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Influence of Temperature and Discharge on Reproductive Timing of Common Carp in a Northern Great Plains River

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ABSTRACT -- Reproductive timing of common carp (*Cyprinus carpio*) was examined in the Red River of the North and compared with environmental factors that might have triggered spawning during 1999 and 2000. We estimated spawn dates for individual common carp larvae collected in the drift by back-calculating from date of capture and by accounting for developmental stage at capture and water temperature during the period of egg incubation. Reproductive timing was compared with discharge and water temperature to determine which of these likely might be a synchronizing cue for spawning of common carp in the Red River basin. In both years of the study, water temperature regimes were similar in comparison with time of year; however, discharge hydrographs differed substantially, which provided an opportunity to test our hypothesis that within a window of suitable temperature (and photoperiod), spawning in common carp is triggered by an increase or peak in discharge. The discharge hydrograph during 1999 was typical for the Red River, with peaks in April from snowmelt and precipitation. In atypical 2000 no early spring peak occurred due to a lack of snow cover and spring precipitation, but heavy precipitation produced a peak in discharge much later than normal during the third week of June throughout most of the study area. In both years successful common carp spawning occurred after the first peak in discharge following the attainment of a minimum spawning temperature. These results supported our hypothesis suggesting that a discharge related environmental factor might act as the synchronizing cue for spawning in common carp in some lotic habitats.

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Key words: common carp, *Cyprinus carpio*, environmental cues, river discharge, spawning.

Environmental cues that signal the availability of suitable spawning conditions are crucial to the timing of successful reproduction (Munro et al. 1990). A number of studies have attempted to discern the relative influence of environmental cues on reproductive cycles in fish (De Vlaming 1972, Stacey 1979, Davies et al. 1986). These generally have concluded that photoperiod and water temperature stimulate reproductive development and spawning; however, photoperiod and temperature are usually correlated in a natural ecosystem and their relative influence cannot be easily determined. In addition to its effect on gonadal development, the attainment of a minimum water temperature in the spring also triggers spawning behavior and the release of gametes for many fish species. For example, rising water temperature has been shown to stimulate walleye (*Sander vitreus*) and sauger (*Sander canadensis*) spawning (Koenst and Smith 1976).

In lotic systems, discharge might act as a synchronizing cue to initiate spawning. Discharge is often highly variable and is possibly the most critical abiotic factor structuring lotic aquatic communities (Bain 1985, Schlosser 1985, Harvey 1987). For many fish species, flooding can be essential because it provides complex habitat for reproduction and an increase in available nutrients for young. Many fish spawn at a rise or peak in water level and discharge, giving offspring floodplain resources and the advantage of predator avoidance (Welcomme 1979, Junk et al. 1989, Bayley 1995). In northern climates, floodplain waters might also warm more quickly, which speeds development of offspring (Bayley 1995).

Studies of common carp (*Cyprinus carpio*) and some of their Asian relatives have demonstrated that these species display synchronization in their reproductive timing that is not associated solely with water temperature (Schrank et al. 2001, Phelps 2006). Observational studies suggest that common carp have a reproductive cycle in lotic systems that is influenced highly by flow regime (Swee and McCrimmon 1966, June 1977). Common carp is classified as a phytophil, which requires vegetation as spawning substrate (Balon 1975). High turbidity and shifting sediments in some rivers might prevent the growth of aquatic plants leaving only the floodplain with inundated terrestrial vegetation to provide spawning habitat for common carp and other phytophils.

The purpose of our study was to test the hypothesis that increasing discharge acts as a synchronizing cue to stimulate spawning behavior of common carp when photoperiod and water temperature are within a suitable range. Our specific objectives were to: 1) estimate spawn date for common carp by using larval carp captured in the drift and 2) compare spawn date with existing water temperatures and discharge to determine which was most likely the synchronizing cue triggering spawning.

