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Induction of Early Spawning of Channel Catfish in Heated Earthen Ponds

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Abstract.—The spawning of channel catfish *Ictalurus punctatus* in earthen ponds is limited to the spring and early summer (late April through June) in North America, when water temperatures range from 24°C to 30°C. Temperature appears to be the primary factor that influences the timing of spawning in channel catfish. The heating of ponds will allow the spawning season to begin early. During the late winter and spring (February to early May) of 1997, 1999, 2000, and 2001, 0.03-ha earthen ponds containing male and female channel catfish broodstock (1.3–4.1 kg, 440–680 mm total length) were heated at about 2°C/d by adding geothermally heated water (36°C) and then maintained within the range of 24–30°C. Four spawning containers were added to each pond and checked for eggs at 3-d intervals. Eggs were removed and evaluated for fertilization percentage. Over the 4 years, spawning in heated ponds occurred from 20 to 62 d in advance of spawning in unheated (control) ponds, and the period of egg production possible within one season was doubled. Spawning usually commenced within 1–2 weeks of the observation of nesting activity, and 2–4 weeks were required to collect a total of four masses (our criterion for the full onset of egg production in a heated pond). Fertilization was 87% ± 8% (mean ± SD) in spawns collected before the onset of spawning in unheated ponds ($N = 67$ masses) and 87% ± 5% in spawns collected during the normal season ($N = 26$ masses). There were no significant differences in the weight ($P = 0.08$) and fertilization percentage ($P = 0.88$) of egg masses collected early and during the normal spawning season. Problems encountered included disease outbreaks of *Cleidodiscus* sp., *Ichthyophthirius multifilis*, and *Flexibacter columnaris* in broodstock. Future studies should evaluate methods to reduce the added costs of heating ponds and incubating egg masses.

The placement of broodstock in open ponds is the dominant method of spawning used by the channel catfish *Ictalurus punctatus* industry and has changed little since farming of this species developed into a commercial venture 40 years ago (Dupree 1995). Channel catfish spawn in ponds during the spring and early summer when water temperatures are in the range of 24–30°C (Brauhn and McCraren 1975; Davis et al. 1986; MacKenzie et al. 1989), although some references cite a range as broad as 20–30°C (Lee 1979; Huner and Dupree 1984; Busch 1985). Farmers place containers such as milk cans, wooden boxes, or metal drums in ponds containing sexually mature channel catfish (Clapp 1929; Steeby 1987). The males enter the containers, prepare them for nesting by removing dirt and debris, and attract females inside where spawning takes place. After spawning, the males drive the females away and care for the egg masses (Huner and Dupree 1984). Farmers typically remove the egg masses from the containers by hand and incubate the eggs in hatcheries in flow-through troughs.

The channel catfish industry relies on pond spawning to provide fingerlings, although egg production can fluctuate with seasonal weather conditions and is not always reliable. For example, spawning will cease or fish will abandon nests if temperatures deviate beyond the range suitable for spawning (Huner and Dupree 1984). This can occur during passage of cold fronts (a common occurrence during the spring), or during unusually warm years. Because farming of this species depends almost entirely on natural pond conditions to provide an appropriate temperature profile, egg production can be arbitrary and unpredictable. Furthermore, the 1–2-month duration of the spawning season limits egg production, fingerling growth, and research on topics such as disease and reproduction to a few months each year.

The channel catfish undergoes an annual cycle of gonad regression and recrudescence, which is punctuated by spawning during the spring and corresponds to the annual temperature cycle (Brauhn and McCraren 1975; Davis et al. 1986; MacKenzie et al. 1989). This cycle follows an endogenous

