Enhancing Domestic Baitfish Production: Developing Techniques for Culturing Emerald Shiners (*Notropis atherinoides*)

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Summary

Emerald shiners comprise a substantial portion of the valuable baitfish industry in the north central United States, but unfortunately major sources of this minnow are from wild stocks that are declining. As a result, supplies rarely meet demand, particularly during periods when the demand is high or when particular sizes of fish are unavailable. In this study we attempted to develop culturing techniques for spawning and raising emerald shiners that could ultimately be used to augment wild sources. Our research showed that good water quality was critical for successfully holding and rearing emerald shiners. Stress, induced by transporting emerald shiners, resulted in high mortalities of numerous brood stock shipments. Our research also showed that growth of emerald shiners could be varied using temperature, food ration, or a combination of approaches. Indoors, maintenance growth rates were achieved using a food ration of 1-2% of body weight per day (40% protein) at 18-23°C while achieving a maximum growth rate at rations of 6% body weight per day at 23°C. Growth rates were not affected by stocking densities in indoor rearing chambers as long as water quality could be maintained. These results can be used determine how to maximize growth or grow specific size classes for future size-specific demand. We were also able to get emerald shiners to spawn in small 1-2 acre rearing ponds but few fish survived to adult sizes presumably due to predation by adults. However, for intensive culturing in ponds to be successful, adults emerald shiners, as well as other species, need to be separated from young after emergence. Indoors, we were unable to induce spawning under artificial lighting conditions. Additional work needs to be conducted on culturing emerald shiners in order to further develop commercial culturing techniques for emerald shiners. Focus on developing spawning techniques should be a high priority if intensive rearing is to be successful under current trends of declining wild stocks. Overall, culturing emerald shiners will require extra care beyond what is required for rearing many of the other baitfish species. Stringent transporting and rearing conditions will be required to insure high survival and good return on investment by growers.

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Introduction

The Emerald Shiner (*Notropis atherinoides*) Rafinesque is a small, cool-water minnow that is native to North America and inhabits large lakes and rivers throughout its range. (Becker 1983, Crossman 1959). Known locally as lake shiner, lake emerald shiner, common emerald shiner, lake silverside, Lake Michigan shiner, and Milwaukee shiner. It is widely distributed from Mobile Bay Basin, Alabama west to Galveston, Texas, north through the Mississippi River Basin and St. Lawrence River drainage to Lake Champlain, VT. From Quebec west through southern Canada to Great Slave Lake and the Mackenzie River, Northwest Territories, and south through the Canadian Atlantic Territories, into Montana, North Dakota, South Dakota to the Red River drainage of Northern Texas (Figure 1).

Historically, the emerald shiner was characterized as being abundant throughout its home range (Lee et. al. 1980, Becker 1983). In the Great Lakes, the emerald shiner was reported as being one of the most abundant species in the region (Hubbs 1934, Cooper 1936, Becker 1983). It periodically reached such high abundance, that on November 17, 1957, emerald shiners blocked the intake screens at the Oak Creek Power Station in Milwaukee, Wisconsin (Flittner 1964). Hubbs and Cooper (1936) documented that as many as 100,000 shiners were routinely collected with one dip of a three foot dip net in areas of Lake Michigan, and a section of the Milwaukee River was also described as being full of shiners, (likely emerald shiners) with their numbers estimated to be in the millions (Lapham 1954). In Illinois, the shiner was considered "excessively abundant...occurring throughout the state" (Forbes and Richardson 1908). Moreover, the

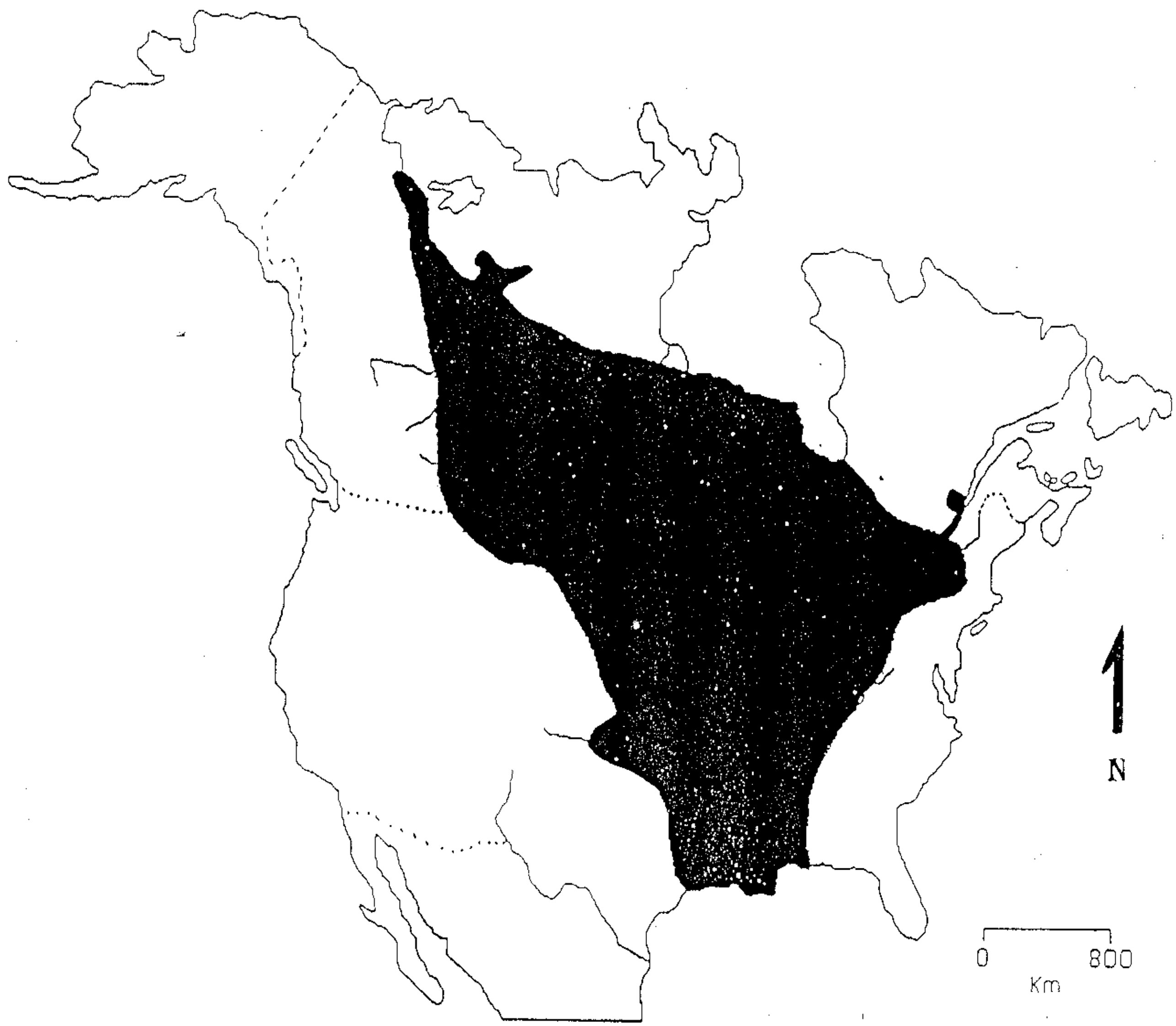


Figure 1. Native range of the Emerald shiner (Modified from Lee et. al. 1980)

emerald shiner was identified as the dominant minnow species in Lewis and Clark Lake, South Dakota (Walburg 1964) and in Lake Simcoe, Ontario (Crossman 1959).

Recent work suggests that emerald shiner populations have declined drastically from historical times in many areas of the Great Lakes (Wells 1970, Crowder 1980, Becker 1983, Thomas 1985). In the early 1950's, emerald shiners in Lake Michigan darkened the waters with their immense numbers but by the 1960's, their numbers were so low that they were almost gone from the lake (Becker 1983). Certain areas of the Wisconsin River, Lake Erie, The St. Mary's River and Lake Champlain (New York) periodically appeared to have harvestable populations (Flittner 1964, Leach and Nepszy 1976, Thomas 1985), but their numbers also appear to be in decline.

Several factors may have contributed to the decline in the abundance of the emerald shiner. In the Great Lakes, the decline has been accredited to the introduction of exotic species like the alewife (*Alosa pseudoharengus*) which may prey upon and compete with larval emerald shiners (Smith 1970, Stewart et. al. 1981). Alewife are known to prey on the pelagic eggs of the emerald shiner and compete for food which may negatively effect many small fishes (Sievert 1972, Stewart et. al. 1981, Thomas 1985). In Lake Michigan the decline in emerald shiners was concurrent with the spread of alewives. The decline initially began in the northern part of the lake and then later in southern areas as alewives dispersed south (Wells 1970). The large populations of alewife occurring in shallow bays once dominated by the emerald shiner during late spring and summer provides additional circumstantial evidence to support this hypothesis (Smith 1968). The effects of alewives on emerald shiners were compounded by the loss of top predators due to sea lamprey (*Petromyzon marinus*) predation. With no predators, alewives were able to increase in abundance and gain the competitive advantage over the emerald shiner and other native forage fish (Smith 1968, Smith 1970).

A decline in water quality, particularly during the 1960's is also suspected as having had an adverse effect on the emerald shiner populations. Emerald shiners are intolerant to many sources of pollution (Lyons 1989). Municipal and industrial sewage wastes, heavy metals, DDT, TCDD, PCB's, thermal pollution, agricultural runoff and acid rain are all potential sources of toxicity and stress to fish (Becker 1983). Vanhorn et. al. (1949) identified the toxicity of paper mill effluent to emerald shiners under conditions of low dilution. Single exposure LC50 concentrations for the shiner exposed to chlorine was 0.10 - 0.44 mg/liter at 25° C (Fonder and Collins 1979, Brooks and Bartas 1984). Furthermore, the loss of habitat and water quality due to the construction of dams, development and industrialization of watersheds and poor land use may have further affected emerald shiners. The alterations of rivers and streams through elimination of periodic flood episodes, variable stream beds and fluctuating water temperatures are well-known cause of fish population declines (Cross et. al. 1985). The general effects of eutrophication and habitat degradation could lead to a change in species composition of fish communities (Leach and Nepszy 1976). This effect is especially crucial during the critical egg and larval developmental stages.

The ecological significance of emerald shiners cannot be understated. The emerald shiner was once described as the greatest forage fish in abundance throughout the Great Lakes (Hubbs 1934), being a vital prey species for commercially-important species of the region (Radcliffe 1931, Cooper 1936) as well as providing a prey base for a variety of sport fish. They have been found in the stomachs of perch (*Perca flavescens*), smelt (*Osmerus mordax*), burbot (*Lota lota*), lake trout (*Salvelinus namaycush*), rainbow trout (*Oncorhynchus mykiss*), rock bass (*Ambloplites rupestris*), pumpkinseed (*Lepomis gibbosus*), northern pike (*Esox lucius*), sauger (*Stizostedion canadense*), walleye (*Stizostedion vitreum vitreum*), smallmouth bass (*Micropterus dolomieui*), largemouth bass (*Micropterus salmoides*), white bass (*Morone chrysops*), gulls, terns, mergansers, and cormorants (Flittner 1964, Fuch 1967, Campbell and MacCrimmon 1970, Scott and Crossman 1973, Becker 1983). Crossman (1959) found the increased growth of rainbow trout followed the introduction of shiners in Paul Lake, British Columbia.

The widespread use and demand of the emerald shiner by anglers to catch a variety of game fish illustrates the importance of the species as a baitfish (Flittner 1964, Campbell and MacCrimmon 1970, Becker 1983, Meronek 1994). A 1992 survey of the bait industry in the north central United States region (Illinois, Michigan, Minnesota, Ohio, South Dakota, and Wisconsin) estimated the total economic value of bait overall at $257,118,710 annually with the estimated total value of the emerald shiner fishery approaching $21,045,193 annually (Meronek 1994). However, shortages of the emerald shiner were reported from June through September in Michigan, Ohio, and elsewhere while Minnesota bait dealers reported a year-round shortage of emerald shiners. Moreover, baitdealers and distributors report handling mortality ranging from 1- 25% for their shiners (Meronek 1994) which further reduces the supply.

Clearly, supply from natural sources does not meet demand. Decreasing access to, or reducing mortality of emerald shiners could help augment supply of valuable forage. The demand for emerald shiners mainly as a fall and winter baitfish has resulted in wholesale distributors going to great measures to meet market demand (Meronek

1994). Requests from wholesalers in Vermont, New Hampshire, Connecticut, Ontario, Quebec, Michigan, Ohio, and Minnesota for shiners from Wisconsin distributors have indicated a widespread shortage occurring in the winter of 1995 and other. In addition to problems with abundance, obtaining the desired size demanded by anglers at specific times of the year has been problematic. Therefore, the ability to produce the preferred size of healthy emerald shiners at the desired time of year would be a great advantage to the commercial baitfishing industry. Such growth scheduling has been accomplished for the common shiner (*Notropis cornutus*) (Dobie et. al. 1956) and fathead minnow (*Pimephales promelas*) (Becker 1983).

Past studies of the emerald shiner have examined toxicity, embryology, taxonomy, age and growth of wild fish, fecundity, mortality, diet composition, seasonal distributions and daily migration patterns (Flittner 1964, Fuchs 1967, Campbell and MacCrimmon 1970, Parsons 1971, Mendelson 1975, Whitaker 1977, Courtney and Blokpoel 1980, Kolurn 1982, Thompson 1984). However, little attention has been placed on developing a method to culture the emerald shiner for commercial purposes.

Emerald shiners have several characteristics which favor its propagation. First, it feeds at low levels of the food chain and thus has potential for high production levels (Campbell and MacCrimmon 1970). Second, under natural conditions, it is capable of achieving a marketable size (greater than 65 mm) in its first growing season which is approximately fifty-five percent of its total size (Fuch 1967). Third, by artificially controlling growing conditions, growth may be attenuated or accelerated using variable combinations of temperature, diet, and rearing density. And because the emerald shiner is sexually mature at about 1 year of age, it is ready to spawn in its second summer, which would further increase reproductive potential (Flittner 1964).

