juvenile lake sturgeon have a chemical defense against fish predators?	Force-feed gelatin capsules (bluegill versus sturgeon meat versus sturgeon skin without scutes) to eight naïve bass. Add a water capsule as a new control.
9. Testing for chemical defense by juvenile lake sturgeon	Might juvenile lake sturgeon have a chemical defense against fish predators?	Force-feed gelatin capsules (fathead minnow versus sturgeon carcass versus sturgeon skin without scutes) to 6 recently caught bass and 6 bass acclimated to aquaria for at least six weeks.

Table 3.–Results of pond experiment 1 to evaluate survival of age-0 lake sturgeon in ponds. Fish were stocked into Pond 6 on June 12, 1998, at a mean length of 35 mm, and into Pond 5 on July 24, 1998, at a smaller size.

Pond	Treatment	Number stocked	Number recovered	Draining date	Length (mm)
Pond 6	Lower density	76	0	10/13/98	
Pond 5	Higher density	458	0	11/20/98	
Pond 5	Unexpected largemouth bass	0	213	11/20/98	Mean: 160 Range: 112–233

Table 4.–Results of pond experiment 2 to evaluate survival of age-0 lake sturgeon in ponds and raceways. Fish were stocked on July 21, 1999, at a mean weight of 0.48 g and a mean length of 51.3±5.7 mm TL. Length and weight measures show mean±SD.

Pond	Treatment	Number stocked	Number recovered	Draining date	Length (mm)	Weight (g)
Pond 7	Higher density	160	7	10/12/99	186±27 [a]	25.5±6.9
Pond 8	Lower density	40	3	10/12/99	208±19 [b]	28.9±6.2
R1N	Cool raceway	97	0	9/28/99		

[a] Four fish had caudal fin damage.
[b] Two fish had caudal fin damage.

Table 5.–Number of crayfish removed per pond during pond experiment 3 to evaluate the effect of trapping crayfish on survival of age-0 lake sturgeon. Trapping began on August 9 and ended on November 27, 2000.

Month	Pond 6	Pond 7	Pond 8	Pond 9	Total
August	1,428	993	1,058	648	4,127
September	1,881	2,106	2,030	1,535	7,552
October	596	1,238	1,046	1,113	3,993
November	76	377	221	182	856
Total	3,981	4,714	4,355	3,478	16,528

Table 6.–Results of pond experiment 3 to evaluate the effect of trapping crayfish on survival of age-0 lake sturgeon. Fish were stocked on August 2, 2000, at a mean weight of 2.0 g and approximately 80 mm TL. Length and weight measures show mean±SD.

Pond	Treatment	Number stocked	Number recovered	Draining date	Length (mm)	Weight (g)
Pond 16	Control	100	0	11/30/2000		
Pond 10	Control	100	0	6/8/2001		
Pond 7	Trap crayfish	100	5	11/29/2000	239±21	69.1±10.8
Pond 8	Trap crayfish	100	0	6/14/2001		
Pond 6	Trap crayfish	200	0	11/29/2000		
Pond 9	Trap crayfish	200	1	11/30/2000	263	95.0

Table 7.–Results of pond experiment 4 to evaluate the effect of largemouth bass on survival of age-0 lake sturgeon. Fish were stocked on July 23, 2002, at a mean weight of 2.0 g and a mean length of 81 mm.

Pond	Treatment	Number stocked	Number recovered	Draining date	Length (mm)	Weight (g)
Pond 5	Control	100	0	4/2/2003		
Pond 7	Control	100	0	4/8/2003		
Pond 6	50 LMB	100	1	4/4/2003	275	97.3
Pond 9	50 LMB	100	0	4/1/2003		

Table 8.–Results of pond experiment 5 on monitoring growth of surviving lake sturgeon from previous experiments. Length and weight measures show mean±SD.

Fish source	Day	Date	Number	Survival (%)	Length (mm)	Weight (g)	Growth rate (% BW/d)
Expt. 2	0	7/21/1999	200	100	51.3±5.7	0.48	
	83	10/12/1999	10	5.0	193±26	26.5±6.5	4.8
	267	4/13/2000	3	1.5	219±24	59±16	0.4
	366	7/21/2000	2	1.0	323 & 376	161 & 249	1.0 & 1.5
Expt. 3	0	8/2/2000	600	100	80±10	2.04±0.71	
	119	11/29/2000	6	1.0	243±21	73.4	3.0
	316	6/14/2001	1 [a]	[a]	295		
	335	7/3/2001	2 [b]	[b]	379 & 387		
Expt. 4	0	7/23/2002	400	100	81	2.0	
	255	4/4/2003	1	0.25	275	97.3	1.5

[a] Three of 6 fish surviving to 11/29/2000 were moved to Pond 6; one survived to 6/14/2001.
[b] Three of 6 fish surviving to 11/29/2000 were moved to Pond 7; two survived to 7/3/2001.

Table 9.–Results of raceway experiment 6 on lake sturgeon growth and timing of mortality, showing total number of survivors, percent of initial number, average length (±SD), and average weight (±SD) of 140 juvenile lake sturgeon stocked on July 27, 2004 (Day 0), into six outdoor raceways at the Saline Fisheries Research Station and measured on ten subsequent dates. Water temperatures during this experiment are shown in Figure 5.