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rhythm, which can function even when uncoupled from most environmental influences (Davis et al. 1986). The primary environmental variable influencing this rhythm in channel catfish appears to be temperature, which can be altered to manipulate the timing of gonad development and spawning. Spawning of channel catfish in ponds has been advanced by 2–3 weeks by holding broodfish in shallow ponds that warm quickly during the spring (Lee 1979; Grizzle 1985). Spawning has been delayed in four of seven fish until August (n = 3) and November (n = 1) in channel catfish maintained in earthen ponds containing cool (~18°C) water for 109 d, followed by exposure to warmer water (24°C) to induce spawning (three of the four fish received injections of carp pituitary extract to stimulate ovulation; Brauhn 1971). Out-of-season spawning of channel catfish has also been accomplished in the laboratory. The 12-month spawning cycle of channel catfish held in indoor recirculating systems has been compressed into 9 months by manipulating photoperiod and temperature, spawning being induced during November, January, and February (Kelly and Kohler 1996). Although some females required injections of synthetic leuteinizing hormone-releasing hormone, ovulation also occurred in females that received no injections.

Use of geothermal water passed through concrete raceways has enabled the cultivation of channel catfish in Idaho, where ambient temperatures seldom exceed 24°C (Ray 1981). Although the season during which spawning occurred was not specified in that report, this represents a practical application of heated water to produce channel catfish in cooler climates. No studies, however, have attempted to use heated water to induce spawning in channel catfish in earthen ponds before the normal spawning season, when ambient temperature would otherwise prevent reproduction. Were such a procedure to be successful, it could be used to increase seasonal production, time available for fingerling growth, and flexibility for producers and researchers of channel catfish.

The goal of this study was to evaluate the extent to which the spawning season could be extended by manipulating water temperature. This not only would allow more control over spawning in ponds but also could provide a closer examination of the events leading to the occurrence of spawning in ponds. Because the duration of prespawning gonadal development was potentially shortened, we also evaluated the quality of eggs produced early in the season. Our specific objectives were to document the events leading to the collection of four egg masses from each of 12 heated broodstock ponds and to compare fertilization in egg masses collected before the onset of the normal spawning season with those collected during the normal season. Benefits and problems encountered during the induction of early out-of-season spawning were identified and discussed. To our knowledge, this is the first report of the use of heated water to induce pond spawning of channel catfish to extend the spawning season.

Methods

Study site.—Fish were held in earthen ponds (0.03 ha) at the Louisiana State University Aquaculture Research Station (ARS). The ponds were 33 m long and 9 m wide, with an average depth of 2 m. When filled to the top of the drain, ponds held about 594 m^3 of water. When not receiving water, ponds typically contained about 445 m^3 of water. Heated water (~36°C) was delivered through 15-cm-diameter plastic piping from a 762-m-deep well capable of delivering approximately 2,400 L of water per minute. The total alkalinity of the water was 323 mg/L as $CaCO_3$, total hardness was 2 mg/L as $CaCO_3$, and pH was 8.5.

Heating of ponds.—Water was delivered into the ponds through 15-cm-diameter gated valves. During years 1 (1997), 2 (1999), and 3 (2000), valves were manually adjusted in increments of 25% of the total range of motion, based on measured and anticipated nightly weather conditions. When a valve was fully open, about 2 L of water were discharged per second, although typical nightly flow was adjusted to be within the range of 1–1.5 L/s. Thus, 5–7% (29–43 m^3; 28,800–43,200 L) of the total pond volume was exchanged during 8 h of heating. During year 4 (2001), the valves were operated manually and through automated control. Temperatures were raised from ambient at about 2°C/d and were maintained at about 27°C thereafter. Surface aerators located about 11 m from the inlet were run continuously when ponds received well water. Temperature in all ponds was monitored hourly by data loggers (Hobo Data Logger; Onset Computer Corporation, Pocasett, Massachusetts) submerged 1 m below the water surface and by use of a hand-held digital thermometer (model HH-21; Omega Engineering Inc. Stamford, Connecticut).

Experimental design.—Broodstock were stocked during the winter months (January–February). Fish were fed daily to satiation with a floating pelleted feed containing 28% protein. Ponds received 24–

30 mature channel catfish of a research population maintained at the ARS (1.3–4.1 kg; 440–680 mm total length), two females being stocked for each male (Huner and Dupree 1984).