In addition to obvious economic benefits and recreational uses, the culture and sale of emerald shiners have other benefits. Culturing may reduce exploitation on already depleted natural populations of emerald shiners preventing further declines and perhaps stimulating recovery of some stocks. Conversely, attempts to restore aquatic ecosystems to historical compositions may further restrict collecting wild fish thus limiting access to wild sources. A culturing technique could also help preserve genetically-distinct populations of emerald shiners which may differ in their ability to reproduce and grow in different environments.

The objectives of this study were to: 1) develop culturing techniques for the emerald shiner by assessing the success of spawning emerald shiners under lab and pond conditions and 2) to determine combinations of temperature and feeding conditions that maximize growth and allow flexibility in raising fish to desirable sizes to fit market demands in indoor tanks and outdoor ponds.

Methods

Laboratory and field experiments were conducted to evaluate reproduction, survival, and growth of emerald shiners under indoor and outdoor culturing conditions. Laboratory experiments were conducted in the Streamflow and Marine Laboratories in the College of Letters and Science Building at the University of Wisconsin-Stevens Point.

GROWTH: LABORATORY EXPERIMENTS

Three sets of growth experiments were conducted to assess growth rates of emerald shiners at varying temperature and feeding ration combinations. Growth was evaluated at 3 temperatures: 23, 21, and 18° C, and at 8 feeding rations: 1-8% body weight/day.

Table 1. Experimental temperature-feed ration combinations used in indoor laboratory experiments. Also shown are each experiment in weeks, and start and end dates

Temperature (°C)	Ration (% body weight/day)	Duration (weeks)	Start Date	End Date
18	1, 2, 3, 4, 5, 6, 7, 8	10	11/30/96	01/03/97
21	1, 2, 3, 4, 5, 6, 7, 8	13	09/30/96	12/22/96
23	1, 2, 3, 4, 5, 6, 7, 8	13	09/30/96	12/22/96

Experiments were run for ten weeks at 18° C and thirteen weeks at 21 and 23° C. For each of the 24 experimental chambers, fifty emerald shiners were randomly selected from batches of fish that were used concurrently in outdoor pond growth experiments. To reduce handling mortality, initial total lengths were taken from a sample of 300 emerald shiners that were then randomly apportioned to experimental chambers. The remaining fish were randomly selected and added to each tank to bring the total to 50. Total weights were then taken for each group of fifty emerald shiners (i.e. batch weight) before being placed into one of the aquaria with an assigned feeding regime and experimental temperature range. Water temperature was controlled with an offset heating system using individual tank heaters and environmental chambers, which kept temperatures within 1°C. The sides of tanks were covered with black plastic film to reduce stress.

Emerald shiners were fed daily between the hours of 11:00 am and 2:00 p.m. throughout the duration of the experiments. Food ration was re-calculated weekly for each tank by randomly selecting and weighing ten fish from each tank and prorating (5 x) to estimate mean tank biomass. Weekly food ration was calculated by multiplying the weight of the 10 shiners by 5 (for 50 shiners/tank) and then multiplying by the percent ration to be fed for that tank. Feed rations were weighed out for the entire week, and weights were recalculated every seven days. Emerald shiners were fed Purina Trout Chow Floating Granules (40% protein). Filters were turned off for approximately 1/2 hr at feeding to allow fish time to feed on floating granules and so food was not filtered out of the system. Granules were either consumed within 1/2 hr or sank to the bottom of the tank and were no consumed by emerald shiners. Tanks in higher feed rations (e.g. above 5%) accumulated large amounts of uneaten food. To prevent nitrogen build-up, twenty to thirty percent of the water volume of each tank was changed daily with tap water using siphons. Aquasafe (1 ml) or ammo lock (1 ml) was added to every 5 gallons of water replaced per tank to remove any chlorine or chloramine present. Each day prior to feeding, each tank was cleaned by siphoning uneaten food out of the tank, cleaning or replacing filters, recording any mortalities, checking tank temperature, and administering medication when needed. If mortalities occurred during the week, they were replaced with similar size fish from a holding tank where fish were being fed 2% body weight/day. Previous work indicated this was a maintenance ration (i.e. no net gain or loss of weight).

Growth was measured weekly during each experiment. Ten emerald shiners were collected from each tank using a 8 x 6" aquarium net and placed in separate 5 gallon buckets containing 0.5 to 1.0% sodium chloride solution to reduce stress from handling. Each batch of ten shiners was then poured into an aquarium net, blotted to remove excess water, placed in a tared beaker of water and then weighed. Weights were recorded to the nearest 0.1 gram after initial rapid movements by shiners ceased. This usually took approximately thirty seconds. Shiners were then placed back into their respective tank. Growth was recorded both as a function of increases in lengths and weights.

Growth curves were calculated for each temperature/feed ration combination using (Ricker 1975): $W_t / W_0 = e^{Gt}$

Where:
- W_t = weight at time (t)
- W_0 = initial weight (g)
- e = exponent
- G = instantaneous rate of growth

GROWTH: STOCKING DENSITY LABORATORY EXPERIMENTS

We assessed the effect of eight stocking densities (i.e. rearing densities) on emerald shiners growth rates in eight flow-through experimental chambers. Stocking densities were based on commercial stocking standards set for minnows of 50,000 – 300,000 fry per acre or up to 1000 broodfish per acre (Higginbotham 1988). In each rearing chamber, emerald shiners were fed Purina Trout Granules (40% protein) per day (5% body weight/day) based on mean tank biomass (on a 40 fish subsample), adjusted weekly for growth. Temperature was maintained at $15.0^{\circ} \pm 1^{\circ}$ C and water was re-circulated through a sand and zeolite filter to maintain water quality. Current velocity was negligible, but inflow of water was maintained to help reduce ammonia nitrate levels.

Fish were stocked into experimental chambers at densities ranging from 226.5 to 4416 g/m^3. (Table 2).

Table 2. Experimental design of stocking density-growth experiments showing density (g/m^3) of emerald shiners stocked, daily ration, and weight of shiners. Density is represented as the grams of shiners per cubic meter of water.

Tank	Density (g/m^3)	Feed Ration	Start Weight	Final Weight	Δ Change in Weight
1	4416.24	5.0 %	222.60	729.80	507.20
2	3800.08	5.0 %	276.87	936.40	659.53
3	3433.01	5.0 %	146.02	598.80	452.78
4	1945.26	5.0 %	97.12	290.80	193.86
5	808.35	5.0 %	41.63	125.60	83.97
6	398.17	5.0 %	18.87	93.13	74.32
7	226.46	5.0 %	10.66	57.58	46.92

GROWTH: POND EXPERIMENTS

Field growth studies were conducted in private ponds. Two, 10-week growth experiments were conducted from 8/15/96 to 10/15/96 in groundwater-fed ponds owned by Okray Family Farms located southwest of Stevens Point (Lat. N 44° 26.73/ Lon. W 89° 40.56). Ponds were approximately one acre in size and had a maximum depth of 3 m. Eight gallons (approximately 60 lb.) of young-of year (YOY) emerald shiners ($\bar{x}$ length = 37 mm) were stocked into each pond. YOY emerald shiners were seined from a pond owned by the Gollon Family, Stevens Point, WI and stocked into 2 ponds owned by Okray Family Farms, Plover, WI (Figure 2). Upon initial stocking, an estimated 1/2 gallon per pond died from stress resulting from transportation and handling. Surviving fish were fed 5% body weight every two days. Purina Trout Chow Granules (40% protein) were fed for the first 4 weeks to accommodate their relatively small size. Purina Trout Chow (40% protein) was fed the remaining 6 weeks of the experiment as fish grew larger. Food was cast out across the surface of the pond approximately 3 m from shore.

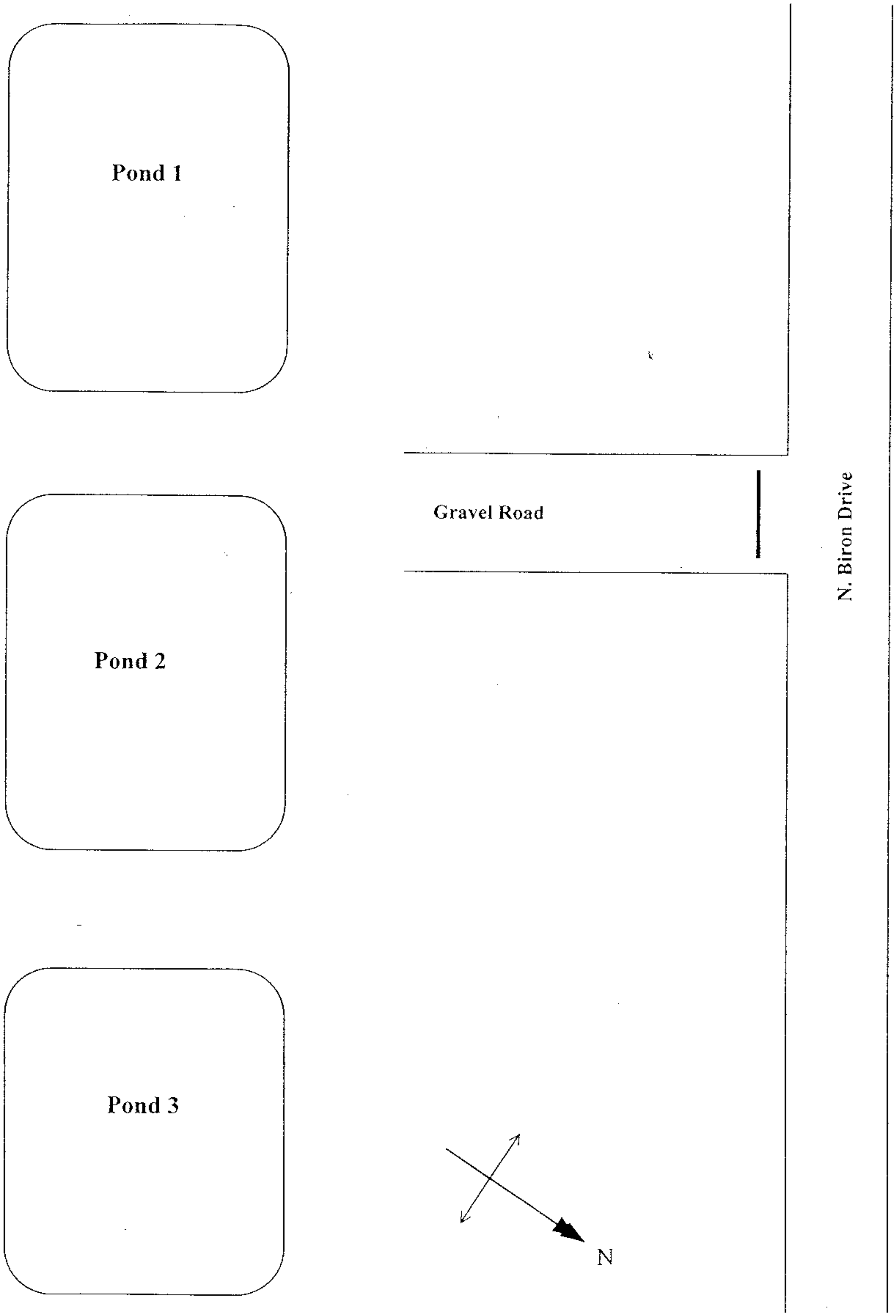


Figure 2. Okray Family Farms Ponds 1, 2, and 3 used in Growth and Reproduction Experiments. Ponds are approximately 1 acre in surface area and approximately 3 meters in depth.

Fish were sampled weekly from each pond using a 1 x 1 m lift net with 3.0 mm mesh. Samples were collected at 10 m intervals along the shoreline casting and retrieving the net quickly until a sample of at least 30 emerald shiners was captured. Shiners were preserved 10% formalin and brought back to the lab where lengths and weights were recorded. Growth (e.g. change in lengths and weights) was then evaluated for the 10-week period. Water temperature and dissolved oxygen profiles of each the pond was collected weekly at 0.5 m intervals. In addition, surface water temperature and oxygen readings were collected every two days (prior to feeding) approximately 1.5 m from shore at a depth of 0.5 m with a Yellow Springs Instrument (YSI) Model 57 temperature/oxygen probe. Air temperature was recorded with a mercury thermometer calibrated using the YSI Temperature probe.

GROWTH: LAKE DUBAY EMERALD SHINER STUDY

Field collections of emerald shiners were made weekly in order to assess natural growth rates of emerald shiners in Lake DuBay near Mullins Cheese Factory, Knowlton, Wisconsin (Lat. N 44° 43.02 /Lon. W 89° 41.19). Collections were made concurrent with the pond growth experiments for comparison purposes. The collection site is located along a sand beach near the cheese factory discharge. Emerald shiners were collected using a 1 x 1 m lift net with 3.0 mm mesh attached to a 3.0 m section of PVC tubing. From shore, the net placed in the water below the surface and lifted at 1-minute intervals until at least thirty YOY emerald shiners were collected. Shiners were preserved 10% formalin, labeled (location and date of capture), and brought back to the lab where lengths and weights were recorded. During sampling, water temperature and dissolved oxygen were collected using YSI Model 57 temperature/oxygen probe. Air temperature was recorded using a mercury thermometer.

REPRODUCTION: LABORATORY EXPERIMENTS

Experiment 1

We assessed whether reproduction could be induced in emerald shiners under indoor culturing conditions. Two-2271 liter (each) re-circulating water systems were used in the Stream Flow Lab at University of Wisconsin-Stevens Point to simulate emerald shiner spawning habitat as described by Flittner (1964). Tanks were 2 m in diameter and 1.75 m deep. 10.89 kilograms of sand (0.023 to 0.50 mm diameter) was placed into 6 trays (each 13 x 38 x 76 cm each) per tank for spawning substrate and suspended horizontally off the bottom using a set of wooden racks. In each tank, photoperiod was controlled by shrouding the tanks with black plastic and using two four-foot florescent bulbs per tank to simulate 15.5 hr day light/9.5 hr darkness as described by Rowan and Stone (1996). Emerald shiners were acclimated to test temperatures gradually with cattle trough heaters. Temperature remained constant throughout experiments between 22-24°C from 4/17/96 to 8/8/96 to coincide with natural reproduction occurring in the wild.