STUDY AREA

The Red River of the North is formed at the confluence of the Otter Tail and Bois de Sioux rivers near Wahpeton, North Dakota, and flows northward into Lake Winnipeg (Fig. 1). The Red River has a drainage area of 104,202 km^2 (Harkness et. al. 2000). It lies in the bed of Pleistocene Lake Agassiz and has a wide, flat

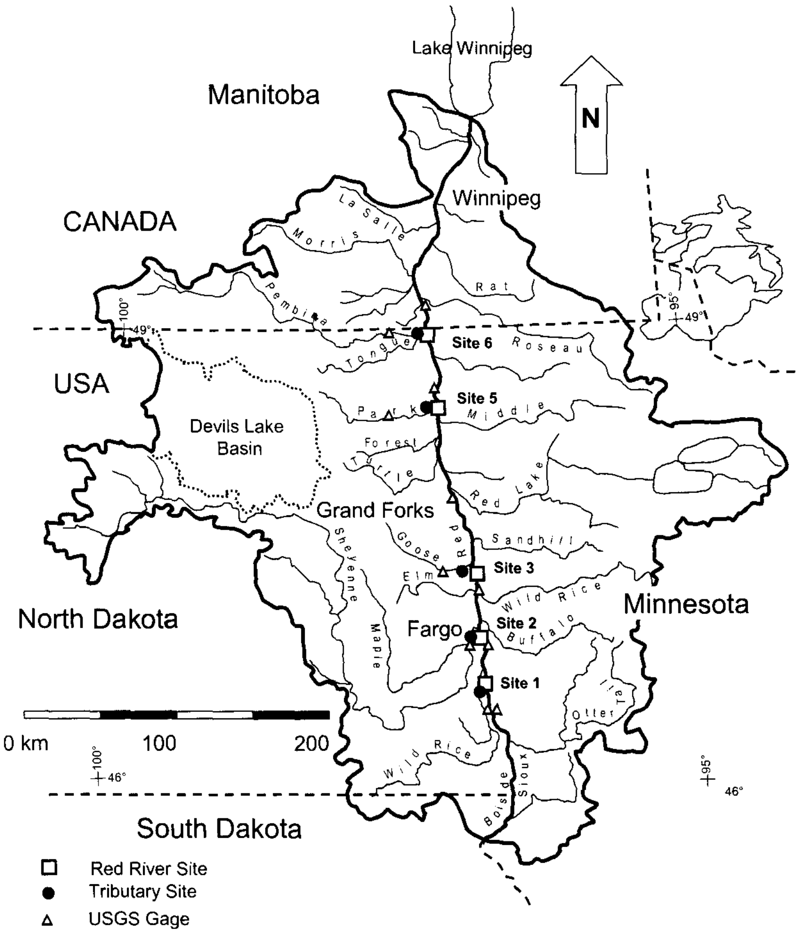


Figure 1. Map of study area displaying five pairs of sites sampled on the Red River North Dakota and associated tributaries.

floodplain that changes in elevation a mere 70 m along its 634 km course from origin to the Canadian border (Stoner et al. 1993). The watershed is altered by low-head dams, small reservoirs in tributary headwaters, and drainage ditches. Regular spring flooding from snow melt and rainfall and occasional summer flooding from widespread heavy precipitation are characteristic of the Red River. Floods often inundate the floodplain for days to weeks during the spring and summer.

METHODS and MATERIALS

All sampling was done in the silt-laden plain of the Red River valley ecoregion. Five pairs of sites were sampled during two years (1999 and 2000) of our study (Fig. 1). Sites on the Red River were located from 10 km south of Fargo, North Dakota (Red 1), north, to within approximately 2 km of the Canadian border (Red 6). Of each pair of sites, one was located on the tributary and the other on the mainstem Red River, both situated 0.5 to 6 km upstream from the confluence. Five of the largest tributaries to the Red River were sampled including the Wild Rice, Sheyenne, Goose, Park, and Pembina rivers.

Larval fish were collected with twin 0.5-m diameter plankton nets set side by side in a stainless steel bongo frame. Plankton nets had mesh size of 500 microns and a 5 to 1 ratio of length to mouth width. Each net had a detachable PVC collection container at the cod end. To estimate the volume of water filtered through each net, General Oceanic Flow Meters were suspended in the center of both net openings.