Steel gasoline cans (120 L) with a single 15-cm-diameter opening were placed in each corner of each egg production pond for use as spawning containers. Cans were checked at 3-d intervals (Busch 1985) for evidence of nesting activity by males or for the presence of eggs. If the cans were clean, dirt was fanned into them to encourage cleaning behavior by the male, which would provide evidence of nesting activity when cans were checked in the future. The criterion for full onset of spawning in a heated pond was the collection of four egg masses.

During 1997, three ponds were heated at 1-week intervals as a preliminary study of induced, early, out-of-season spawning. One pond was left unheated to serve as a control. The purpose of this pilot study was to evaluate the feasibility of heating ponds, and data collected during this period were not used for further analysis.

During March and April 1999, two sets of two ponds each were heated, and one set of two ponds remained unheated and served as a control. When fish in both heated ponds in a set reached full onset of spawning, the ponds were seined for collection of broodstock for artificial spawning in the laboratory (a companion study; see Lang 2001), after which the next set of two ponds was heated.

During February, March, and April 2000, three sets of two ponds each were heated; one unheated set of ponds served as a control for the first two sets that were heated, and an additional unheated pond served as a control for the third set of heated ponds. Additionally, one pond containing only males and one pond containing only females was heated concurrently with the egg production ponds for use in artificial spawning. When fish in one of the two heated ponds reached full onset of spawning, the all-male and all-female ponds were seined for use in artificial spawning, followed 7 d later by the group that had reached full onset of spawning (Lang 2001). Fish in the second heated pond were allowed to continue spawning until no further masses were produced.

During February, March, and April 2001, single ponds were heated concurrently with three other ponds containing only male or female channel catfish. When full onset of spawning was reached in the heated egg production pond, fish from the all-male and all-female ponds were collected for use in artificial spawning (Lang 2001), and the next group of four ponds was heated. Two of three egg-production ponds were heated during 2001, and both were used to evaluate egg production. One unheated pond served as a control. Only the results of pond spawning are reported in this manuscript.

Collection and rearing of egg masses.—Eggs were collected from cans by using a rubber spatula and were transported to the hatchery within 15 min of collection (Jensen et al. 1983) in a closed cooler that contained water from the pond from which the eggs were collected (24–30°C, depending on time of collection). The quantity of eggs per egg mass was estimated by counting the number of eggs in three 10-g samples. Eggs were considered early spawns if they were collected from a heated pond before the onset of spawning in the unheated ponds. The estimated quality of the eggs was based on observed rates of fertilization. Fertilization percentage was estimated by systematically examining six regions of the mass for unfertilized eggs. Eggs were treated with an iodine-based disinfectant (Argent Chemical Laboratories, Redmond, Washington) on collection and were raised in 80-L tanks in a recirculating system equipped with a 0.6-m^3 bubble-washed bead filter (Aquaculture Systems Technologies, New Orleans, Louisiana).

Statistical analysis.—Percentage data were arcsine-square-root transformed before statistical analysis. To compare the quality of eggs produced early and those produced during the normal spawning season, differences in fertilization percentages and weights were analyzed by using the general linear model function of the SAS system (SAS Institute 1999). Tukey's Studentized range test was used to compare treatment differences. Differences were considered to be significant at $P \leq 0.05$.

Results

Preliminary Trial

In 1997, ponds were brought into the spawning temperature range (24–30°C) at 1-week intervals, and water temperature was maintained by adding heated water (Figure 1). Spawning occurred in heated ponds 12–16 d after the average daily water temperature reached the spawning range. Spawning was confirmed in a heated pond on March 30, 12 d after nightly water temperature in heated ponds was within the appropriate range, and 30 d before the onset of spawning in the unheated ponds (April 24). Overall, 19 egg masses were collected from the heated ponds during 4 weeks, during which time none of the 12 cans in the unheated control pond yielded any egg masses.