Adult shiners (x length = 85 mm) were stocked in both tanks at a rate of 3.79 liters of shiners per tank (approximately 700 emerald shiners). Evidence of spawning on the sand trays was checked daily using an underwater view tube constructed of PVC pipe that was 115 cm in length and 10 cm in diameter and having a clear Plexiglas end cap.

After viewing all trays, any tray suspected of containing eggs was raised and examined closer in detail for eggs. Fish in each tank were fed a daily ration that was equal to 4% of the mean tank biomass and which was recalculated weekly. Food was a crushed 4.2 mm floating pellet Purina Trout Chow (40% protein). Feed rations were adjusted when mortalites occurred during the experiment.

Experiment 2

Three, 113 liter tanks having gravel were stocked with 10 to 30 adult Wisconsin River emerald shiners during November 1994 and late May 1995, respectively. A fourth tank, with a sand substrate was stocked with 10 Lake Champlain shiners during late May 1995. All four tanks were kept at 19-21°C during experiments. Each tank had a box filter, was covered with black plastic to shield from direct light, and fish were fed a 4% body weight/day ration of Purina Trout Chow Granules (40% protein). Filters and water were changed weekly. Tanks were checked daily for eggs and larvae.

Experiment 3

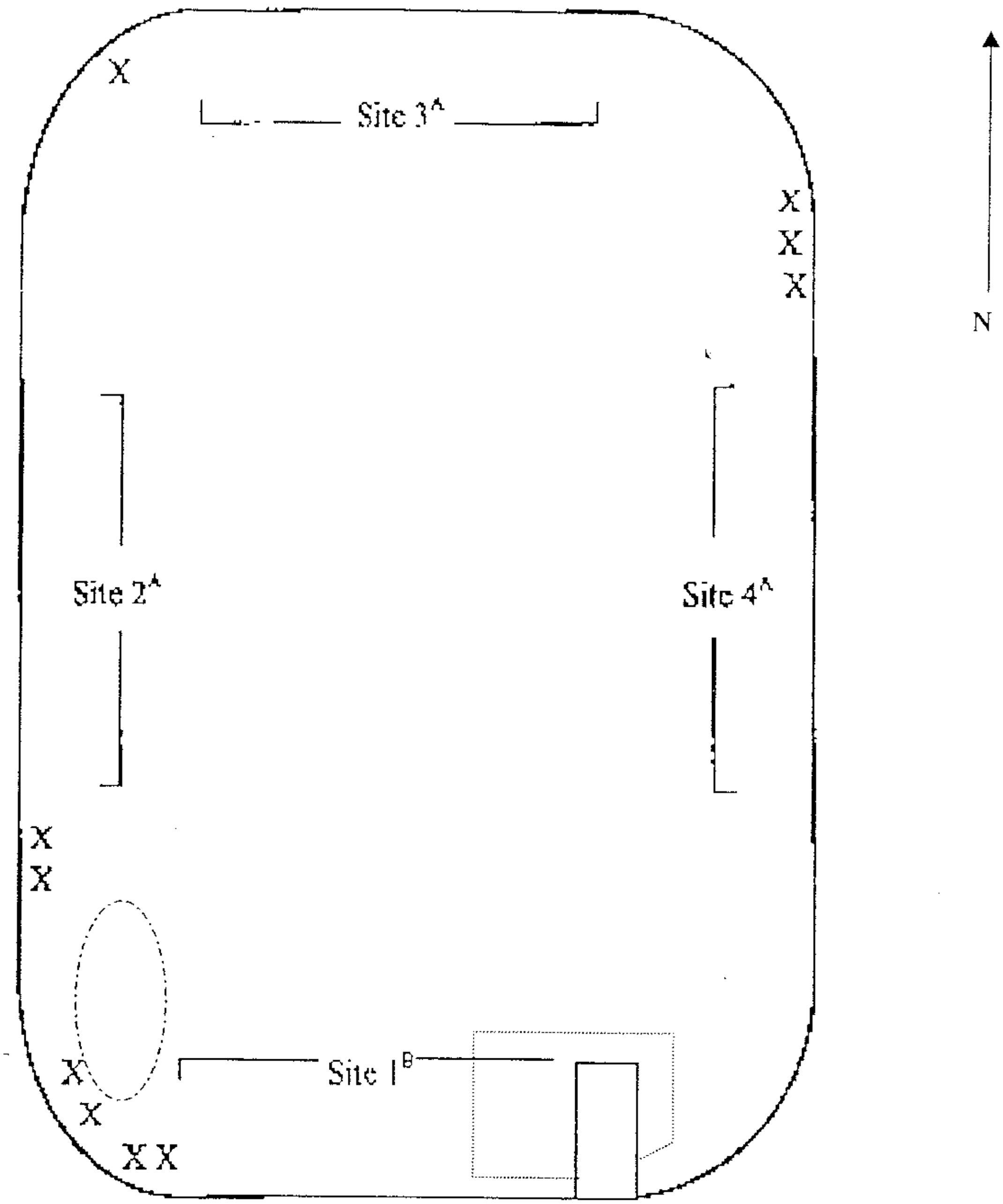
Two 1135 liter recirculating raceways were stocked with 3.79 liters of adult ($\geq$ 85 mm) emerald shiners from the Wisconsin River in June of 1995. A third 1514 liter recirculating tank was also stocked with 50 adult ($\geq$ 85 mm) emerald shiners from the Wisconsin River. Tanks were stocked at 18°C and raised 1°C per week to mimic Wisconsin River temperatures. At 23°C temperatures were held constant. Photoperiod was held at 12-h light/12-h darkness. Dissolved oxygen and nitrites were monitored daily using a Hack Kit. To reduce stress, waste was siphoned out every other day and sodium chloride was added (up to 1.0% per tank) every 7-10 days. Fish were fed a ration of Purina Trout Chow Granules (40% protein).

REPRODUCTION: FIELD EXPERIMENTS

Field experiments were conducted to evaluate spawning feasibility in outdoor ponds. Ponds used are owned by the Wachowiak family (1 pond) and Okray Family Farms (3 ponds).

Experiment 1

Fifty-six liters (5921 fish/acre foot) of adult (x length = 85 mm) emerald shiners obtained from the Wisconsin River were stocked into the Wachowiak pond on 3/30/95 to assess suitability of ponds for reproduction. The pond was located on County Highway M and owned by the Wachowiak family. The Wachowiak Pond was approximately 1.9 acres in size with a maximum depth of 3 m and substrate that consisted mostly of sand and silt (Figure 3). Spawning condition, spawning activity, presence of shiner fry, water temperature, and dissolved oxygen, were monitored biweekly to assess spawning activity. During sampling, surface water temperatures (13 cm below surface), bottom temperatures (13 cm above bottom), and dissolved oxygen (13 cm below surface) were recorded 6 m from shore. Visual surveys were conducted at night from a small rowboat with a light and during the daytime by snorkeling, observing from the pier, and walking the entire shoreline. Each visit, one complete traverse of the shoreline was made stopping at four locations to record spawning activity or fry emergence. Observations of spawning activity were also made at night with a light from a small rowboat that was rowed around the perimeter of the shoreline. Ten random transects were swam from shore during daylight hours to observe spawning activity and fry emergence.



[A] - Sites characterized by sand/silt substrates
[B] - Site characterized by sand substrates
--- Area where schools of Emerald Shiner Fry have been observed
--- Area where schools of Emerald Shiner Fry were collected
------ Area where adult shiners observed spawning

Figure 3. Diagram of the Wachowiak Pond (private residence, Stevens Point, WI.) depicting location of emerald shiner fry, different substrates. Approximate area 1.9 acres, with maximum depth of 3.0 meters

Changes in spawning condition and emergence of fry were evaluated weekly using three sampling methods: a 300-micron plankton net was towed behind a row boat pulled one length of the pond 2-3 times per sampling day, a 1 x 1 m lift net with 0.3 cm mesh was used at four standard sampling sites. A 300-micron D-net was also used for spot sampling at the beach site where schools of shiner fry were sighted. The four standard sampling sites were 10 m long and were seined using a 6 x 1 m seine with 0.3 cm mesh. All fish collected during sampling were placed in coolers or buckets, treated with sodium chloride (0.5 - 1.0 % solution) and ice if necessary and then returned to the laboratory for identification. Fry were acclimated to within 3° C of tank temperatures and placed in aquariums to allow growth and development which aided in positive identification.

Experiment 2

Three ponds at the Okray Family Farms site were stocked with 1, 1.5, and 1.5 gallons of adult shiners, (TL $\geq$ 85 mm) respectively on 6/29/96 to assess spawning potential. Ponds were approximately 1 acre in size and 3 m in depth (designated ponds 1, 2, and 3). Spawning observations were made and 3 times each week water temperature, dissolved oxygen profiles, air temperature, and fish samples were collected. Samples of adult emerald shiners were collected at observation sites using a dipnet and then preserved in a solution of 10% formalin so growth and a gonadosomatic index (GSI) could be determined in the laboratory. Three times a week, day and evening observations for spawning activity and presence of emerald shiner fry were made by walking the entire shoreline of ponds and randomly sampling for fry with a 1 x 1 m dip net. Randomly-selected transects were placed and run from the shoreline toward the center of the pond to determine fry emergence from 0.5 - 2.0 m depths. Ponds were also seined on 7/29/96 using a 30.5 x 2.4 m seine with 0.635 cm mesh to obtain samples so growth and GSI could be determined on adult shiners. Water temperature, dissolved oxygen profiles, and air temperature were collected at this time. Temperature and oxygen profiles for each pond were collected in the middle of each pond at 0.5 m depth intervals. Air temperature was recorded using a mercury thermometer.

Results

GROWTH: LABORATORY EXPERIMENTS

In general, emerald shiner growth was higher at warmer temperatures and at higher food rations, although there were some discontinuous growth rates among the temperature/feeding combinations.

<u>23° Celsius</u>

LENGTHS

At 23°C, the mean length of emerald shiners increased among all food rations tested (Figure 4). The increase in length was generally similar for rations 2-8% body weight/day. The fish fed 6% body weight/day had the highest growth and growth for fish fed 1% body weight/day was lower than all other feed rations. Change in mean lengths for feed rations 1 - 8% were 2.69, 7.24, 8.28, 7.12, 6.60, 10.35, 7.25, and 7.71 mm, respectively (Table 3).

WEIGHTS

At 23°C, all fish increased in total weight regardless of feed ration during the experiment (Figure 5, 6). Fish fed 6% body weight/day had the highest net increase in weight, followed by 3% and the 5% feed rations. The 1% body weight/day ration had the

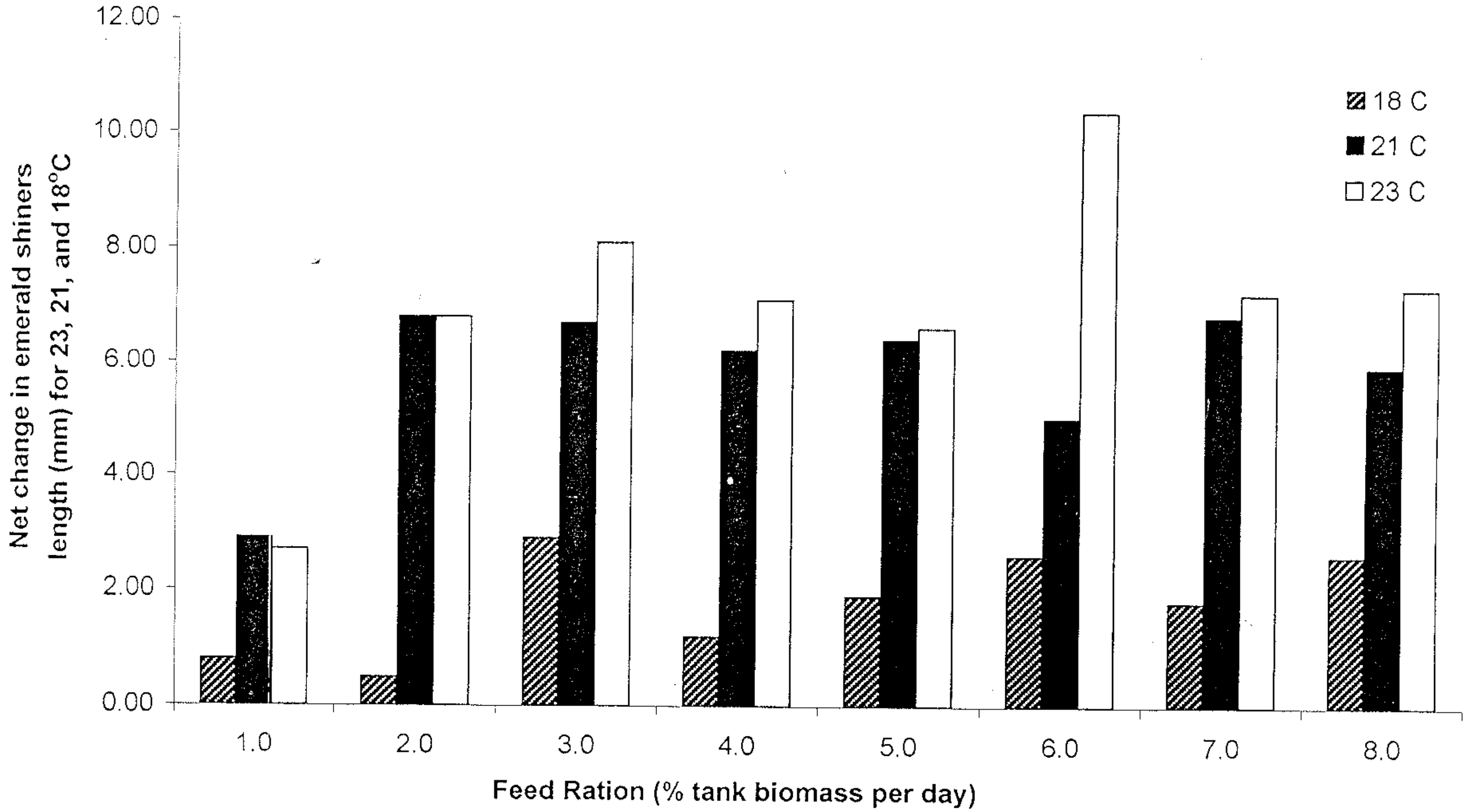


Figure 4. Change in emerald shiner total length in experimental chambers at 23, 21, and 18oC, fed rations daily 1-8% (body weight/day). Fish were fed Purina trout granules (40% protein) adjusted weekly for growth (n = 50 fish/chamber). Initial length $\pm$ 1 standard error for emerald shiners in 21 and 23°C x = 45.4 $\pm$ 0.31, 18°C = 47.3 $\pm$ 0.42.