Samples were collected from 13 May 1999 through 31 July 1999 and from 17 April 2000 through 31 July 2000. Sites were sampled once a week. Nets were deployed from bridges by using a winch and boom assembly to ensure safe access during flood conditions. Plane shaped depressor weights with additional downrigger weights were attached to the steel cable to submerge the nets in the current.

Nets at Red River sites were set at different positions in the cross channel plane to accommodate spatial variability in the drift (i.e., mid-channel surface, near-shore surface, and mid-channel mid-depth). Nets were deployed only at the mid-channel surface position on tributaries. Nets were deployed for 15 to 60 minutes depending on the current velocity and amount of debris suspended in the water column. In situations when current velocity was inadequate to sample from a bridge, a small boat was used to tow the nets upstream from the regular bridge sampling station. The volume of water filtered by nets ranged from 100 to 250 cubic meters for all samples.

After each collection, nets were rinsed and contents transferred to Whirl-Pack sample bags. All samples were fixed in a five-percent buffered formalin solution in the field and placed on ice (Markle 1984). In the lab, samples were drained and washed under running water. Samples often contained large amounts of detritus, zooplankton, and macro-invertebrates. Larval fish were separated from other material and identified by using a dissecting scope and several identification guides (Auer 1982, Fuimen et al. 1983, Holland-Bartels et al. 1990).

Discharge hydrographs were obtained from five United States Geological Survey (USGS) gages (Hickson, Fargo, Halstad, Drayton, and Emerson) on the Red River and the nearest USGS gage upstream on each of the five tributaries included in our study (Wild Rice at Abercrombie, Sheyenne at West Fargo, Goose at Hillsborro, Park at Grafton, and Pembina at Niche; Harkness et al. 2000 and 2001). Daily mean water temperatures were recorded at the USGS gages on the Red River near Fargo, North Dakota (Red 2) and Halstad Minnesota (Red 3) and on the Sheyenne River near West Fargo, North Dakota. All tributaries sampled had at least one USGS gage located on it. The surface current velocity was estimated by measuring the time it took for blocks of wood to travel a known distance.

We adapted a method developed by Nesler et al. (1988) to estimate spawn date (i.e., the date of oviposition and fertilization) for individual common carp larvae for use as an index of reproductive timing and spawning intensity. Spawn date was calculated on the basis of age determined from developmental stage and estimated incubation time. Common carp larvae were classified into eight developmental stages: 1, 2, 4, 7, 10, 15, 21 day, and 1 month based on a description of morphological characteristics, egg yolk absorption, and lengths (Verma 1970). Spawn date was calculated by using a method similar to Nesler et al. (1988) by subtracting age derived from Verma's age at developmental stage key and incubation time from capture date as follows:

$$Spawn = Capture - Age - (67/T_{C^\circ})$$

where Spawn = spawn date (Julian days), Capture = capture date (Julian days), Age = age at capture (days), 67 (degree-days) × $T_{C^\circ}^{-1}$ = incubation time (days), 67 degree days = average of incubation times and temperatures taken from several sources (Swee and McCrimmon 1966, Verma 1970, Auer 1982), and T_{C°= daily average temperature over the incubation period. Incubation time was calculated by using a degree-day model where 67 degree-days are estimated for common carp eggs to hatch. The degree-day model was chosen to describe the relationship between egg incubation time and temperature because the model has been shown to provide similar precision to other more complex models (Hamel et al. 1997).

The spawn dates for 1999 and 2000 were compared by using a non-parametric Mann-Whitney U test. Correlations (Pearson Product Moment) were examined between discharge, and rate of change in discharge and Loge transformed larval carp numbers. A correlation also was performed between surface current velocity and the density of carp in the drift. At individual sites, spawn dates were compared graphically with the hydrograph and temperature regimes.