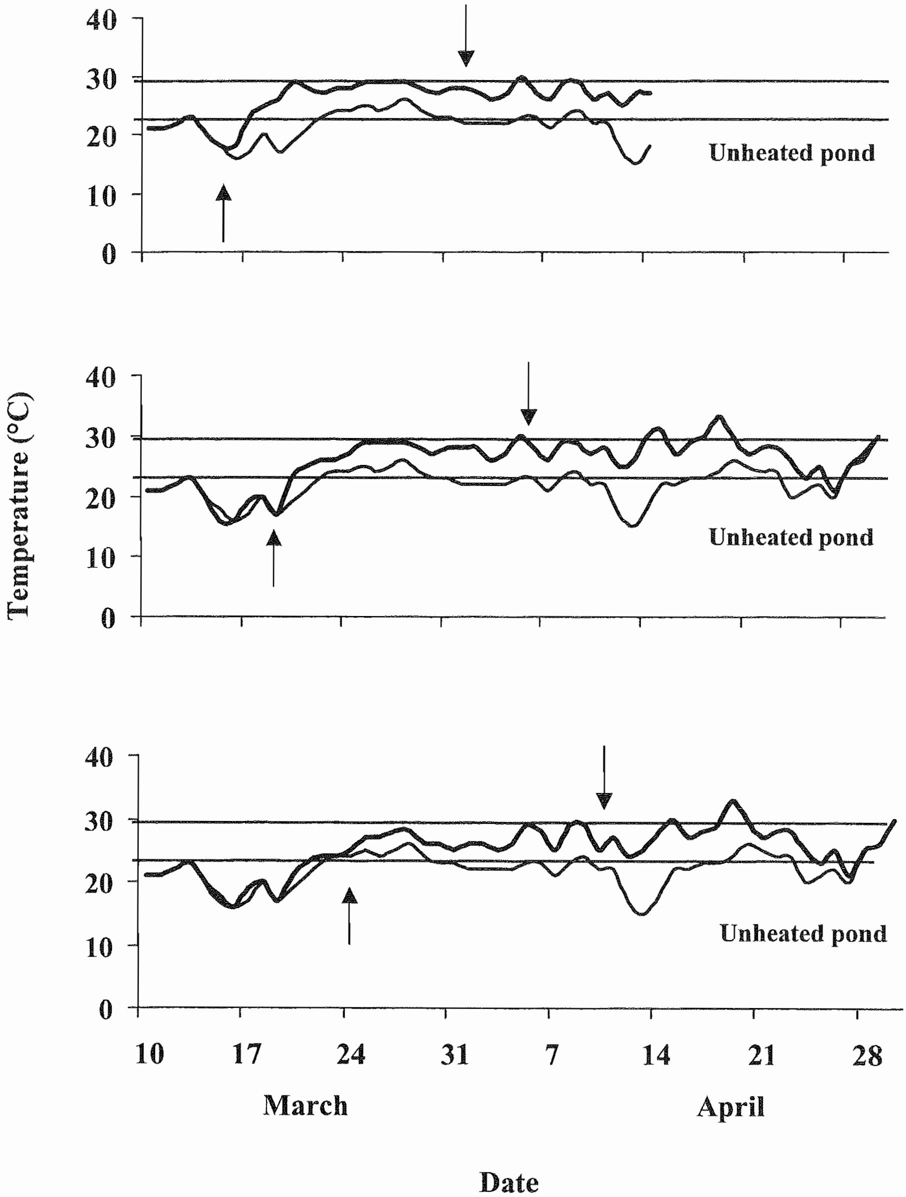

FIGURE 1.—During 1997, three 0.03-ha ponds containing channel catfish broodstock were heated sequentially at 1-week intervals with geothermal water and maintained at about 27°C. Horizontal lines indicate the range of temperatures conducive to channel catfish spawning. The lower arrows indicate the initiation of pond heating and the upper arrows the dates that spawning was first recorded in each heated pond. No spawning occurred in unheated ponds during this period.