Table 3. Growth (mm) of emerald shiners as a function of temperature and food ration in experimental laboratory chambers. Mean start length ± one standard error, mean final length ± one standard error, and change in length per tank through the course of the experiment. Rations fed were 1 to 8% (body weight/day) daily (adjusted weekly for growth).

Temperature	Feed ration (%)	x Start length	x Final length	Δ Change in length
23 °C	1.0	45.40 ± 0.31	48.09 + 0.62	2.69
	2.0	45.40 ± 0.31	52.64 + 0.74	7.24
	3.0	45.40 ± 0.31	53.68 + 0.57	8.28
	4.0	45.40 ± 0.31	52.52 + 0.56	7.12
	5.0	45.40 ± 0.31	52.00 + 0.65	6.60
	6.0	45.40 ± 0.31	55.75 + 0.52	10.35
	7.0	45.40 ± 0.31	52.65 + 0.68	7.25
	8.0	45.40 ± 0.31	53.11 + 0.66	7.71
21 °C	1.0	45.40 ± 0.31	48.32 + .59	2.92
	2.0	45.40 ± 0.31	52.21 + .66	6.81
	3.0	45.40 ± 0.31	52.13 + .55	6.73
	4.0	45.40 ± 0.31	51.60 + .64	6.20
	5.0	45.40 ± 0.31	51.88 + .57	6.48
	6.0	45.40 ± 0.31	50.41 + .65	5.01
	7.0	45.40 ± 0.31	52.21 + .76	6.81
	8.0	45.40 ± 0.31	51.33 + .61	5.93
18 °C	1.0	47.42 ± .42	49.45 + 0.81	2.55
	2.0	47.42 ± .42	49.45 + 1.18	2.20
	3.0	47.42 ± .42	51.86 + 0.96	4.61
	4.0	47.42 ± .42	50.22 + 0.64	2.97
	5.0	47.42 ± .42	50.90 + 1.03	3.65
	6.0	47.42 ± .42	51.62 + 0.69	4.37
	7.0	47.42 ± .42	50.75 + 1.13	3.50
	8.0	47.42 ± .42	51.75 + 0.87	4.32

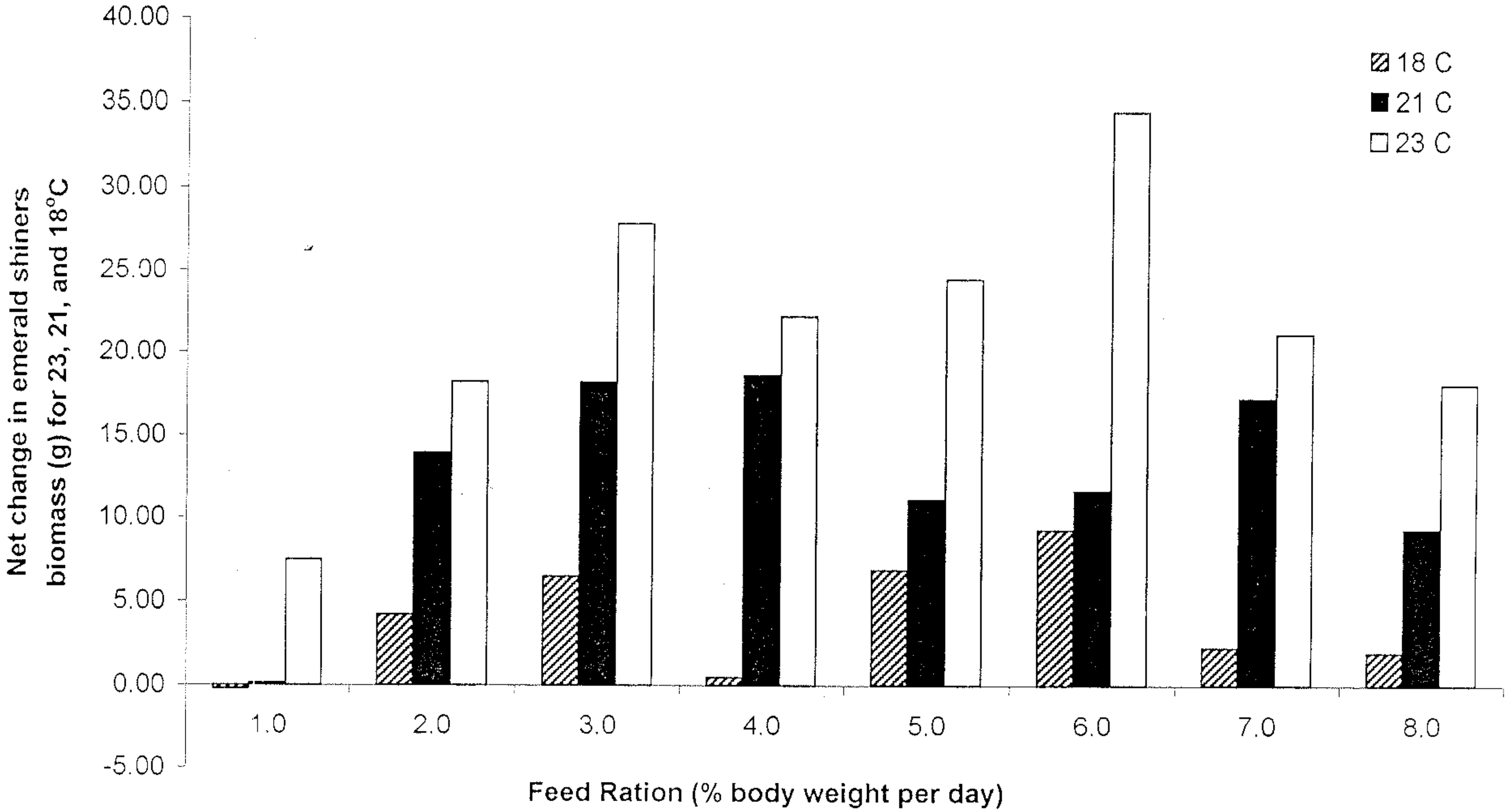


Figure 5. Change in emerald shiner total boimass in experimental chambers at 23, 21, and 18°C, fed rations daily 1 8% (body weight/day). Fish were fed Purina trout granules (40% protein) adjusted weekly for growth (n = 50 fish/chamber). Fish were fed Purina Trout Granules (40%protien).

Table 4. Growth (gm) of emerald shiners as a function of temperature and food ration in experimental laboratory chambers. Rations fed were 1 to 8% (body weight/day) daily (adjusted weekly for growth), mean start weight, mean final weight per tank, and change in weight for each tank. Weights represent 50 fish-combined.

Temperature	Feed ration (%)	x Start length	x Final length	Δ Change in length
23 °C	1.0	30.90	38.37	7.47
	2.0	39.90	58.11	18.21
	3.0	34.10	61.93	27.83
	4.0	37.10	59.29	22.19
	5.0	33.60	58.08	24.48
	6.0	33.70	68.13	34.43
	7.0	39.20	60.32	21.12
	8.0	38.70	56.80	18.10
21 °C	1.0	36.90	37.05	0.15
	2.0	39.20	53.14	13.94
	3.0	33.00	51.19	18.19
	4.0	35.10	53.72	18.62
	5.0	38.00	49.13	11.13
	6.0	36.60	47.64	11.64
	7.0	37.90	55.13	17.23
	8.0	38.90	48.22	9.23
18 °C	1.0	41.58	41.36	-0.22
	2.0	38.80	43.00	4.20
	3.0	41.00	47.50	6.50
	4.0	40.80	41.30	0.50
	5.0	40.60	47.50	6.90
	6.0	40.20	49.50	9.30
	7.0	40.20	42.50	2.30
	8.0	40.60	42.60	2.01

lowest increases in weight. Change in weights for tanks 1 - 8% were 7.47, 18.21, 27.83, 22.19, 24.48, 34.43, 21.12, and 18.10 grams, respectively (Table 4).

Growth curves at 23° C (Figure 6) show feed rations 1-8% body weight/day resulted in increased growth of 0.579, 1.419, 2.177, 1.732, 1.913, 1.905, 1.647, and 1.410, respectively (Table 5).

21° Celsius

LENGTHS

At 21°C, the mean length of emerald shiners increased among all food rations tested (Figure 4). The increase in length was generally similar for rations 3-8% body weight/day. The fish fed 4% body weight/day had the highest growth. Growth for fish fed 1% body weight/day was lower than other feed ration. Change in length for feed rations 1-8% were 2.92, 6.81, 6.73, 6.20, 6.48, 5.01, 6.81, and 5.93 mm, respectively (Table 3).

WEIGHTS

At 21°C, all fish increased in total weight regardless of feed ration during the experiment (Figure 5, 7). Fish fed the 4% body weight/day had the highest net increase in weight followed by 3% and 7% feed rations. The 1% body weight/day ration had the lowest increases in weight. Change in weights for tanks 1-8% were 0.15, 13.94, 18.19, 18.62, 11.13, 11.64, 17.23, and 9.23 grams, respectively (Table 4).

Growth curves at 21° C (Figure 7) show feed rations 1-8% body weight/day resulted in increased growth of 0.015, 1.083, 1.385, 1.452, 0.864, 0.857, 1.341, and 0.722, respectively (Table 5).

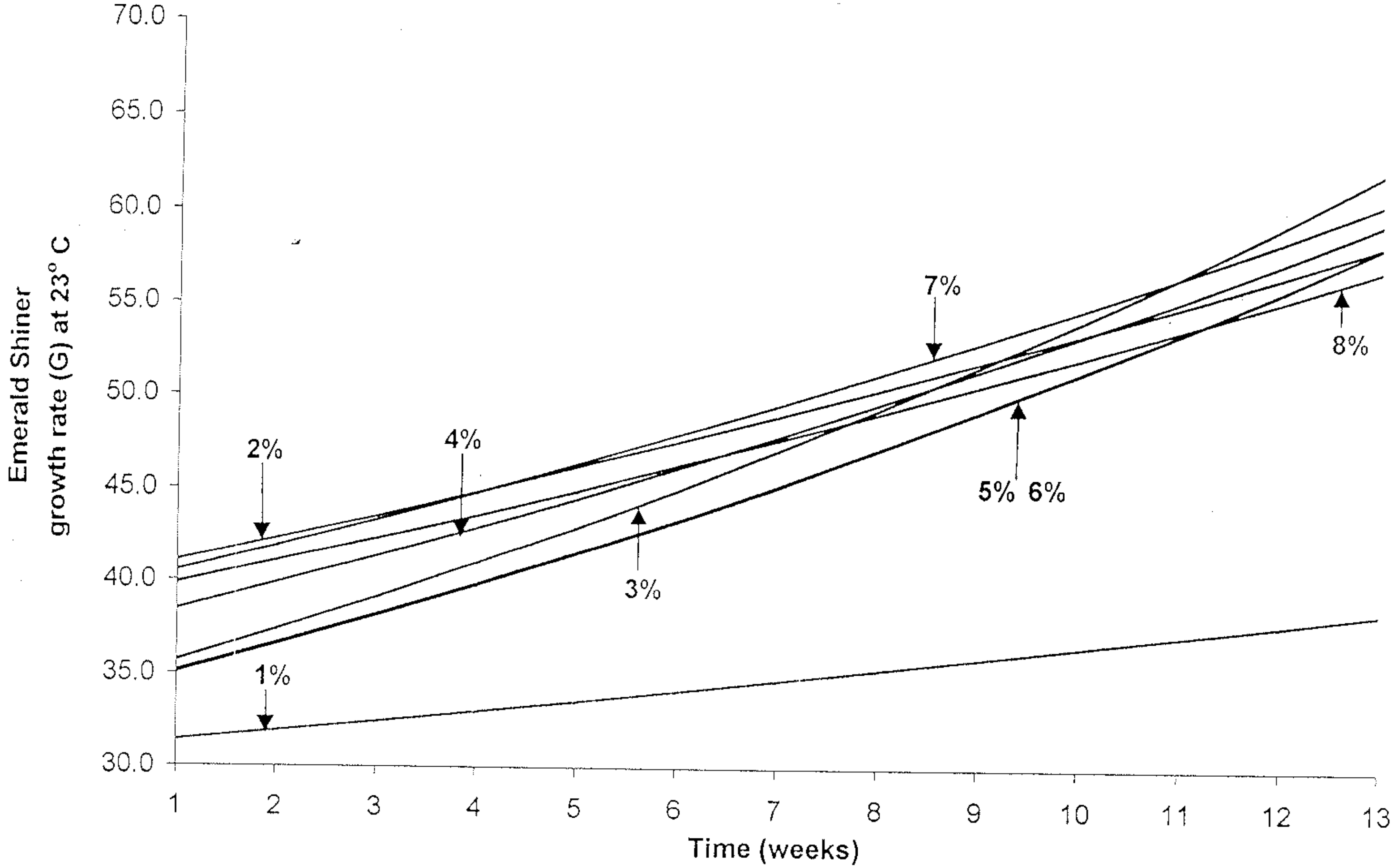


Figure 6. Calculated growth curves for rations of 1-8% body weight adjusted weekly at 23° C using instantaneous rate of growth (G) (Ricker 1975). The slope of each line indicates the growth rate. All rations 1-8% body weight/day showed increases in biomass across the 13 week period. Rations of 5 and 6% have identical growth rates.