Day	Date	Number	Survival (%)	Length (mm)	Weight (g)
0	7/27/04	140	100	78±10	1.60±0.66
14	8/10/04	26	18.6	99±19	3.64±1.96
23	8/19/04	13	9.3	122±19	6.66±2.71
36	9/01/04	13	9.3	143±23	10.8±4.4
45	9/10/04	11	7.9	160±23	14.8±5.0
55	9/20/04	8	5.7	174±23	18.4±5.4
65	9/30/04	8	5.7	179±22	21.0±5.6
92	10/27/04	8	5.7	186±21	24.7±6.3
129	12/3/04	7	5.0	192±23	27.9±7.1
252	4/5/05	3	2.1	198±12	30.6±3.8
366	7/28/05	1	0.7	293	79.0

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Kevin E. Wehrly, Reviewer
Lizhu Wang, Editor
Alan D. Sutton, Graphics
Ellen S. Grove, Desktop Publisher

Approved by Tammy J. Newcomb

Appendices

Table A1.–Monthly mean water temperatures in 1989-95, and grand monthly means, for Pond 7, Saline Fisheries Research Station (J. E. Breck, unpublished data). Monthly means are based on hourly values recorded with a digital thermometer (TempMentors S/N 901012, deployment 001; S/N 901326, deployments 001 through 012; S/N 902686, deployments 006 and 007).

Year	Monthly mean temperature (°C)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1989	4.1	4.2	6.8	11.4	16.6	22.2	25.0	24.0	20.1	12.0	5.7	3.6
1990	4.5	4.2	7.1	12.0	17.0	21.9	25.0	24.4	20.6	12.9	7.3	3.5
1991	3.2	4.3	6.8	13.3	21.2	25.5	24.8	22.9	19.0	13.3	5.6	3.1
1992	3.0	3.8	5.5	10.5	18.0	21.4	22.9	22.5	19.8	12.0	5.8	3.0
1993	3.5	4.2	4.6	10.7	18.8	22.0	25.4	24.6	18.3	11.3	5.5	4.4
1994	2.7	2.3	5.4	9.6	18.5	23.1	24.6	21.9	20.0	13.6	7.6	4.3
1995	2.9	3.9	5.9	10.1	16.7	23.3	25.5	26.9	19.1	13.0	4.6	3.0
Mean	3.4	3.8	6.0	11.1	18.1	22.8	24.7	23.9	19.6	12.6	6.0	3.6

Appendix A2.–Daily mean water temperatures from May 1996 to March 1997, with monthly summaries, for Pond 7, Saline Fisheries Research Station. The monthly summaries are based on hourly values recorded with a digital thermometer (TempMentor S/N 902686, deployments 008 and 009). Pond 7 was drained on July 24, 1996, and on March 26, 1997.

	Daily mean temperature (°C)											
Day	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
1			19.7	28.2			16.3	6.1	4.1	3.2	1.8	4.7
2			20.3	27.3			17.7	5.2	3.4	3.4	2.0	4.9
3			21.0	25.5			15.5	4.8	3.0	3.8	2.1	5.0
4			21.3	24.0			14.3	4.9	3.1	4.2	2.3	4.9
5			20.3	23.9			14.3	5.7	3.2	5.1	2.5	4.7
6			19.9	24.4			14.5	6.9	2.6	2.4	2.6	3.8
7			20.0	25.3			15.4	8.1	2.9	0.8	2.8	3.0
8			20.7	25.9			15.1	8.5	2.8	1.3	3.0	4.0
9			21.2	24.9			13.4	8.1	2.3	1.8	3.1	3.7
10			21.8	22.7			12.0	6.9	2.4	1.9	2.9	3.7
11			22.6	22.4			11.3	5.5	3.0	1.9	2.9	4.8
12			22.6	22.8			11.2	4.1	3.0	1.9	2.9	5.3
13			22.7	23.4			12.1	3.3	3.0	1.9	2.5	5.1
14			23.8	23.5		17.3	13.9	3.7	3.5	2.0	2.6	3.4
15			24.9	24.0		16.4	13.8	3.9	3.8	2.0	2.7	1.7
16			25.9	23.9		16.6	14.1	4.2	3.7	1.9	2.6	2.5
17			25.5	24.1		16.8	15.1	4.3	3.2	1.8	2.3	4.1
18			23.2	24.1		17.3	15.2	4.5	3.1	1.7	2.5	5.1
19			23.2	24.9		17.9	12.8	4.2	2.8	1.6	2.9	5.1
20			24.5	23.8		18.3	12.1	3.9	2.6	1.6	3.1	6.8
21			24.4	23.0		18.4	12.5	4.0	2.4	1.5	3.4	8.6
22			25.4	22.7		18.3	12.6	3.9	2.7	1.7	3.7	9.0
23			25.3			17.9	12.2	4.1	3.0	1.9	4.0	6.9
24			25.7			18.3	10.8	4.2	3.2	2.0	4.3	5.6
25		18.9	25.5			17.6	10.7	3.7	3.0	1.9	4.6	6.0
26		18.5	25.3			17.3	11.4	2.4	2.8	1.9	4.4	
27		17.5	25.8			17.2	12.8	2.2	2.5	1.9	4.8	
28		16.6	26.4			16.9	13.3	2.9	2.7	1.8	4.9	
29		17.4	27.3			15.8	11.8	3.2	3.1	1.7		
30		17.9	28.0			15.4	10.9	3.6	3.2	1.7		
31		18.9					7.8		3.2	1.7		
Monthly average		17.9	23.5	24.3		17.3	13.1	4.7	3.0	2.1	3.1	4.9
Monthly minimum		15.9	19.0	20.8		14.4	6.9	1.3	1.6	0.4	1.7	0.7
Monthly maximum		19.9	28.9	28.7		19.3	18.7	9.4	4.6	5.9	5.1	10.2
Ave. daily range		1.7	1.4	1.8		1.6	1.7	1.0	0.7	0.5	0.5	1.8
Cum. degree days		125.6	704.2	534.7		293.6	406.8	141.2	93.1	66.1	86.3	122.3
Number of days		7	30	22		17	31	30	31	31	28	25