RESULTS and DISCUSSION

Eastern North Dakota received above average precipitation in 1999 and 2000, resulting in widespread flooding in the Red River Valley for periods during both years of our study. Flooding was present particularly along the section downstream from Grand Forks adjacent to the Forest and Park rivers. In 1999 peak discharge occurred in late April, which is typical of the northern plains climate due to spring snowmelt and rain. In atypical 2000 the region received little snowfall and spring precipitation, which produced low early-spring discharge. At times, several tributaries had no measurable current velocity. Peak discharge occurred later in 2000 following widespread precipitation that occurred in June. USGS gages marked a rise above flood stage at all our study sites north of Fargo, North Dakota. Water temperature regimes were similar at monitoring sites in 1999 and 2000.

In 1999 400 larval fish samples were collected and processed and 541 were collected and processed in 2000. Common carp, with 6,272 larvae caught, were the most abundant species collected. Common carp were captured in the drift later in the season in 2000 than in 1999 (Table 1). In 1999 the first common carp larvae were captured on 26 May and in 2000 the first larvae were captured on 13 June. The peak capture date occurred one month later in 2000 (26 June) than in 1999 (26 May). Common carp larvae might have been present in the drift after we ended sampling during both years, however, numbers dropped off substantially during the last two weeks of our study.

Seventy-seven percent of common carp larvae captured in plankton nets were classified as 1-, 2-, or 4-day-old larvae. Common carp in these classifications retain some of their yolk sack, a morphological feature that is identified easily. After the 4-day-old stage much of egg yolk sac has been absorbed (Verma 1970). With incubation times of 3 to 4 days, the spawn dates for the majority of captured individuals were estimated to be 4 to 8 days prior to the capture date.

Median spawn date for common carp was significantly different (Mann-Whitney U test; $Z = -53.808$, $p < 0.001$, $n = 6{,}080$) between 1999 (median = 31 May 2000) and 2000 (median = 22 June 2000) when it occurred 22 days later. In 1999, the duration of common carp spawning also was longer (15 May 1999 to 9 July 1999) than in 2000 (6 June 2000 to 9 July 2000). Spawning in 2000 most likely was constrained by lack of an early rise in discharge (Fig. 2).

Common carp in the Red River basin were found to spawn at similar temperatures reported in other studies. Temperatures recorded at USGS sensors (daily mean) on days when spawning was estimated to have occurred ranged from 15° C to 25° C during the two years of our study (Fig. 2). Optimal spawning temperature ranges have been reported to be 18 to 23° C (Auer 1982) and 19 to 23°

Table1. Number collected and capture dates for larval common carp collected in 0.5 m plankton nets (500 µm) in the Red River, North Dakota for 1999 and 2000.

Season	Number of carp larvae captured	Date of first carp larvae captured	Peak date of carp larvae capture	Date of last carp larvae captured
1999	2,130	26 May	27 May	30 July
2000	4,142	13 June	26 June	26 July

C (Swee and McCrimmon 1966). In 1999, carp spawning occurred as water temperatures approached 15° C. Peak (mode) spawning occurred on 29 May 1999 when USGS sensors recorded daily mean temperatures between 17.9 and 18.7° C. Temperatures had been increasing steadily during the prior days. In 2000, water temperature exceeded minimum reported spawning temperatures earlier in the season and rose above 20° C on 6 May 2000 but failed to trigger any successful spawning activity as indicated by the lack of larvae in the drift. After 15 May 2000, water temperatures remained within the 15 to 25° C range until the first week of July when 25° C was exceeded. Spawning in 2000 did not begin until 9 June when water temperatures ranged from 21.9 to 24.1° C. Peak (mode) spawning in 2000 was on 21 June; nearly seven weeks after the water temperatures exceeded the minimum threshold (15° C).

Peak common carp spawning appeared to coincide with discharge spikes at most sites during both years of the study (Fig. 3). Spawning activity did not coincide with peak discharge in 1999 at the Red 1 site. This might be due to the diminished accuracy of our method in back calculating spawn dates of the older larvae (i.e., stage category > 7-day old) of which these samples mostly were comprised. After the 2-day old stage in Verma's (1970) key, stages are identified at intervals of several days (e.g., 4-day old, 7-day old, 10-day old), which caused artificial gaps in the distribution of calculated spawn dates.