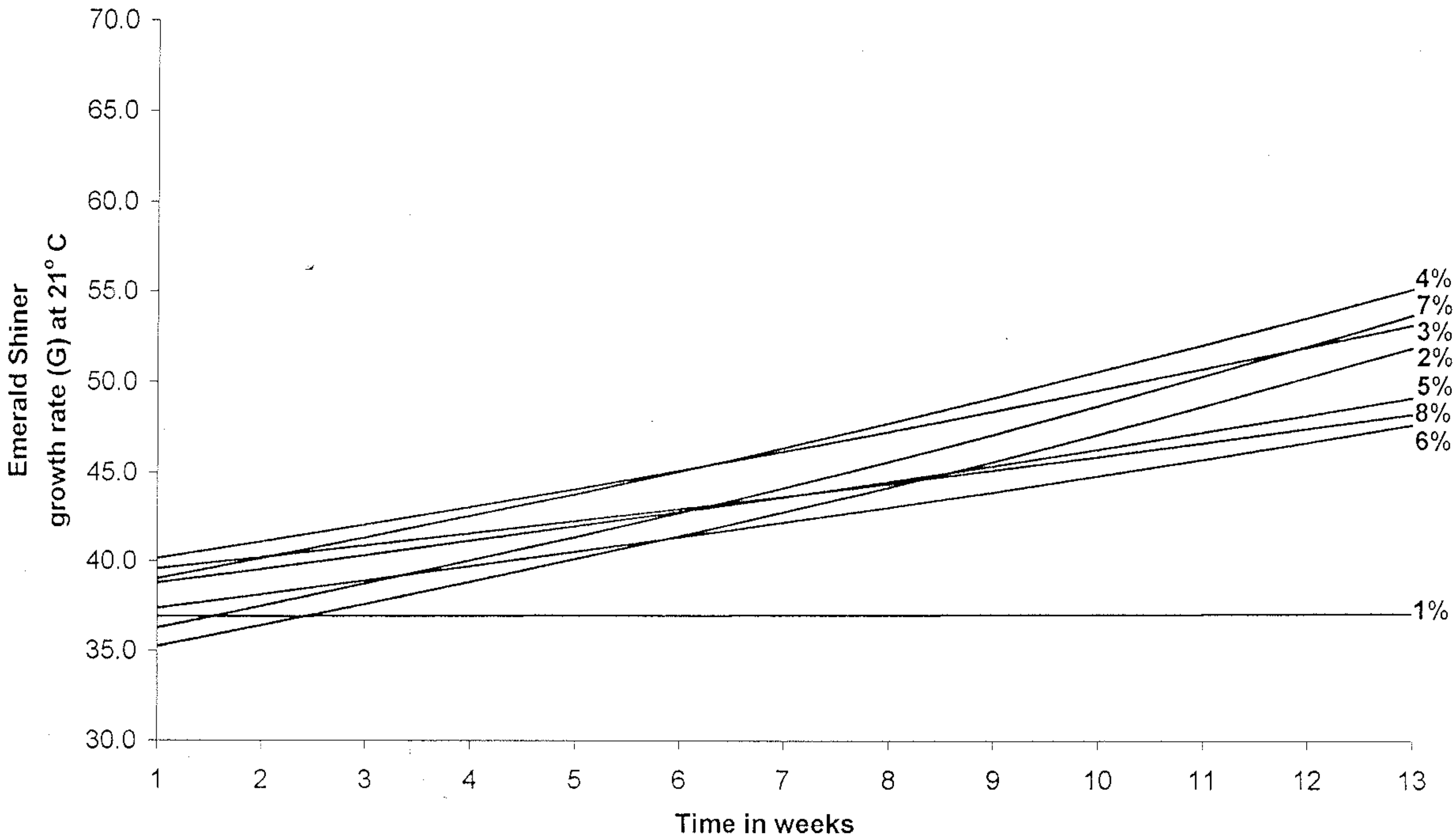


Figure 7. Calculated growth curves for rations of 1-8% body weight adjusted weekly at 21° C using instantaneous rate of growth (G) (Ricker 1975). The slope of each line indicates the growth rate. All rations 1-8% body weight/day showed increases in biomass across the 13 week period.

18° Celsius

LENGTHS

At 18°C, the mean length of emerald shiners increased among all food rations tested (Figure 4). The increase in length was generally similar for rations 1-8% body weight/day. Fish fed 3% body weight/day had the highest growth. Growth for fish fed 1% body weight/day was lower than other feed ration. Change in lengths for tanks 1-8% were 2.55, 2.20, 4.61, 2.97, 3.65, 4.37, 3.50, and 4.32 mm, respectively (Table 3).

WEIGHTS

At 18°C, 2-8% body weight/day, feed rations show increases in net weigh during the experiment. Fish fed the 1% body weight/day show a net decrease for the experiment Fish fed the 4% body weight/day had the highest net increase in weight (Figure 5). Change in weights for tanks 1 - 8% were – 0.22, 4.2, 6.5, 0.5, 6.9, 9.3, 2.3, and 2.01 grams, respectively (Table 4).

Growth curves at 18° C (Figure 8) shows that fish fed a ration of 1% body weight/day decreased in size (i.e., negative growth). Rations from 2-8% body weight/day had increased growth. Growth curves for 1-8% body weight/day were, - 0.012, 0.338, 0.378, 0.110, 0.373, 0.267, 0.090, and 0.171, respectively (Table 5).

GROWTH: STOCKING DENSITY LABORATORY EXPERIMENT

Overall growth of emerald shiners appeared to decrease slightly with increasing stocking densities but the effects were not significantly different among the stocking densities. The lowest growth occurred in rearing tanks stocked at 4416.24 and 808.35 g/m^3. The highest growth occurred in experimental chambers stocked at 226.46,

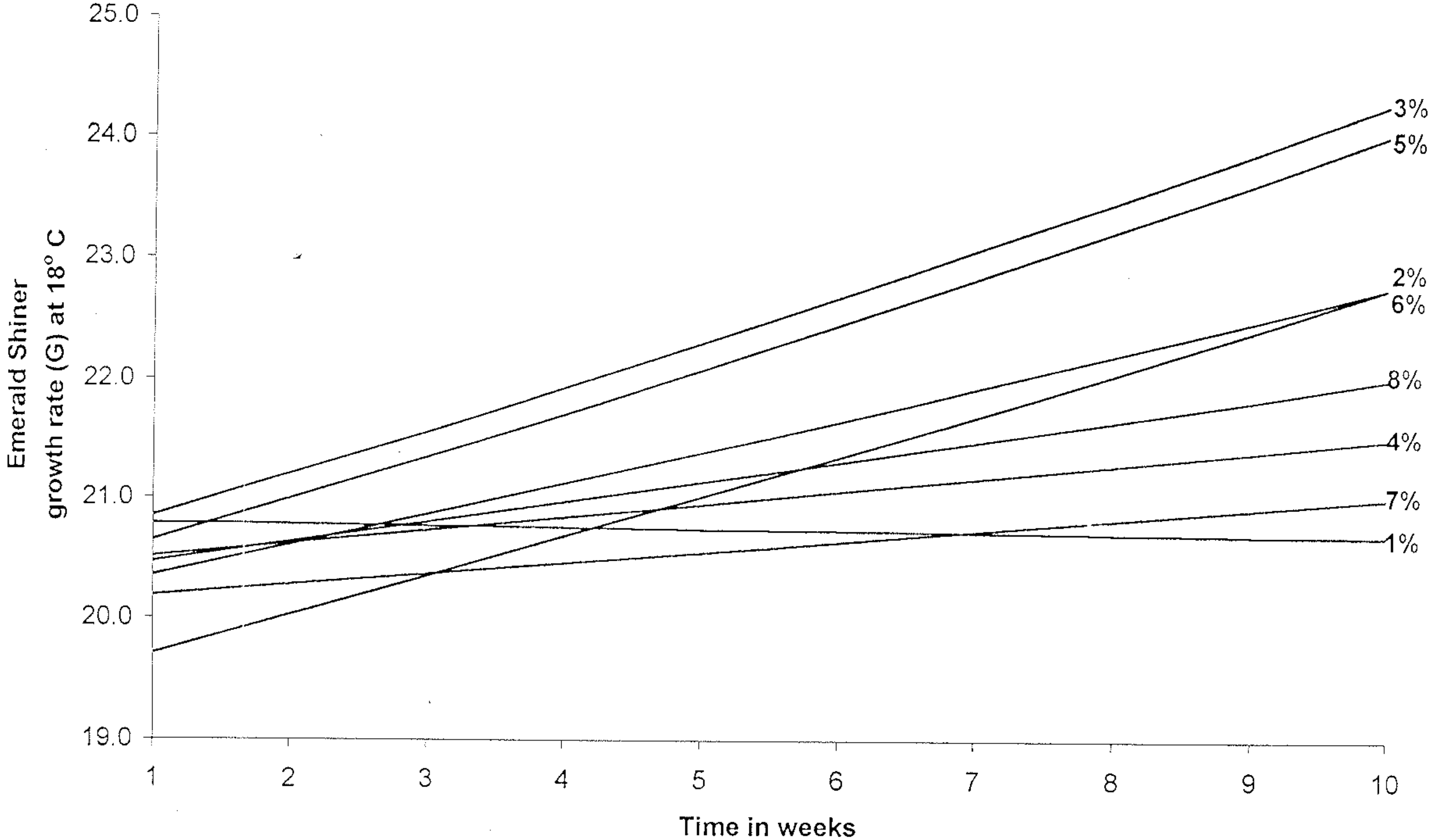


Figure 8. Calculated growth curves for rations of 1-8% body weight adjusted weekly at 18° C using instantaneous rate of growth (G) (Ricker 1975). The slope of each line indicates the growth rate. Only the ration of 1% body weight/day showed no increase in biomass across the 10 week period.

Table 5. Predicted growth of emerald shiners as a function of temperature and food ration in experimental laboratory chambers. Growth equation, sign of slope (indicates positive or negative growth) and G, instantaneous rate of growth (Ricker 1975) are presented. Rations fed were 1 to 8% (body weight/day) daily (adjusted weekly for growth).

Temperature	Feed ration (%)	Growth equation	Slope sign (+, −)	(G) Instantaneous rate of growth
23 °C	1.0	y = 0.579x + 30.74	+	0.01665
	2.0	y = 1.418x + 39.22	+	0.02892
	3.0	y = 2.177x + 32.48	+	0.04590
	4.0	y = 1.732x + 36.07	+	0.03606
	5.0	y = 1.913x + 32.28	+	0.04210
	6.0	y = 1.906x + 32.40	+	0.04187
	7.0	y = 1.646x + 38.30	+	0.03315
	8.0	y = 1.409x + 38.01	+	0.02952
21 °C	1.0	y = 0.015x + 36.90	+	0.00312
	2.0	y = 1.083x + 38.77	+	0.02340
	3.0	y = 1.385x + 33.39	+	0.03377
	4.0	y = 1.452x + 34.31	+	0.03274
	5.0	y = 0.864x + 37.71	+	0.01976
	6.0	y = 0.857x + 36.31	+	0.02028
	7.0	y = 1.341x + 37.25	+	0.02883
	8.0	y = 0.722x + 38.70	+	0.01652
18 °C	1.0	y = −0.012x + 30.74	−	- 0.00055
	2.0	y = 0.338x + 19.34	+	0.01028
	3.0	y = 0.378x + 20.43	+	0.01472
	4.0	y = 0.110x + 20.39	+	0.00319
	5.0	y = 0.373x + 20.25	+	0.01569
	6.0	y = 0.267x + 20.06	+	0.02081
	7.0	y = 0.090x + 20.10	+	0.00556
	8.0	y = 0.171x + 20.29	+	0.00480

Table 6. Growth of emerald shiners stocked at varying densities in experimental laboratory chambers. Density represents the grams of fish that are in one meter of water (g/m^3). Feed ration is the daily ration of food optimal to each tank during the experiment, adjusted weekly for growth. Start weight is the biomass in each tank at the start of the experiment. Final weight is the biomass in each tank at the end of the experiment. Δ Change in weight is final tank biomass minus the start biomass.

Density (g/m^3)	Feed ration (%)	Start weight	Final weight	Δ Change in weight
4416.2	5.0	222.6	729.8	507.2
3800.1	5.0	276.9	936.4	659.5
3433.0	5.0	146.0	598.8	452.8
1945.3	5.0	97.1	290.8	193.9
808.4	5.0	41.6	125.6	83.9
398.2	5.0	18.9	93.2	74.3
226.5	5.0	10.7	57.6	46.9

1945.26 and 3433.0 g/m^3 whereas intermediate growth occurred in tanks 3800.08 and 398.17 g/m^3 (Table 6).

GROWTH: POND EXPERIMENTS

Emerald shiners in Okray Family Farm ponds had a mean growth of 10 and 13 mm in ponds 1 and 3 respectively, after 10 weeks (Table 7). Pond raised-shiners also increased in weight 0.31 and 0.62 (g) per fish in ponds 1 and 3, respectively after 10 weeks (Table 8). Increases in lengths of emerald shiners in the Okray Family Farm pond experiments were similar to growth of emerald shiners in experimental chambers at 23°C and were higher than growth of emerald shiners in the 21 and 18°C experimental chambers.

Table 7. Growth of emerald shiners (length) in the 10-week experimental growth study in Okray Family Farms Pond 1 and 3.

Pond	Start Length	End Length	Δ Change in Length(mm)
Okray Pond 1	37.0 ± 0.36	47.0 ± 0.51	10
Okray Pond 3	37.0 ± 0.36	50.0 ± 0.73	13

Table 8. Growth of emerald shiners (weight) in the 10-week experimental growth study in Okray Family Farms Pond 1 and 3.

Pond	Start weight	End weight	Δ Change in Weight
Okray Pond 1	0.41 + 0.010	0.72 + 0.025	0.31
Okray Pond 3	0.41 + 0.010	1.03 + 0.055	0.62

Temperature profiles for experimental ponds 1 and 3 shows that temperature and oxygen were suitable (≥ 5 ppm. O_2) at nearly all depths for emerald shiners rearing purposes (Figure 9, 10, 11, and 12). Ponds were stratified initially, with cooler water at lower depths, but stratification weakened in fall and temperatures became more homogenous (Figures 9,10).

GROWTH: LAKE DUBAY EMERALD SHINER STUDY

Mean length of emerald shiners collected from Lake DuBay increased from 20.5 $\pm$ 0.026 (mm) on 07/30/96 to 30.8 $\pm$ 0.03 (mm) on 09/07/96 and mean weight increased from 0.07 $\pm$ 0.002 (g) to 0.31 $\pm$ 0.03 (g) (Table 10, Figure 13). Average temperature during this period was 23.8° C. After week 6, the mean weights of captured emerald shiner fry decreased as larger fish were no longer being caught in the collection area (Table 11). By weeks 9 and 10, no emerald shiner fry were captured at the sampling site.