Extension of the Spawning Season of Channel Catfish in Earthen Ponds

Overall, the duration of egg collection from ponds was extended by 20 d in 1999, 30 d in 2000, and 62 d in 2001. From 1 to 5 d were required to increase the water temperatures into the range suitable for spawning. From this point, 0–9 d elapsed before evidence of male nesting activity was observed. Spawning usually commenced within 1–2 weeks of observed nesting activity (Figure 2). During 1999, spawning was documented on March 26 in heated ponds and on April 28 in unheated ponds (Figure 3). During 2000, spawning was documented on February 26 in heated ponds and on

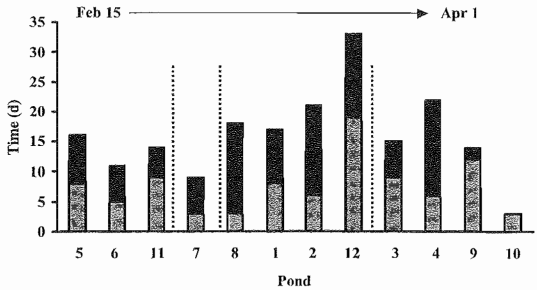

FIGURE 2.—Average time (number of days) required for collection of four egg masses from each of 12 heated ponds during the spring of 1999, 2000, and 2001 after the ponds reached spawning temperature (27°C). Lighter-shaded bars indicate the time required before spawning was first observed in ponds, and black bars indicate the time required until four masses (in total) were collected. Vertical dotted lines separate groups of ponds in which the initial heating occurred within 2 weeks of that of other groups. During 2001, spawning ceased for approximately 1 month in pond 12 during an outbreak of *Flexibacter columnaris* and *Cleidodiscus* sp. Pond 10 produced only three masses in 2001.

April 26 in unheated ponds (Figure 4). During 2001, spawning was documented on March 7 in heated ponds and on April 29 in unheated ponds (Figure 5). Throughout the 3-year test period, full onset of spawning was recorded in 11 of 12 ponds; 11–34 d elapsed between the initial heating of ponds and full onset of spawning, and 67 egg masses were collected before the onset of spawning in unheated ponds.

Fertilization was 87% ± 8% (mean ± SD) in spawns collected before the onset of spawning in unheated ponds ($N = 67$), and 87% ± 5% in spawns collected during the normal season ($N = 26$; Table 1). There were no significant differences in fertilization percentage ($P = 0.88$) or egg mass weight ($P = 0.08$) between early spawns and normal-season spawns.

During 2000, seven broodstock females and five broodstock males from a heated pond died. Live and dead specimens were submitted to the Aquatic Animal Diagnostic Laboratory, School of Veterinary Medicine, Louisiana State University, for formal investigation, where they were diagnosed as having infestations of *Ichthyophthirius multifilis* and *Cleidodiscus* sp. (J. Hawke, Aquatic Animal Diagnostic Laboratory, personal communication).