Appendix A3.–Daily mean water temperatures in 1998, with monthly summaries, for Pond 5, Saline Fisheries Research Station. The monthly summaries are based on hourly values recorded with a digital thermometer (TempMentor S/N 902686, deployment 013). Age-0 lake sturgeon were stocked into Pond 6 on June 12 and into Pond 5 on July 24, 1998.

	Daily mean temperature (°C)				
Day	Jul	Aug	Sep	Oct	Nov
1		23.6	23.5	19.5	13.2
2		23.9	23.1	17.7	12.7
3		23.8	22.5	16.5	11.1
4		23.3	22.6	15.5	9.4
5		22.3	22.7	15.7	8.2
6		22.2	23.5	16.7	7.4
7		23.3	23.8	17.7	7.5
8		24.5	21.8	16.8	7.9
9		25.6	20.4	16.2	8.0
10		26.0	20.3	15.8	8.8
11		25.8	20.9	15.9	8.1
12		25.2	21.4	16.3	7.1
13		24.8	22.5	16.2	7.2
14		24.6	22.6	14.5	7.2
15		24.5	22.6	14.4	7.6
16		24.6	22.7	14.6	7.6
17	28.0	24.9	23.0	15.6	
18	27.3	25.3	22.7	16.0	
19	27.1	23.9	22.7	15.3	
20	27.7	23.4	23.2	14.5	
21	27.7	24.1	23.7	12.9	
22	27.5	25.1	22.6	11.7	
23	27.4	26.0	20.6	11.6	
24	26.2	26.5	19.0	12.0	
25	25.0	26.4	19.1	12.3	
26	24.3	25.9	20.4	12.6	
27	24.5	25.6	21.6	12.6	
28	25.0	24.8	21.4	13.2	
29	25.5	24.7	20.4	12.9	
30	24.5	24.6	20.6	13.0	
31	23.5	24.1		13.0	
Monthly average	26.1	24.6	21.9	14.8	8.7
Monthly minimum	22.6	21.7	18.0	10.7	6.6
Monthly maximum	29.2	27.5	24.7	20.6	13.4
Average daily range	2.2	1.8	1.9	1.3	1.1
Cum. degree days	391.1	763.1	658.0	459.3	138.9
Number of days	15	31	30	31	16

Appendix A4.–Daily mean water temperatures in 1999, with monthly summaries, for Pond 5, Saline Fisheries Research Station. The monthly summaries are based on hourly values recorded with a digital thermometer (TempMentor S/N 904340, deployment 010).