Temperature and dissolved oxygen profiles for the sampling site at Lake DuBay show little variation from 8/16/96 through 9/13/96 (Figure 14). Turnover of Lake DuBay appears to take place during the sampling weeks of week 9/21/96, approximately the same time turnover occurs on Okray Family Farm ponds 1 and 3.

REPRODUCTION: LABORATORY EXPERIMENTS

In each experimental trial, lab spawning experiments indicated that fish raised in the lab appeared to attain gonadal maturation using photoperiod and temperature conditions in the lab that mimicked natural conditions. However, in none of the three experiments, were we able to induce emerald shiners to spawn. We observed no spawning behavior, nor were eggs or larvae collected in any experimental chamber. Shiners dissected four weeks after the prescribed temperature and photoperiod were attained showed that maturation of gonads was attained but eggs were being resorbed.

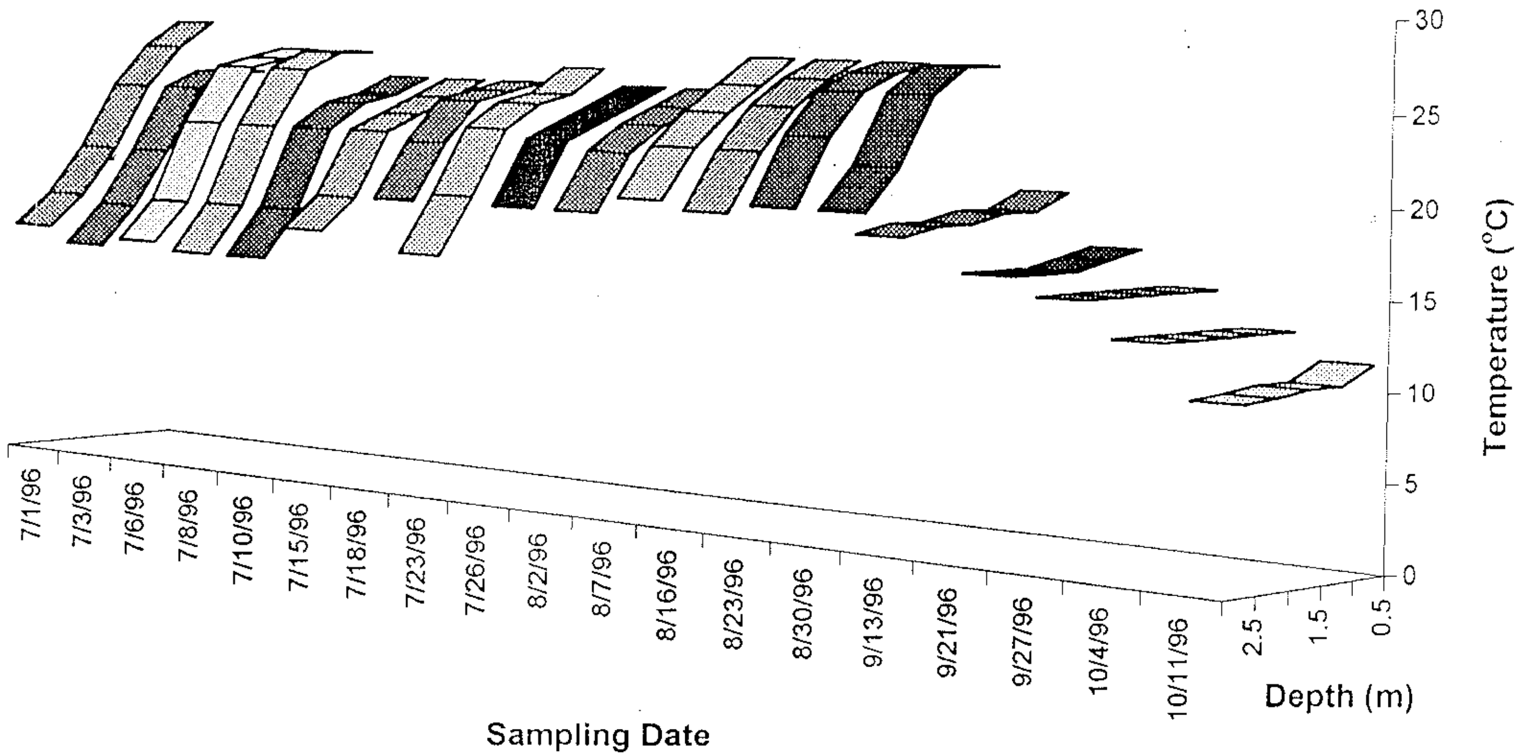


Figure 9. Temperature profile (°C) in Okray' Family Farm Pond 1 from 7-1-96 through 10-11-96.

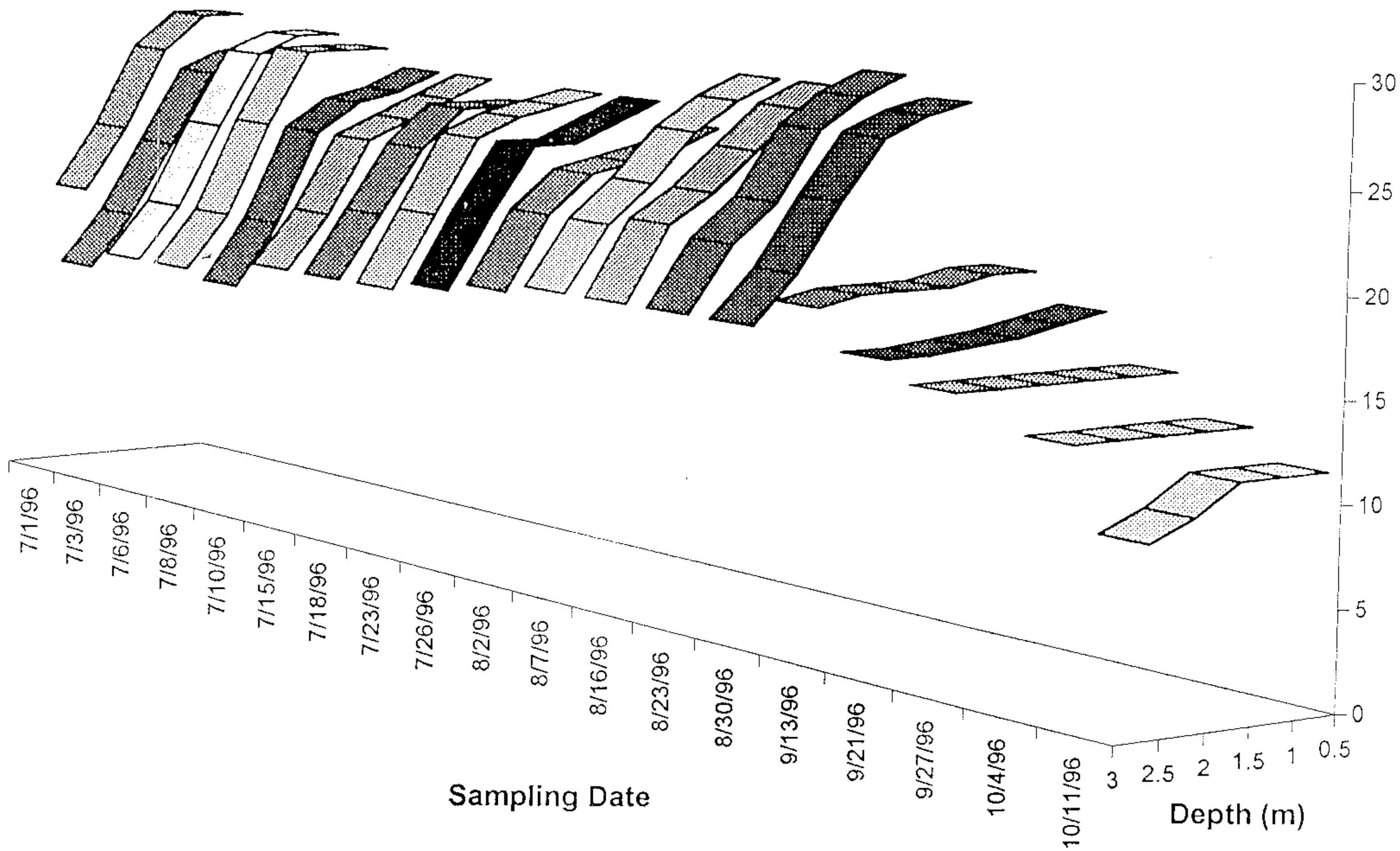


Figure 10. Temperature profile (°C) in Okray' Family Farm Pond 3 from 7-1-96 through 10-11-96.

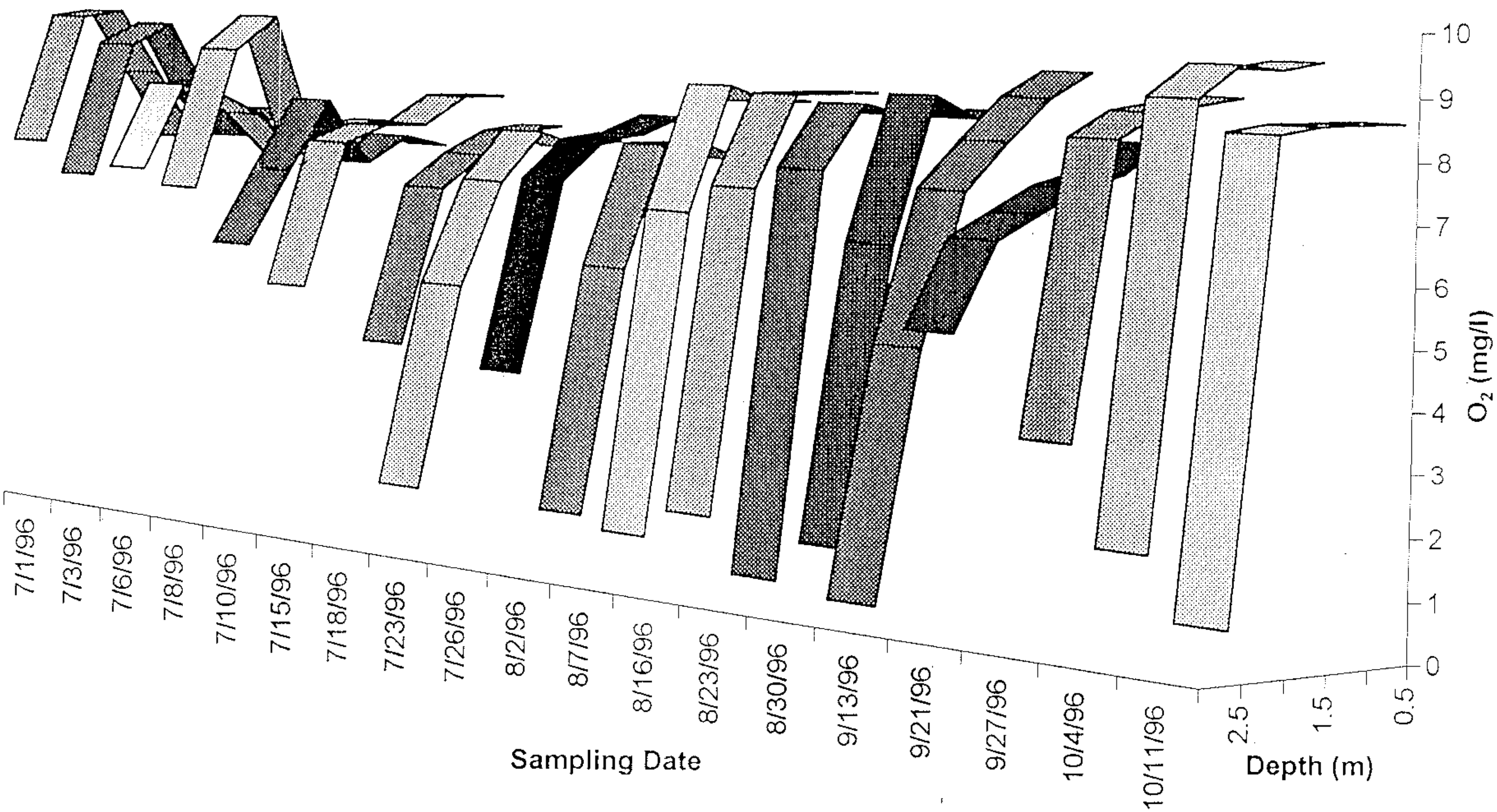


Figure 11. Dissolved oxygen profile Okray Family Farm Pond 1 during growth and reproduction experiments. Depth in pond varied during study due to the porous surficial geology and level of precipitation.