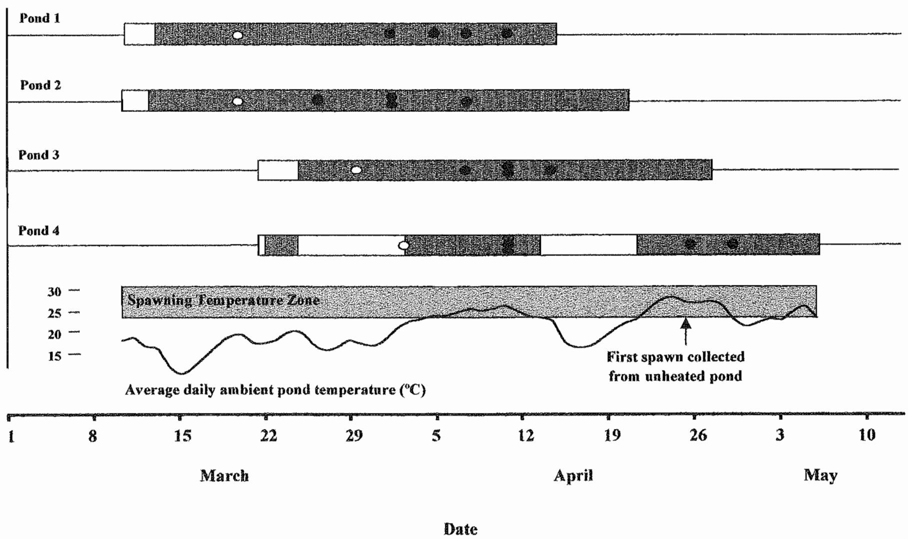

FIGURE 3.—During 1999, channel catfish were induced to spawn in four heated ponds during March and April. White bar segments indicate the days after initiation of heating during which ponds were not within the range conducive to spawning (24–30°C); shaded segments indicate the dates in which pond temperatures were within the spawning range; discovery of evidence of can cleaning by males is denoted by open circles; collection of spawns from heated ponds is represented by closed circles. The lowest graph displays the corresponding ambient temperatures in unheated ponds and the date at which spawning began in the unheated ponds. The single shaded circle in pond 4 indicates a mass that was lost in that pond. Pond 4 cooled during a time when heated well water was unavailable. Spawning occurred in that pond when temperatures rose naturally, 18 d before the onset of spawning in unheated ponds.

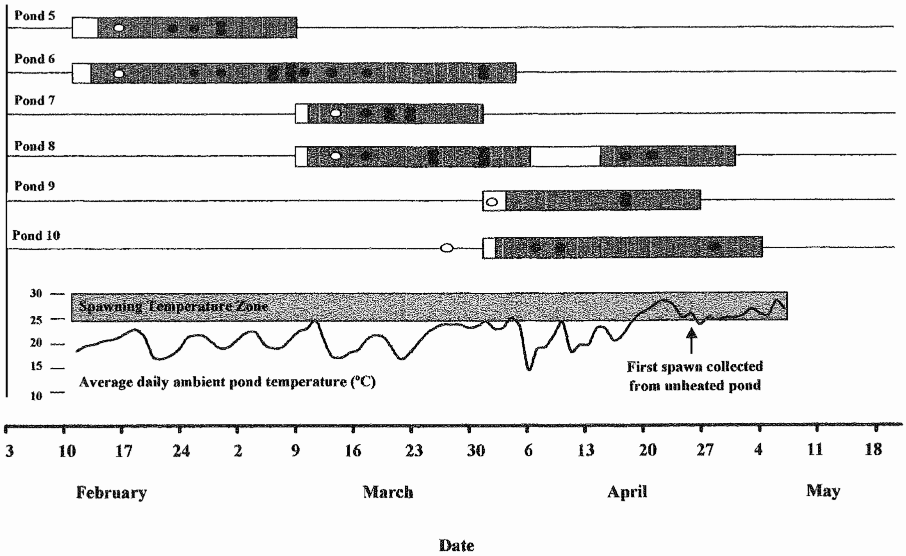

FIGURE 4.—During the 2000 spawning season, channel catfish in six heated ponds were induced to spawn during February through April, when ambient temperatures would otherwise have inhibited spawning. See Figure 3 for additional explanations.

During 2001, spawning ceased in the second heated pond (pond 12), and only two spawns were collected from this pond before masses had been collected in the unheated ponds. Fish in pond 12 were subsequently diagnosed with *Flexibacter columnaris* and *Cleidodiscus* sp.