	Daily mean temperature (°C)							
Day	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1		3.7	12.8	17.0	23.3	25.1	30.1	24.1
2		3.7	13.3	18.0	23.7	25.0	28.8	24.6
3		3.6	14.3	19.0	22.5	26.3	27.3	25.2
4		2.8	14.7	19.8	22.7	28.4	26.9	25.2
5		3.3	13.4	20.1	23.4	30.3	26.5	25.5
6		1.7	13.2	20.0	25.2	30.7	25.8	26.3
7		1.4	12.5	19.6	27.2	29.3	25.3	26.2
8		3.0	14.3	18.9	28.1	28.5	25.2	
9		3.6	13.3	18.7	28.3	28.0	24.2	
10		3.8	11.7	19.2	28.7	26.7	24.2	
11		4.2	11.1	19.7	29.7	26.1	23.7	
12		4.5	10.8	19.7	29.9	26.5	24.5	
13		4.4	12.1	17.7	28.6	26.7	25.1	
14		4.7	12.9	17.0	27.3	27.0	24.7	
15		5.0	13.5	18.9	24.8	27.5	23.8	
16		5.7	12.2	20.0	23.3	28.1	24.3	
17		6.8	11.8	21.3	22.5	28.6	26.0	
18		6.4	11.7	21.9	21.9	27.7	25.4	
19	3.9	5.8	12.1	21.2	22.7	27.5	24.1	
20	3.9	6.8	12.8	21.6	23.0	27.2	23.3	
21	3.9	6.8	13.4	22.2	24.3	27.1	23.9	
22	3.8	5.6	12.9	22.3	25.1	27.5	24.5	
23	3.8	6.1	11.7	21.0	26.1	28.1	24.2	
24	3.8	7.1	11.2	19.1	27.3	28.4	23.5	
25	3.9	6.9	12.4	16.3	28.0	29.0	23.5	
26	4.1	6.7	14.1	16.7	28.3	28.6	23.8	
27	4.0	7.6	15.2	18.7	28.4	28.2	24.2	
28	4.0	8.7	14.7	19.7	28.4	28.9	25.4	
29		10.3	14.8	21.7	27.8	29.6	25.6	
30		10.7	15.9	23.4	26.3	30.4	24.2	
31		11.9		23.9		31.1	24.0	
Monthly average	3.9	5.6	13.0	19.8	25.9	28.0	25.0	25.3
Monthly minimum	3.5	0.0	9.0	14.7	20.7	24.0	22.0	22.8
Monthly maximum	4.8	14.1	18.0	24.6	30.9	32.7	31.6	28.1
Average daily range	0.6	1.9	2.1	2.4	2.2	1.9	1.9	2.6
Cum. degree days	39.1	173.1	391.0	614.3	776.9	868.2	775.9	177.1
Number of days	10	31	30	31	30	31	31	7

Appendix A5.–Daily mean water temperatures in 1999, with monthly summaries, for Raceway 1 North, Saline Fisheries Research Station. The monthly summaries are based on hourly values recorded with a digital thermometer (TempMentor S/N 901893, deployment 013).

	Daily mean temperature (°C)		
Day	Jul	Aug	Sep
1		19.2	15.1
2		18.0	15.6
3		17.0	15.9
4		16.8	15.6
5		17.4	16.1
6		16.7	17.0
7		16.3	17.3
8		17.2	16.4
9		15.9	16.3
10		15.6	13.9
11		16.8	14.3
12		16.2	14.9
13		17.5	16.0
14		17.2	13.7
15		15.9	12.6
16		16.4	13.1
17		17.8	13.1
18		16.4	12.9
19		15.0	13.4
20		15.6	14.1
21		16.0	13.0
22		16.1	11.4
23		14.7	12.2
24	22.0	15.4	13.9
25	21.3	17.1	12.6
26	18.7	16.7	13.4
27	19.2	17.3	14.3
28	19.5	17.7	
29	19.8	16.7	
30	20.2	15.2	
31	19.5	15.3	
Monthly average	20.0	16.6	14.4
Monthly minimum	15.9	12.4	8.6
Monthly maximum	25.5	23.2	20.4
Average daily range	6.7	5.6	5.2
Cum. degree days	160.3	513.2	388.3
Number of days	8	31	27

Appendix A6.–Daily mean water temperatures from August 7 to November 29, 2000, with monthly summaries, for Pond 7, Saline Fisheries Research Station. The monthly summaries are based on hourly values, recorded with a digital thermometer (ONSET Optic StowAway S/N 264671). Pond 7 was drained on November 29, 2000.

	Daily mean temperature (°C)											
Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1									26.3	16.5	11.4	
2									26.3	17.8	11.7	
3									26.2	18.7	12.5	
4									25.1	18.2	11.6	
5									22.1	16.8	10.5	
6									21.1	15.1	10.0	
7								25.8	21.0	13.0	10.3	
8								25.5	21.9	11.6	10.7	
9								25.5	22.6	10.9	11.4	
10								25.8	22.6	11.1	11.0	
11								25.7	22.3	11.7	9.8	
12								25.1	22.5	12.2	9.4	
13								23.9	21.9	13.1	8.6	
14								23.3	20.7	14.1	6.8	
15								24.1	18.8	14.5	5.5	
16								24.6	17.7	14.4	4.9	
17								23.2	17.9	14.5	4.4	
18								21.8	18.4	14.7	3.5	
19								21.8	19.5	14.4	3.1	
20								21.8	20.0	14.7	2.5	
21								21.7	18.6	14.8	1.5	
22								21.3	17.3	14.7	2.0	
23								22.6	17.8	14.5	2.4	
24								24.2	17.8	15.0	3.1	
25								24.5	16.2	15.8	3.3	
26								24.8	15.3	16.3	3.7	
27								24.0	15.9	16.6	4.1	
28								23.4	16.2	15.8	3.7	
29								24.1	15.9	13.6	3.5	
30								25.2	15.9	12.3		
31								26.0		11.6		
Monthly average								24.0	20.1	14.5	6.8	
Monthly minimum								20.3	14.4	10.1	1.1	
Monthly maximum								27.1	27.1	19.3	13.3	
Ave. daily range								1.8	1.7	1.5	1.0	
Cum. degree days								599.0	601.8	449.0	198.3	
Number of days								25	30	31	29	

Appendix A7.–Daily mean water temperatures from January 1 to December 31, 2001, with monthly summaries, for Pond 3, Saline Fisheries Research Station. The monthly summaries are based on hourly values, recorded with a digital thermometer (ONSET Optic StowAway S/N 264669).