These results support our hypothesis that spawning is linked with discharge when water temperature is within a suitable range, suggesting that a discharge related environmental factor might be the cue triggering common carp to spawn. In 2000, common carp spawning coincided not with a minimum critical temperature but with increasing discharge after heavy rainfall in mid June ($r = 0.567$, $p = 0.001$, $n = 33$). The portion of watershed upstream from Fargo, south of the point where the Sheyenne and Buffalo rivers enter the Red River, did not receive the heavy summer rainfall like other parts of the watershed. The sampling station in this area (Red 1) did not receive the spike in discharge inundating the floodplain like other sites and as expected few common carp larvae were collected from this site.

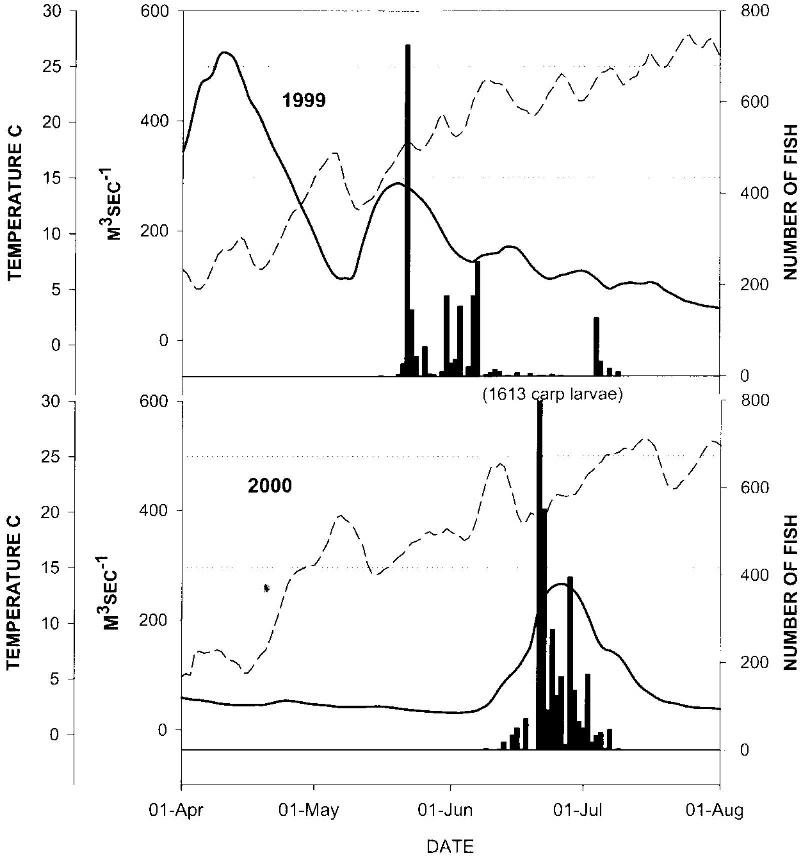


Figure 2. Calculated common carp spawn dates (bars), water temperature (dashed lines; average for all sites), and discharge rates (solid lines; average daily mean for all sites) for 1999 and 2000, The horizontal dotted lines represent the lower and upper bounds of the spawning temperature range reported in Auer (1982).

In 1999 discharge peaked in early April and river levels did not fall below flood stage until the end of May in much of the basin. Unlike the 2000 season, spawn dates in 1999 were not correlated significantly with increasing discharge (r = 0.09, p = 0.598, n = 36). During that year, common carp appeared to begin spawning as water levels were decreasing once temperature reached the lower end of their optimal range (18° C) in the third week of May. However, water levels were high in late May when temperatures rose to and remained above 18° C, the minimum temperature reported for optimal spawning (Auer 1982).