Discussion

Using geothermal water to heat ponds during February, March, and April extended the spawning of channel catfish at the ARS by 2 months. This is the first report known to us of inducing early out-of-season spawning in channel catfish held in

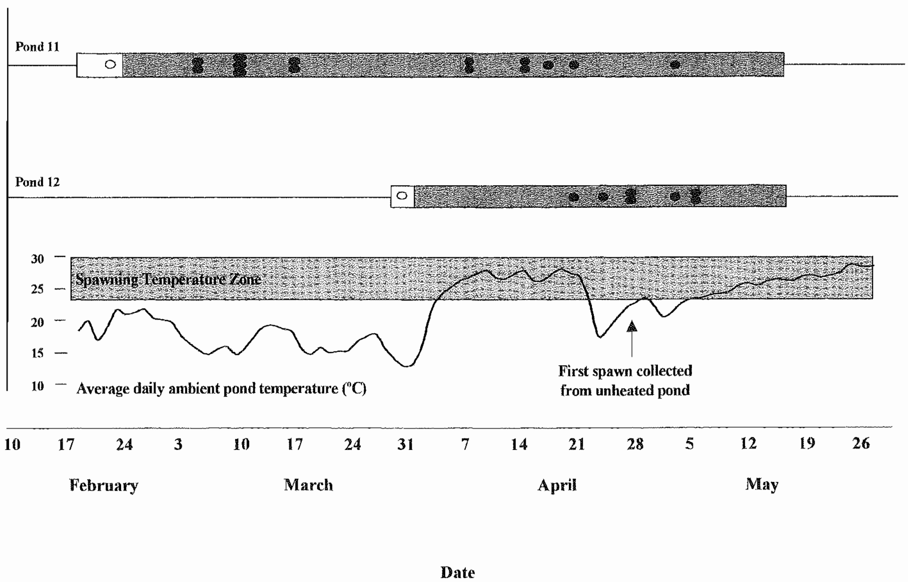

FIGURE 5.—During the 2001 spawning season, channel catfish in two heated ponds were induced to spawn during the months of March and April before the onset of normal spawning.

TABLE 1.—Summary for pond spawning during 1999, 2000, and 2001. Ponds containing male and female channel catfish broodstock were heated using geothermal water to induce early spawning. During 1999, each pond was seined when four egg masses had been collected from that pond. During 2000, three of six ponds were seined when four masses had been collected. During 2001, ponds were not seined. There was no significant difference between egg mass weight among masses collected early and during the normal season ($P = 0.07$), nor was there a significant difference in the percentage of fertilized eggs in masses collected early and during the normal season ($P = 0.88$).

Year	Females stocked	Number of masses collected		Mean egg mass weight (kg; ±SD)		Mean fertilization (%; ±SD)	
		Early	Normal season	Early	Normal season	Early	Normal season
1999	90	16	8	1.2 ± 0.8	0.9 ± 0.2	87 ± 7	86 ± 5
2000	96	36	5	1.2 ± 0.6	1.2 ± 0.6	87 ± 1	83 ± 4
2001	60	15	13	0.9 ± 0.5	1.0 ± 0.1	85 ± 11	90 ± 0
Total	246	67	26	1.2 ± 0.6	0.9 ± 0.3	87 ± 8	87 ± 5

earthen ponds, in which no manipulation of photoperiod or use of gonadotropic hormones was involved. Initiation of spawning in heated ponds was consistent in timing each year, and egg production was usually observed within 2–3 weeks of heating, except for one pond that experienced an outbreak of disease. Eggs collected early were of satisfactory quality (>50% fertilization) and were not different in total mass weight or fertilization from those collected after the onset of spawning in unheated ponds. During the early season, diseases that are common to channel catfish culture were problematic in two heated ponds; producers should thus take care to manage for disease and to avoid stressing broodstock.

The ability to control and advance the timing of spawning could benefit fingerling producers and farmers. Eggs could be produced at times convenient to the fingerling producer. By advancing the timing of production, fry could have as much as two additional months for growth in one season, yielding a larger fingerling for sale. Farmers could in turn benefit from increased time for fingerling growth within one season, increasing the yield of channel catfish (kg) per hectare, without increasing the initial investment of fingerling purchase. However, such operations would be subject to increased costs due to heating, especially in broodstock ponds (4 ha or greater) currently utilized by large commercial fingerling producers, and would require an inexpensive source of heat or heated water.