	Daily mean temperature (°C)											
Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	3.9	3.1	4.8	7.5	18.6	19.0	29.2	28.0	24.4	17.0	11.9	9.8
2	4.0	3.1	5.0	7.5	20.0	17.7	26.1	28.6	23.8	17.8	12.9	8.8
3	4.2	3.3	4.8	9.3	21.3	16.7	25.7	28.7	23.8	18.6	12.9	8.4
4	4.1	3.2	4.7	9.6	22.3	16.6	25.9	28.7	25.0	19.3	12.5	9.1
5	4.2	3.4	4.5	10.3	21.6	17.5	26.4	28.5	24.4	18.1	11.7	10.1
6	4.2	3.6	4.5	11.4	20.4	17.8	25.4	28.5	23.7	15.6	10.6	11.1
7	3.9	3.5	4.6	12.6	19.8	18.5	25.1	29.0	24.3	13.8	10.9	9.8
8	3.8	3.5	4.4	15.3	20.7	20.4	25.9	30.0	25.3	12.7	11.2	9.1
9	3.8	3.4	4.2	15.9	21.1	22.3	27.4	30.6	25.4	13.4	10.4	8.6
10	3.8	3.2	4.3	13.6	21.1	23.5	28.0	30.0	24.4	14.3	10.2	7.5
11	3.8	3.1	4.8	12.4	22.0	24.7	27.5	28.3	23.7	15.2	10.1	6.8
12	3.8	3.1	5.0	13.8	21.2	25.5	26.5	27.7	23.5	15.9	9.2	6.7
13	3.2	3.1	4.6	14.0	19.8	25.7	26.4	27.1	23.2	16.7	8.8	7.6
14	3.2	3.1	4.7	14.4	19.6	27.1	26.4	26.0	20.6	17.4	9.7	7.8
15	3.5	3.3	6.2	12.6	18.8	27.7	26.6	25.4	19.8	15.9	10.7	7.4
16	3.2	3.5	4.9	10.7	17.2	27.5	27.4	25.0	19.2	14.1	12.3	7.2
17	3.5	3.5	4.0	9.1	18.1	27.8	27.8	23.5	19.5	11.5	12.4	7.4
18	3.7	3.6	5.5	9.5	19.6	26.8	27.6	23.5	20.4	11.1	12.4	7.6
19	3.6	3.9	5.9	10.4	20.5	27.1	28.1	23.9	21.0	11.8	12.1	7.3
20	3.5	4.3	6.9	11.6	21.7	27.3	28.5	24.0	20.5	11.9	10.3	6.3
21	3.3	4.3	7.8	11.9	22.2	25.1	28.6	23.8	19.9	13.3	9.2	5.9
22	3.3	4.1	8.9	13.4	21.5	23.5	28.3	23.9	19.2	13.9	8.7	6.4
23	3.4	4.3	9.8	15.6	20.2	24.7	28.8	23.3	19.3	14.8	8.5	6.3
24	3.4	4.2	8.4	16.2	19.0	25.1	29.1	23.6	18.8	16.1	9.5	4.9
25	3.5	4.0	5.6	14.9	18.3	26.6	28.7	24.2	16.0	14.7	11.3	4.9
26	3.4	3.8	3.9	15.5	18.1	27.5	26.4	24.8	14.5	10.7	11.0	5.3
27	3.5	3.8	4.0	17.6	17.3	28.5	25.8	25.0	14.9	9.2	10.9	5.4
28	3.1	4.2	5.2	17.2	16.9	29.4	25.7	25.9	15.6	8.8	10.3	5.5
29	3.1		6.2	17.2	18.7	29.5	26.6	25.5	15.9	9.6	10.0	5.7
30	3.1		6.9	17.6	18.7	29.9	26.4	25.0	16.6	10.5	10.0	5.9
31	3.1		7.9		19.3		27.2	25.6		11.0		6.0
Monthly average	3.6	3.6	5.6	13.0	19.9	24.2	27.1	26.3	20.9	14.0	10.8	7.3
Monthly minimum	3.1	3.1	3.1	6.1	15.8	15.8	23.5	22.8	14.0	8.3	8.0	4.2
Monthly maximum	4.2	4.6	10.9	19.6	24.2	30.7	30.3	31.5	26.3	19.6	13.7	11.6
Ave. daily range	0.3	0.3	1.4	2.4	2.0	2.1	1.8	1.4	1.6	1.5	1.0	0.8
Cum. degree days	111.3	100.1	172.8	389.0	615.6	726.9	839.2	815.3	626.6	434.8	322.6	226.7
Number of days	31	28	31	30	31	30	31	31	30	31	30	31

Appendix A8.–Daily mean water temperatures from January 1 to December 31, 2002, with monthly summaries, for Pond 3, Saline Fisheries Research Station. The monthly summaries are based on hourly values, recorded with a digital thermometer (ONSET Optic StowAway S/N 264669).