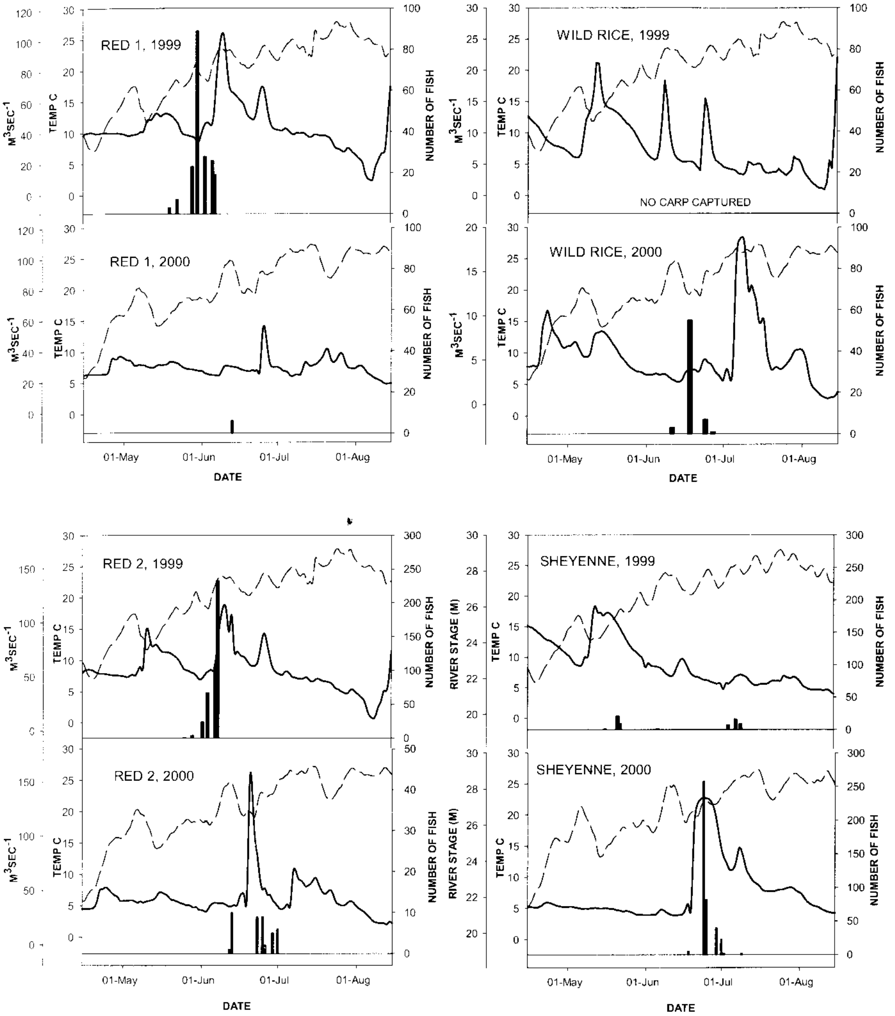
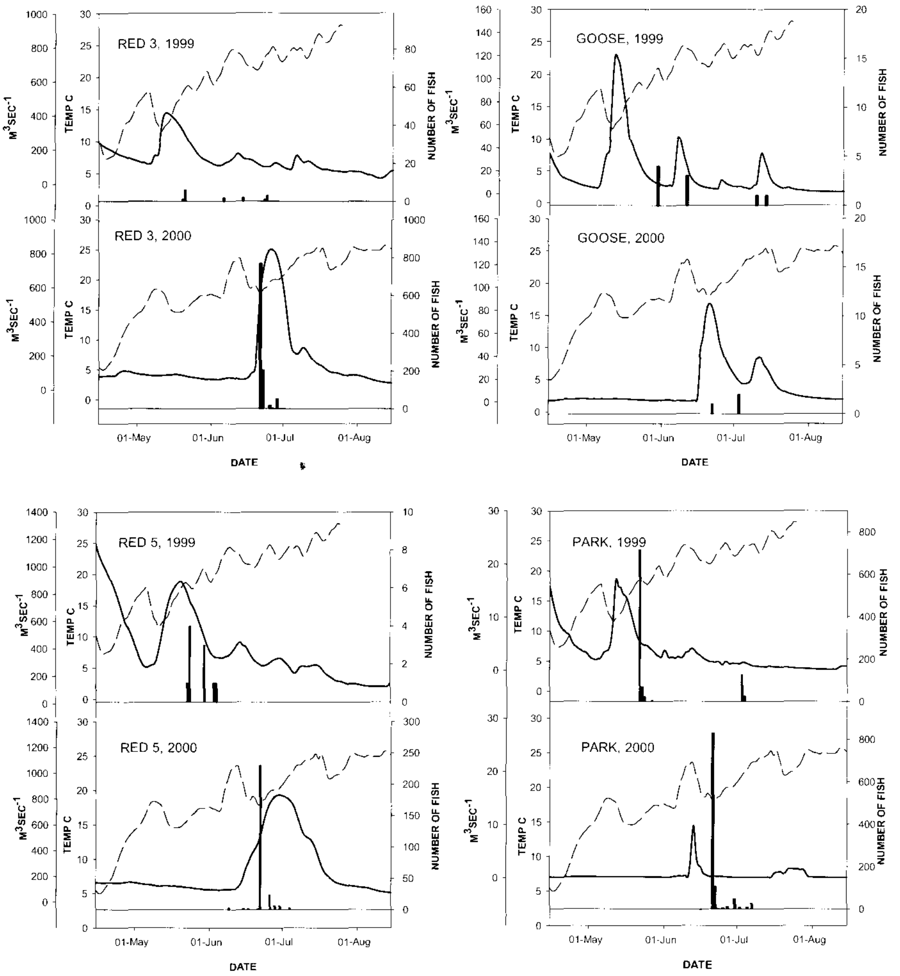