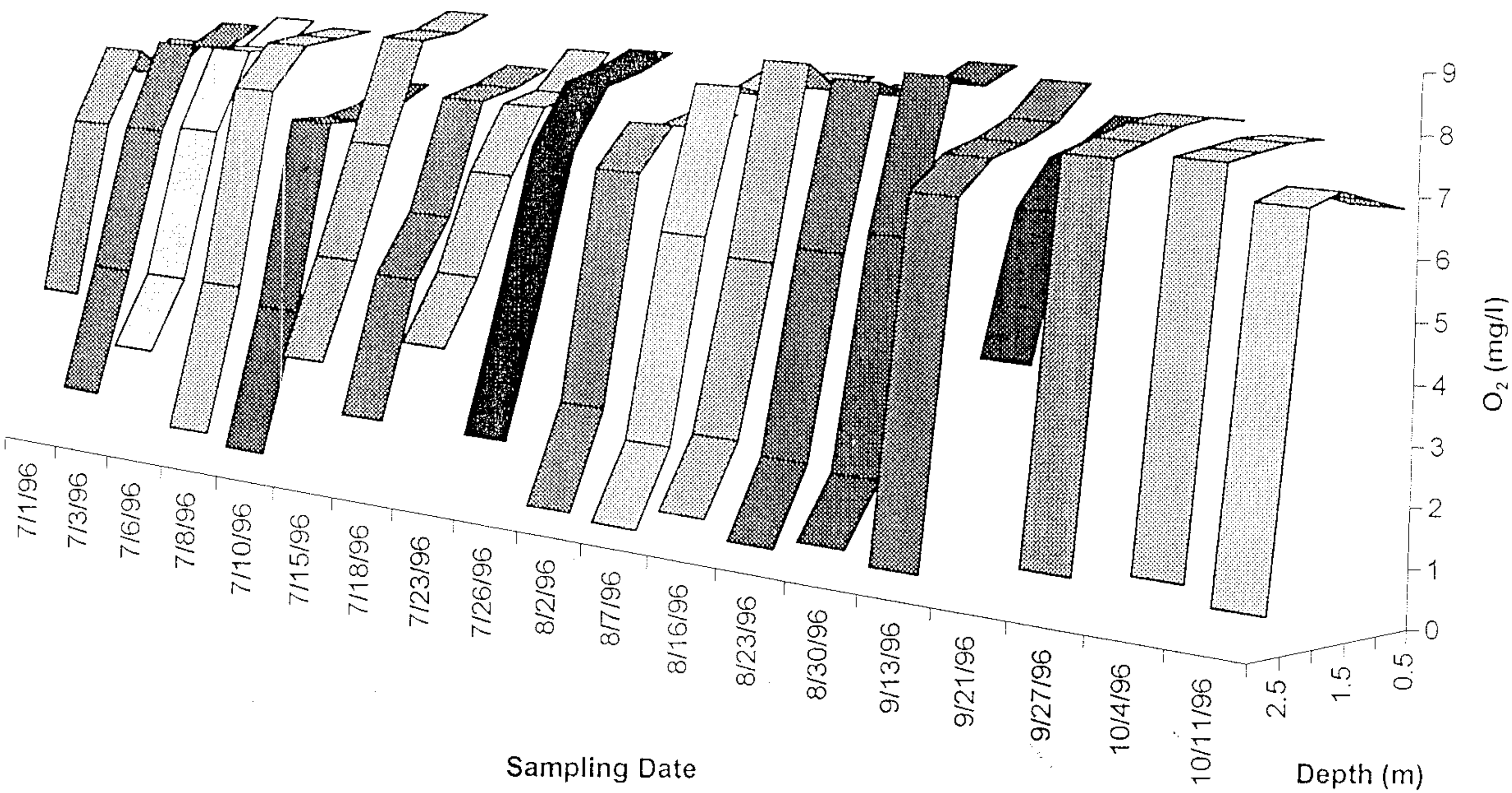


Figure 12. Dissolved oxygen profile Okray Family Farm Pond 3 during growth and reproduction experiments. Depth in pond varied during study due to the porous surficial geology and level of precipitation.

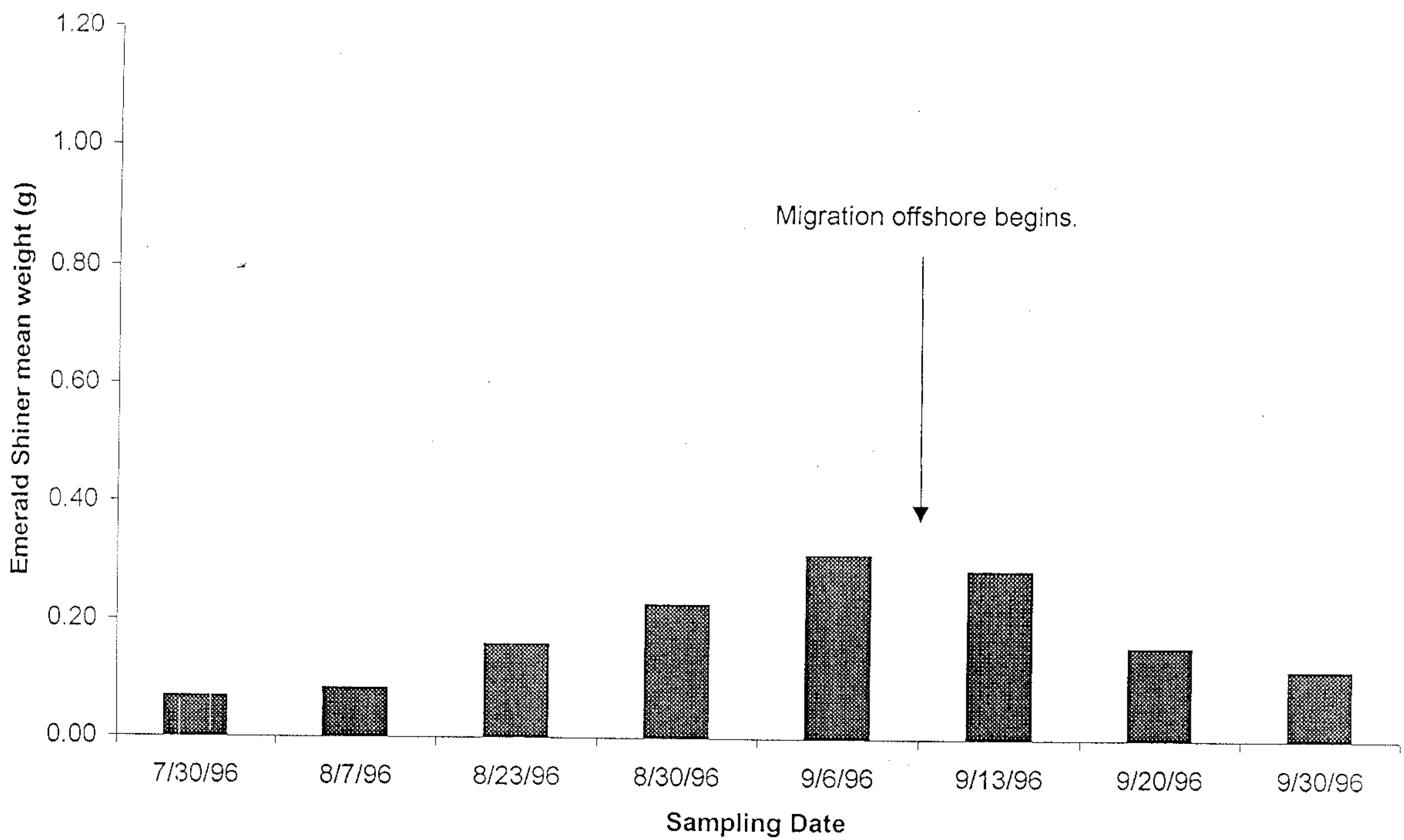


Figure 13. Mean weight of emerald shiners collected from littoral zone in dipnet samples from Lake DuBay (Wisconsin River) near Mullins Cheese Factory (n = 541).

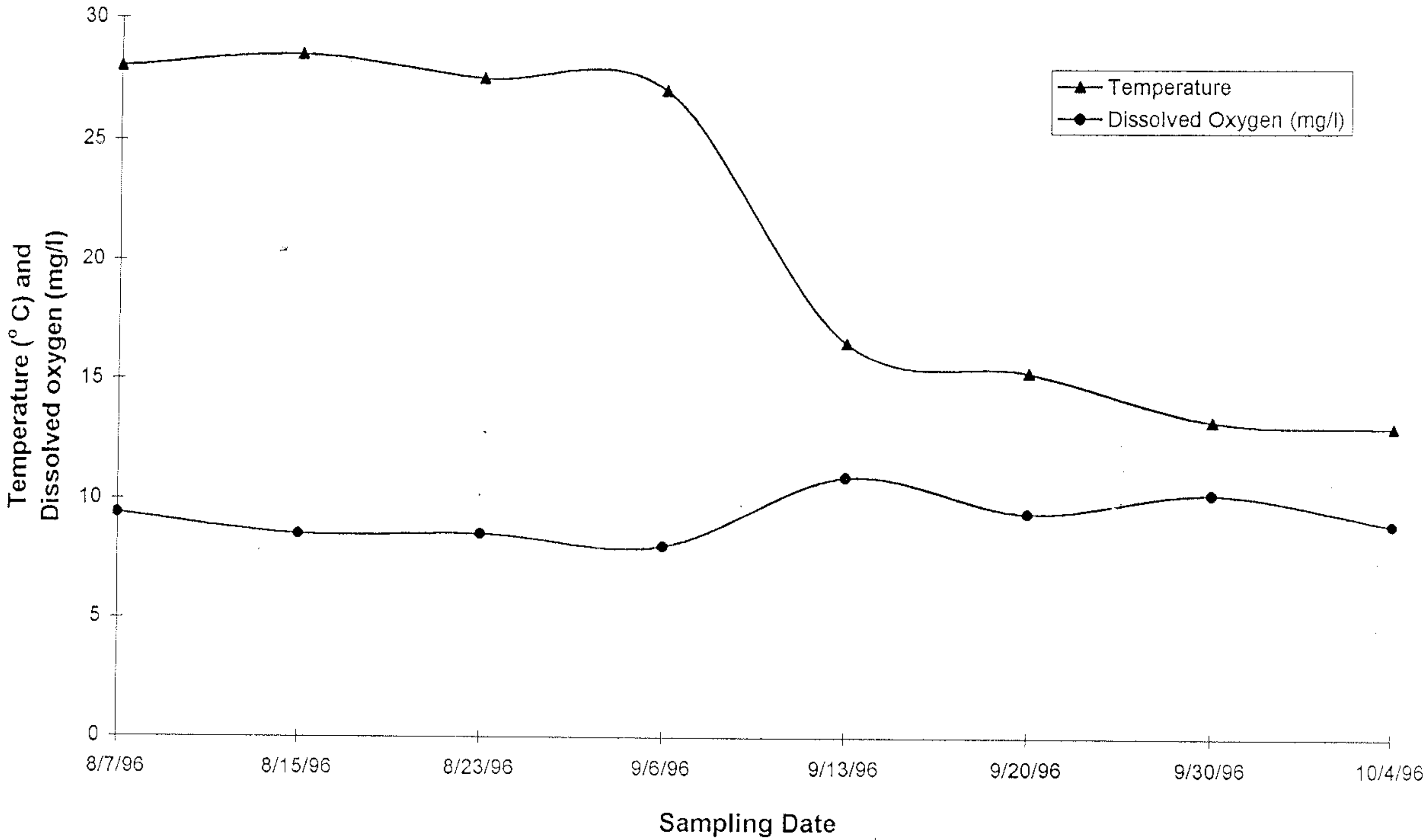


Figure 14. Littoral water temperatures and dissolved oxygen in the littoral zone of Lake DuBay from 8/07/96 through 10/04/96. Samples were collected concurrently with collections of emerald shiners near Mullins Cheese Factory, Knowlton, WI.

Table 9. Weekly mean length of wild emerald shiners in Lake DuBay compared to pond reared emerald shiners in Okray Family Farm Pond 1 and 3. Lake DuBay fish were wild caught fish while Okray's fish were fed 5% body weight/day.

Sampling Site	Date (m/d/yy)	Mean Length (mm)
Lake DuBay	7/30/96	20.5 $\pm$ 0.262
	8/07/96	22.4 $\pm$ 0.351
	8/15/96	24.6 $\pm$ 0.510
	8/24/96	28.3 $\pm$ 1.080
	9/07/96	30.8 $\pm$ 0.855
	9/13/96	30.7 $\pm$ 1.040
	9/21/96	26.5 $\pm$ 0.661
	9/27/96	23.0 $\pm$ 0.507
Okray's Pond 1	8/15/96	37.0 $\pm$ 0.360
	8/24/96	33.0 $\pm$ 0.926
	8/30/96	41.0 $\pm$ 1.052
	9/07/96	43.0 $\pm$ 0.767
	9/13/96	41.0 $\pm$ 0.930
	9/21/96	42.0 $\pm$ 0.896
	9/29/96	41.0 $\pm$ 0.849
	10/04/96	42.0 $\pm$ 0.956
	10/15/96	47.0 $\pm$ 0.514
Okray's Pond 3	8/15/96	37.0 $\pm$ 0.360
	8/24/96	33.0 $\pm$ 0.926
	8/30/96	41.0 $\pm$ 1.052
	9/07/96	42.0 $\pm$ 0.641
	9/13/96	43.0 $\pm$ 0.819
	9/21/96	43.0 $\pm$ 0.999
	9/29/96	41.0 $\pm$ 0.927
	10/04/96	47.0 $\pm$ 1.038
	10/15/96	50.0 $\pm$ 0.731

Table 10. Weekly mean weight of wild emerald shiners in Lake DuBay compared to pond reared emerald shiners in Okray Family Farm Pond 1 and 3. Lake DuBay fish were wild caught fish while Okray's fish were fed 5% body weight/day.