	Daily mean temperature (°C)											
Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	5.7	5.1	6.8	10.9	13.0	24.9	28.1	29.6	25.2	22.1	7.6	4.3
2	5.6	5.1	6.7	10.1	12.9	25.0	29.1	29.8	25.6	23.2	6.9	5.2
3	5.7	5.7	6.8	9.4	13.1	23.0	29.3	29.2	25.8	22.1	6.6	5.4
4	5.7	6.2	5.3	9.2	14.6	21.2	29.7	28.9	25.0	21.0	7.3	5.4
5	5.7	6.2	5.8	9.0	16.3	22.4	28.8	28.4	24.5	20.2	6.7	5.6
6	5.9	6.4	6.6	8.9	17.7	21.7	27.2	27.1	24.4	18.6	6.6	5.5
7	5.7	6.6	6.8	9.6	17.4	22.0	27.2	25.5	24.4	17.3	6.9	5.6
8	5.9	6.8	7.0	10.2	16.4	23.2	27.5	24.8	24.9	16.0	7.9	5.6
9	6.0	7.1	8.2	11.4	15.9	24.7	27.7	25.1	25.3	15.6	9.0	5.5
10	6.1	7.3	5.4	11.8	16.1	26.1	26.7	25.3	25.7	15.7	10.5	5.5
11	6.3	5.9	5.4	13.6	15.3	27.2	25.7	26.0	24.7	16.5	11.6	5.6
12	6.4	5.7	7.0	15.1	14.2	27.1	25.2	26.9	23.0	17.2	10.6	5.5
13	6.4	5.3	8.7	16.3	14.2	25.8	25.6	27.1	22.5	17.3	9.5	5.4
14	6.5	6.1	10.7	16.5	14.8	24.7	26.1	26.8	22.9	14.6	9.5	5.5
15	6.4	6.8	11.1	17.2	16.3	22.9	26.7	25.7	23.2	13.7	8.7	5.6
16	6.3	6.5	10.5	18.9	18.4	21.7	27.7	26.0	22.1	13.4	6.6	5.7
17	6.1	5.6	9.4	20.7	17.4	21.6	28.5	26.0	21.9	11.7	5.4	5.6
18	6.3	6.4	9.0	21.8	15.7	22.1	28.1	26.9	22.1	10.8	5.2	5.6
19	6.5	6.5	8.8	22.9	15.4	23.0	27.7	25.7	22.9	11.2	5.9	5.7
20	6.5	7.1	9.1	21.9	15.1	24.2	27.5	23.9	23.7	10.9	6.8	5.7
21	6.3	7.3	8.2	17.7	14.6	25.1	27.5	24.4	23.4	10.7	7.4	5.7
22	6.2	6.4	5.3	13.7	16.0	25.1	27.5	25.3	22.2	11.5	6.0	6.0
23	6.1	6.5	5.9	13.1	17.8	25.8	27.6	25.1	19.4	11.4	5.1	6.3
24	6.1	7.3	6.6	14.8	20.1	27.1	26.6	24.6	19.2	10.3	5.4	6.5
25	6.3	8.7	5.0	15.2	18.7	27.7	26.2	25.2	18.6	9.3	5.2	6.5
26	6.8	8.3	3.8	14.1	17.6	28.1	26.3	25.8	18.8	9.6	5.2	6.4
27	7.0	6.8	5.4	14.0	19.5	27.7	26.4	26.0	19.4	9.9	5.6	6.2
28	7.3	6.7	7.3	13.0	21.1	27.1	26.4	25.7	19.3	10.2	5.6	6.0
29	7.3		8.5	11.8	22.2	27.1	27.4	25.4	19.8	8.4	5.7	5.7
30	6.9		9.4	12.6	23.2	27.3	27.6	25.2	20.9	7.7	5.0	5.7
31	5.5		10.6		24.6		28.6	25.1		7.7		5.7
Monthly average	6.2	6.5	7.5	14.2	16.9	24.8	27.4	26.2	22.7	14.1	7.1	5.7
Monthly minimum	3.8	4.2	3.5	7.2	11.2	20.3	23.8	22.4	17.2	6.5	3.8	3.5
Monthly maximum	7.6	10.1	11.9	24.9	26.3	28.9	30.7	30.7	26.3	23.8	12.3	6.9
Ave. daily range	0.4	1.2	1.7	2.2	2.4	1.9	1.9	1.8	2.0	1.8	1.1	0.4
Cum. degree days	193.7	182.6	231.4	425.8	525.4	742.6	848.0	812.7	680.9	435.6	212.1	176.2
Number of days	31	28	31	30	31	30	31	31	30	31	30	31

Appendix A9.–Daily mean water temperatures from January 1 to May 30, 2003, with monthly summaries, for Pond 3, Saline Fisheries Research Station. The monthly summaries are based on hourly values, recorded with a digital thermometer (ONSET Optic StowAway S/N 264669).