Several methods of heating ponds are possible. Geothermal water has been used successfully for aquaculture in northern areas of the United States, including Oregon (Johnson and Smith 1981) and Idaho (Ray 1985). Industrial cooling water (which is often warm after use) could be used to heat ponds directly or through heat exchangers. Cooling water from electric power plants, for example, has been used in flow-through tanks for producing seedstock of the abalone *Haliotis discus hannai* and red seabream *Pagrus major* and in ponds for the culture of yellowtail *Seriola quinqueradiata* (Tanaka 1979). Heated industrial effluent has been used directly to heat ponds for the overwintering and production of the tropical shrimp species *Penaeus vannamei* (Chamberlain et al. 1981), and black drum *Pogonias cromis* have been cultured in cages held in industrial cooling lakes (Jones and Strawn 1985). Without access to heated water, smaller ponds (1-ha ponds or less) could utilize inexpensive greenhouses to trap heat during the day and minimize heat loss during the night. Lower-cost methods of solar heating of ponds have been proposed that raised temperatures by 9°C during January in greenhouses in Arizona (Brooks and Kimball 1983). Such an application could also be used with nursery ponds to provide appropriate temperatures for fry growth when produced earlier in the season.

Finally, pulsed exposure to warm temperatures apparently also can advance the timing of spawning. During the 1999 season, one of two ponds in the second set of heated ponds was heated for 3 d and then cooled when heated well water became unavailable. Spawning occurred in that pond when temperatures rose naturally, 18 d before the onset of spawning in unheated ponds (Figure 6). Thus, the full extent to which even short-term exposure to heating affects the timing of spawning remains unknown. Perhaps this spawning resulted in response to the pattern of rising and falling temperature, which is typical for spring as cool weather fronts move through. Replication of this temperature profile, if similarly successful, might be advantageous to the culturist by reducing the amount of heat required to initiate spawning and possibly

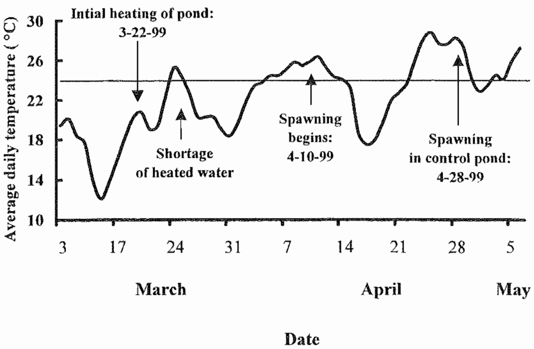

FIGURE 6.—In 1999, a broodstock pond that was heated for 3 d cooled during a shortage of heated water. Spawning occurred in that pond when temperatures rose naturally, 18 d in advance of spawning in unheated ponds. The horizontal line represents the minimum temperature threshold for spawning (24°C).

allowing closer synchronization of spawning across ponds. Future studies should examine the effect of various temperature profiles on the spawning of channel catfish to maximize egg production.

Manipulation of water temperature appeared to control the timing of reproduction of channel catfish in this study, which agrees with earlier laboratory findings (Davis et al. 1986), although we cannot exclude the effect of water exchange on spawning in the heated ponds. Channel catfish are assumed to require a period of ovarian regression each season to reinitiate growth and maturation of oocytes (Grizzle 1985; MacKenzie et al. 1989), but the earliest possible initiation of channel catfish spawning in ponds is yet unknown. Although this study documented the biological feasibility of out-of-season production in ponds, further study is needed to minimize costs for use in commercial situations. Given an inexpensive method of heating ponds (or a culture system that minimizes the quantity of heat required) and a fast-growing population of catfish, it might become possible to produce a market-sized catfish within one extended growing season. Until such time, techniques described here could be of potential use to the channel catfish industry by offering producers more control over the timing and duration of production of fingerling catfishes, including hybrids with blue catfish *I. furcatus*.

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