Sampling Site	Date (m/d/yy)	Mean Weight (g)
Lake DuBay	7/30/96	0.07 ± 0.002
	8/07/96	0.08 ± 0.004
	8/15/96	0.16 ± 0.016
	8/24/96	0.23 ± 0.026
	9/07/96	0.31 ± 0.027
	9/13/96	0.28 ± 0.030
	9/21/96	0.16 ± 0.011
	9/27/96	0.12 ± 0.014
Okray's Pond 1	8/15/96	0.41 ± 0.010
	8/24/96	0.44 ± 0.019
	8/30/96	0.53 ± 0.028
	9/07/96	0.55 ± 0.027
	9/13/96	0.51 ± 0.036
	9/21/96	0.61 ± 0.039
	9/27/96	0.53 ± 0.034
	10/04/96	0.51 ± 0.037
	10/15/96	0.72 ± 0.025
Okray's Pond 3	8/15/96	0.41 ± 0.010
	8/24/96	0.44 ± 0.019
	8/30/96	0.53 ± 0.028
	9/07/96	0.50 ± 0.024
	9/13/96	0.60 ± 0.038
	9/21/96	0.69 ± 0.045
	9/27/96	0.57 ± 0.039
	10/04/96	0.72 ± 0.052
	10/15/96	1.03 ± 0.055

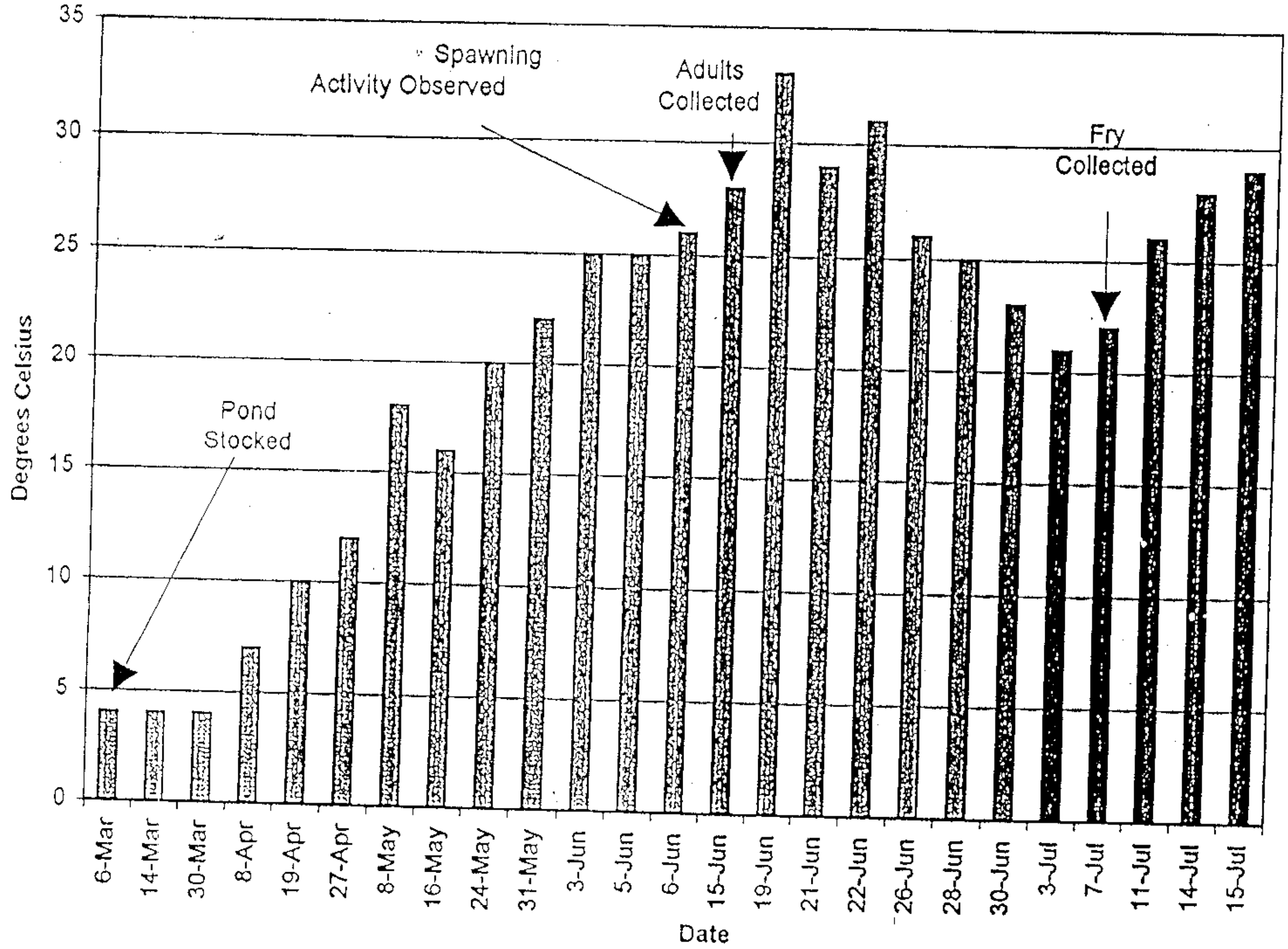


Figure 15. Temperature s of the Wachowiak Pond (Private residence, Stevens Point, WI) taken 15. 2 cm below water surface and 6.1 meters from shore.

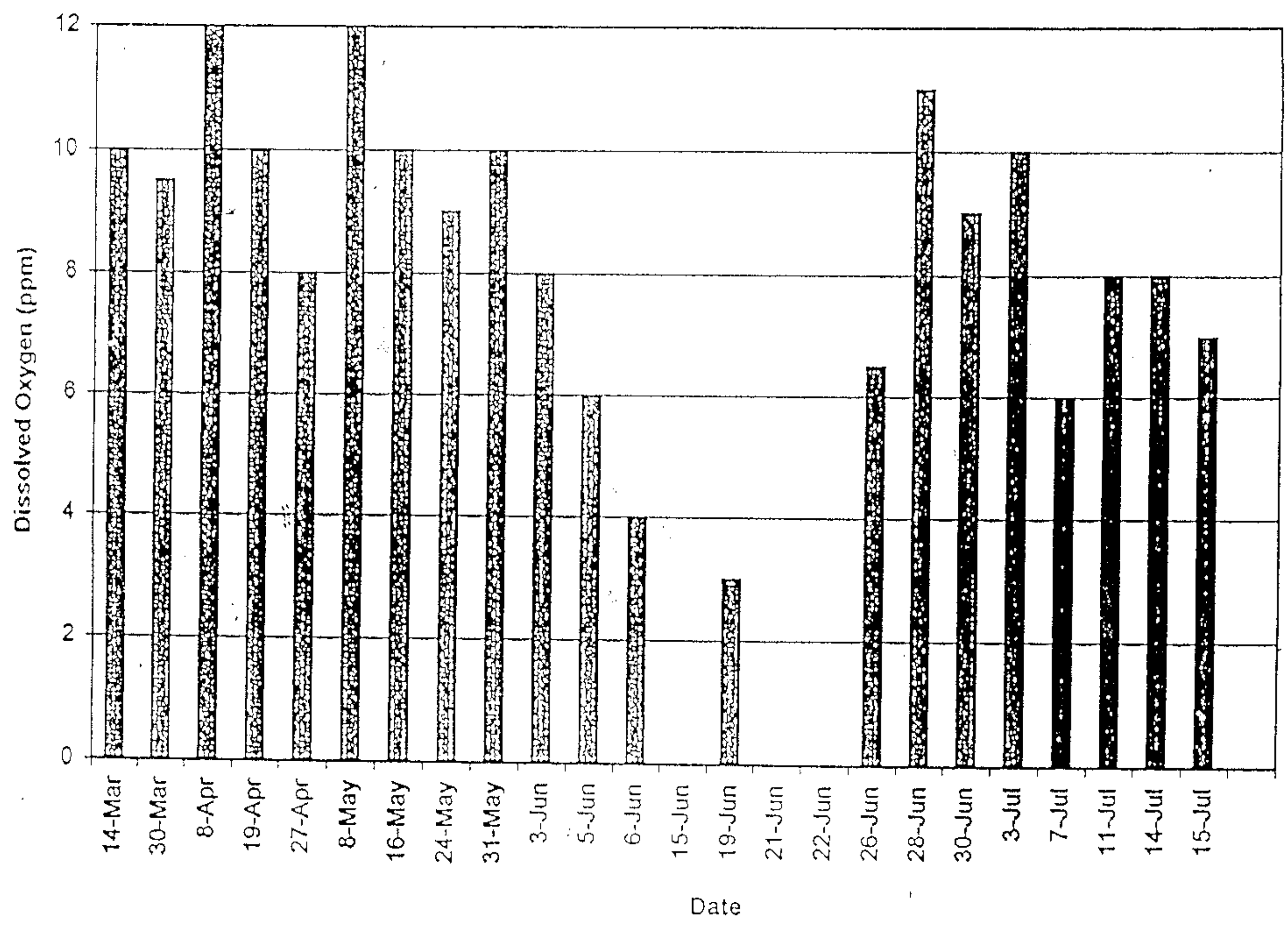


Figure 16. Dissolved oxygen profile for Wachowiak Pond (Private residence, Stevens Point, WI) taken 15. 2 cm below water surface and 6.1 meters from shore.

REPRODUCTION: FIELD EXPERIMENTS

We confirmed that emerald shiners did spawn in man-made ponds approximately 1-2 acres in size. We observed emerald shiners spawning along sandy shorelines (Wachowiak Pond) on 06/03/95 between the hours of 9:00 p.m. and 12:00 p.m. Water temperature during the observed spawning was 26° C. A total of 150 emerald shiner fry were later collected on 07/07/95; 98 were collected using a 1 x 1 m lift net while 52 were collected using the 300 micron D-net.

Dissolved oxygen and temperature profiles show a drop in dissolved oxygen as temperature increases (Figure 15, 16). To maintain oxygen levels in this pond a commercial aeration system would probably be needed to sustain an emerald shiner fry.

Discussion

Our research demonstrated the feasibility of culturing emerald shiners by the baitfish industry. In particular, our research indicates that emerald shiners can be raised at very high densities if adequate food ration and water conditions can be provided. Our research also shows that growth can be accelerated or retarded using temperature, food ration or a combination and can be raised indoors in tanks, raceways, or outdoors in ponds and tanks. Moreover, our research can help growers meet size needs at different times of the year and indefinitely keep stock at the desired size, reducing mortality, feed cost, and maintenance. Growth rates developed in this study could be applied to a wide array of culturing situations

On the other hand, our research also indicated that emerald shiners are not as easy to raise as some other minnows species such as the fathead minnow (*Pimephales promelas*), golden shiners (*Notemigonus crysoleucas*), goldfish (*Carassius auratus*), and mosquitofish (*Gambusia affinis*) (McLarney 1987, Higginbotham 1988, Becker 1983, Pounds 1992). Mortality of brood stock was a persistent problem. Four different batches of brood stock had 100% mortality after holding them for less than two weeks and some of the other batches suffered higher mortality. Emerald shiners do not handle stress well, are prone to infections and parasites, and require very clean water. Emerald shiners are not very tolerant to wide temperature sings nor higher levels of metals such as copper, and lead or to chlorine. Similar rearing problems have been experienced by bait dealers handling emerald shiners (Fred Gollon personal communication).

We were unable to induce spawning in emerald shiners in the laboratory. We speculate that the use of florescent lighting may not have provided as natural a lighting condition required to initiate spawning in emerald shiners; perhaps wavelengths were not suitable. It is just as likely that other environmental cues were insufficient to invoke spawning behavior. As such, until spawning techniques are developed bait dealers will have to rely on wild emerald shiners to supply the demand from sports fisherman. However, this is problematic. First, sources of young emerald shiners may not exist and handling mortality may be extremely high. Second, this may result in further depletion of wild populations of emerald shiners which may limit food resources and increasing competition among game species that feed on emerald shiners in the wild.

Although emerald shiners did not reproduce under laboratory conditions, we did have reproductive success in our pond reproduction experiments. In the Wachowiak pond, emerald shiner spawning activity was observed in early June but the numbers were sporadic in ponds. However, despite this success, it appeared that survival to larger sizes was not very successful in the ponds. Predation by other fish species in the pond and by adult emerald shiners brood stock may have been the cause. We speculate that adult shiners need alternate prey or adults need to be removed for young to survive to larger sizes. Greater success may have been achieved with the emerald shiner reproduction as it has been with these species by:

1) stocking ponds with brood fish by mid-April before spawning temperatures have been reached.
2) fertilizing rearing ponds at least 2 to 4 weeks prior to stocking brood fish to increase survival of young by stimulating phytoplankton and zooplankton production.

This would allow time for plankton production which shiner fry need during their first two weeks of development. Applying an inorganic fertilizer of 20-20-50, at a rate of 50 lb. per surface acre, or manure might produce the desired effect (Higginbotham 1988), although further research would be needed to confirm these rates. Fertilizers should not be applied after June 1 so that oxygen depletion does not become a problem as good water quality is crucial to emerald shiner culturing (Losordo1992, Masser 1992).

A critical problem in small pond culturing is good water quality during the growing season. Installation of an oxygen-metering device, oxygen pumps and diffusers are a good investment. A water source should be available that is capable of producing 30 gallons per minute per surface acre so that water is available for dilution and cooling purposes. This equipment is fairly inexpensive and should be incorporated into an aquaculture plan to protect your baitfish crop (Higginbotham 1988).

As with fathead minnows, when fry reach two weeks of age, a regular feeding regime should be started. Commercial high protein feeds are available for all sizes of fish. Start with a fine meal and move up to pellet feed as fish grow (Kloubec 1986). In our growth experiments, feed rations of 1 to 8% body weight/day showed increased growth, with 2% body weight weight/day showing the best results. There appeared to be little difference above rations of 2% body weight/day. Growers should select the feed/temperature combination that best fits the needs of their operation. For maximum growth, a 23°C, a grower would select 6% body weight/day feed ration adjusting periodically for increased growth. To minimize expenditures and to hold fish at a specific size a grower would select a 2% body weight/day feed ration at 18°C, or 1% body weight/day feed ration at any temperature.

Emerald shiners reach up to 65 mm their first year of growth (Fuch 1967) and are able to reproduce their second summer (Flittner 1964). After spawning, the brood stock could be seined from rearing ponds and be held until distributed to baitshops. This would allow for greater growth of YOY with less competition and cannibalism from adults. The following spring, ponds should be fertilized in preparation for fry and harvesting brood stock would complete a yearly cycle of harvesting emerald shiner crop. Rearing emerald shiners in ponds would reduce pressure on wild stocks of emerald shiners.

Emerald shiners are less abundant today than they have been throughout their native range according to historical accounts (Hubbs 1934, Cooper 1936, Lee et. al. 1980). Consequently, bait dealers are having greater difficulty obtaining emerald shiners of preferred size (1.5 - 3.5 ") when demand is the greatest, usually late winter through early summer (Pounds 1992 Meronek 1994). Buying shiners from out-of-state sources to supply market demand is a common practice when they are not available locally (Meronek 1994).

The live bait market has grown in recent years at a moderate rate (Pounds 1992), and rearing shiners in ponds can be a profitable business. Small ponds that are owned or that can be leased without having to invest in land and excavation costs can produce up to 800 lb. minnows per surface acre (Kloubec 1986) which can be a substantial return per acre depending on market price (Pounds 1992). Moreover, rearing shiners in ponds has advantages over capturing wild populations of shiners. Shiners reared in ponds are subject to less transport stress which reduces mortality and minnow tend to be heartier, stay alive longer in the bait bucket, and last longer on the hook (Kloubec 1986).

Further work needs to be conducted on culturing emerald shiners in order to provide more guidance on efficient and cost-effective rearing techniques. In particular, developing spawning techniques and proper field rearing techniques for YOY needs further investigation. Unlike other species that are cultured, emerald shiners will require extra care and more stringent rearing conditions. Interest in emerald shiner rearing is high, but until additional problems can be solved, any operations culturing emerald shiners should start out small.

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