	Daily mean temperature (°C)											
Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	5.7	5.4	5.0	10.3	19.0							
2	5.7	5.4	5.1	12.9	18.6							
3	5.5	5.4	5.1	13.9	16.7							
4	5.7	5.4	5.0	10.9	17.1							
5	5.7	5.4	5.1	8.1	17.8							
6	5.8	5.4	5.1	7.6	19.1							
7	5.7	5.4	5.1	5.8	19.7							
8	5.7	5.3	5.1	4.6	18.2							
9	5.7	5.1	5.2	6.6	18.2							
10	5.5	5.0	5.2	9.8	19.5							
11	5.4	5.0	5.2	12.6	20.0							
12	5.4	5.1	5.2	14.8	16.0							
13	5.5	5.2	5.2	14.9	15.3							
14	5.5	5.0	5.4	15.8	17.6							
15	5.5	5.0	5.3	18.0	18.3							
16	5.4	5.0	5.4	19.0	17.7							
17	5.3	5.0	5.6	14.9	19.6							
18	5.3	4.9	6.0	13.5	22.1							
19	5.3	5.0	6.6	14.6	22.7							
20	5.3	5.4	7.2	16.6	22.3							
21	5.2	5.5	7.7	17.0	19.2							
22	5.1	5.7	8.0	14.0	19.4							
23	5.3	5.5	8.4	13.1	19.0							
24	5.4	5.4	9.1	14.2	16.7							
25	5.3	5.4	10.4	15.2	17.0							
26	5.2	5.3	10.8	16.0	18.8							
27	5.1	5.0	10.8	16.8	17.3							
28	5.0	5.1	12.4	18.2	17.2							
29	5.2		12.1	19.4	19.6							
30	5.3		9.1	19.4	21.9							
31	5.3		9.1									
Monthly average	5.4	5.2	7.0	13.6	18.7							
Monthly minimum	5.0	4.6	5.0	3.8	13.0							
Monthly maximum	6.1	5.7	14.0	20.7	25.6							
Ave. daily range	0.4	0.2	1.0	3.1	3.5							
Cum. degree days	168.2	146.3	216.1	408.7	579.2							
Number of days	31	28	31	30	30							

Appendix A10.–Daily mean water temperatures from June 15 to December 31, 2004, with monthly summaries, for Raceway 3 North, Saline Fisheries Research Station. The monthly summaries are based on hourly values for June 15-October 7, and half-hourly values for October 7-December 31, recorded with a digital thermometer (TempMentor S/N 902685, deployments 002 and 003). Raceways were drained on August 10 & 19, September 1, 10, 20, & 30, October 27, and on December 3, 2004.

	Daily mean temperature (°C)											
Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1							18.1	18.5	17.8	11.9	10.0	5.6
2							18.6	19.0	17.8	13.5	10.6	4.2
3							18.4	20.0	17.7	10.6	9.4	3.9
4							18.9	19.3	17.9	10.9	9.0	3.8
5							19.3	17.8	18.8	9.5	7.7	4.5
6							19.0	16.8	18.8	9.3	7.7	5.1
7							19.6	17.2	19.7	11.1	8.7	6.9
8							17.6	17.7	17.2	11.7	7.0	6.8
9							16.9	18.8	17.1	14.4	5.0	5.8
10							18.4	18.1	16.5	11.6	5.4	6.4
11							19.3	16.9	16.0	10.4	7.7	5.1
12							19.4	15.1	16.3	10.0	5.6	4.2
13							19.4	14.7	16.9	10.7	4.7	3.7
14							19.7	15.3	17.2	11.7	4.2	2.4
15						22.8	18.6	15.5	17.7	11.4	4.6	2.5
16						18.3	18.1	15.3	17.9	10.0	7.2	2.9
17						20.2	19.0	16.0	15.9	8.1	9.2	3.4
18						21.2	18.4	16.4	14.3	8.1	10.8	3.1
19						19.4	18.1	17.0	14.3	9.1	10.5	2.0
20						16.2	18.3	15.2	14.1	10.1	10.5	0.6
21						15.8	19.4	15.0	14.1	11.0	9.7	1.2
22						16.7	20.1	15.1	14.2	11.1	7.1	2.4
23						15.7	21.2	16.6	14.8	10.6	7.6	1.0
24						17.8	17.5	17.2	15.2	11.6	7.1	0.6
25						16.2	16.9	18.4	15.2	10.9	4.1	0.4
26						16.1	16.7	19.3	15.2	10.8	4.0	0.9
27						16.0	16.1	19.3	13.7	12.5	6.2	0.6
28						16.2	16.7	20.1	12.7	12.2	6.3	1.2
29						16.4	17.7	18.5	12.7	12.6	4.5	2.8
30						17.4	17.4	17.4	12.3	13.8	5.4	4.1
31							18.7	16.7		11.8		4.9
Monthly average						17.4	18.4	17.2	16.0	11.1	7.2	3.3
Monthly minimum						13.0	14.0	12.6	10.6	7.4	3.3	-0.1
Monthly maximum						24.4	24.0	22.8	21.8	15.4	11.7	8.1
Ave. daily range						4.8	4.6	4.2	4.1	2.3	1.9	1.4
Cum. degree days						278.8	571.6	533.9	480.0	344.1	58.3	60.2
Number of days						16	31	31	30	31	30	31

Appendix A11.–Daily mean water temperatures from January 1 to December 31, 2005, with monthly summaries, for Raceway 3 North, Saline Fisheries Research Station. The monthly summaries are based on half-hourly values for January 1-May 13, recorded with a digital thermometer (TempMentor S/N 902685, deployment 003) and two-hourly values for May 16-December 31, recorded with new digital thermometer (ONSET Optic StowAway S/N 264671). Raceways were drained on April 5 and July 28, 2005.

	Daily mean temperature (°C)											
Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	2.8	1.5	2.6	8.0	9.8	17.3	20.5	22.7	22.3	17.0	15.9	8.8
2	3.7	1.6	2.3	7.1	9.7	17.5	19.2	23.3	21.9	18.6	14.0	8.0
3	4.3	2.1	2.2	6.9	7.7	17.2	19.0	23.6	21.2	20.9	14.2	7.4
4	3.5	2.4	2.6	8.9	9.4	17.8	20.4	22.4	20.6	21.2	15.4	8.0
5	1.9	3.1	3.8	11.6	11.5	19.0	21.5	22.7	20.9	20.8	16.1	8.2
6	1.3	3.4	4.9	13.1	12.1	20.1	20.1	22.4	21.0	20.3	16.8	7.1
7	2.1	4.2	3.8	12.4	14.6	20.2	19.6	22.7	21.4	18.1	13.9	6.4
8	2.7	3.0	1.1	10.3	14.4	20.5	20.3	22.9	22.0	16.5	14.1	6.1
9	3.6	1.8	1.4	11.3	14.4	20.7	19.8	23.1	22.0	15.9	16.1	6.3
10	4.4	2.1	1.8	12.0	16.6	21.1	20.8	22.9	21.0	16.4	13.7	6.9
11	3.6	1.5	3.1	12.4	14.9	20.3	20.8	22.4	20.9	17.4	11.8	7.6
12	3.9	3.3	3.7	10.5	12.9	20.2	21.2	22.3	21.4	17.7	12.0	7.1
13	2.8	2.8	3.5	10.0	11.3	19.7	22.7	23.4	21.7	18.4	14.5	6.6
14	1.0	2.3	3.7	10.8		20.8	21.8	22.5	21.8	18.4	12.7	7.4
15	0.7	1.8	4.5	11.4		19.0	20.9	22.2	21.2	17.6	13.3	7.8
16	0.8	1.5	4.4	11.3	14.0	17.3	20.9	22.4	19.8	15.9	13.2	8.1
17	0.5	1.1	4.9	12.3	12.9	15.5	23.3	23.1	19.8	14.5	8.8	7.4
18	0.5	0.9	5.1	13.8	14.4	15.0	23.6	22.8	20.1	15.7	8.0	6.3
19	0.9	1.6	4.3	14.6	12.6	15.9	23.3	23.6	19.9	15.8	9.6	6.3
20	1.7	1.8	4.7	15.2	14.3	17.8	22.4	23.5	21.4	14.5	10.2	6.1
21	1.4	2.9	4.4	12.8	15.5	17.9	23.7	23.3	20.7	14.4	10.6	7.2
22	0.5	3.5	5.9	10.1	13.5	19.1	24.7	21.2	20.3	14.2	9.9	7.5
23	0.2	3.6	4.2	8.0	13.1	18.4	23.4	20.6	21.8	13.8	7.9	8.6
24	0.4	3.5	4.9	5.0	12.8	19.9	22.7	21.0	20.1	13.5	7.4	9.1
25	2.0	2.9	6.4	7.3	14.3	21.5	24.5	21.1	20.4	13.5	6.2	9.5
26	3.0	3.3	5.8	9.6	15.3	22.0	23.7	22.5	22.0	13.1	7.6	8.8
27	1.0	2.5	6.2	8.7	15.0	21.4	22.8	23.1	19.9	12.5	9.3	8.5
28	0.4	3.4	7.5	9.8	14.9	20.2	22.2	22.4	18.7	12.9	11.7	9.3
29	1.1		8.4	11.0	14.9	20.9	21.7	22.9	19.0	11.7	12.6	8.7
30	2.1		10.1	10.5	16.1	20.2	22.2	22.2	16.5	11.8	9.5	7.9
31	1.5		10.3		16.4		21.8	22.5		14.3		8.2
Monthly average	1.9	2.5	4.6	10.6	13.5	19.1	21.8	22.6	20.7	16.0	11.9	7.6
Monthly minimum	-0.4	-0.4	-0.1	4.1	5.8	13.0	15.1	18.2	14.4	10.5	5.7	5.7
Monthly maximum	5.2	5.3	13.6	18.3	20.5	25.3	27.4	26.7	24.6	22.8	17.2	10.1
Ave. daily range	1.5	2.2	3.6	5.6	6.2	5.8	5.9	4.9	3.6	2.4	2.2	1.1
Cum. degree days	60.2	69.4	142.3	316.5	389.7	574.3	675.5	699.5	621.5	497.4	357.0	237.0
Number of days	31	28	31	30	29	30	31	31	30	31	30	31