Figure 3. Calculated common carp spawn dates (vertical bars) with corresponding water temperature (dashed lines) and discharge rates (solid lines) for individual mainstem Red River and tributary sites in 1999 and 2000.



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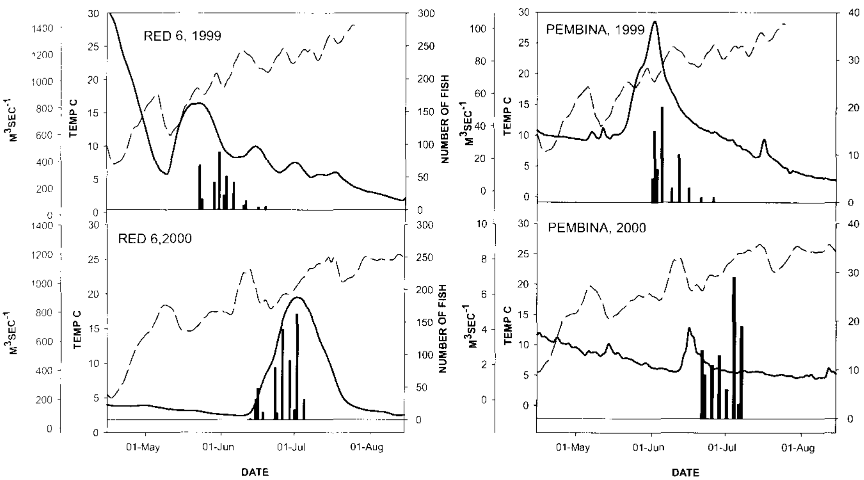

Figure 3, continued.

In 1999 when a large peak in spawning activity occurred early in the year, a smaller peak occurred at the beginning of July (Fig. 2). This peak might represent a second spawning event for common carp that spawned previously. Others have documented fractional spawning in this species (Swee and McCrimmon 1966, June 1977). A protracted spawning period, similar to what Phelps (2006) observed for common carp in South Dakota glacial lakes, also might explain this pattern. Our data indicated that successful spawning had ceased for the season by 10 July in both 1999 and 2000 because only larger individuals were captured during the last three weeks of sampling.

River discharge probably affected the susceptibility of carp larvae to capture by plankton nets. In addition to causing higher turbidity, high current velocity could displace larvae from flood plain and near-shore nursery habitat to the main channel where we targeted our sampling. Nesler et al. (1988) referred to this as a 'flushing effect'. So there was reason to consider the possibility that in 2000 common carp might have spawned earlier than our results suggested, but because of low discharge, might not have been sampled effectively until discharge began increasing mid June. We think this alternative explanation is unlikely for the following reasons. Current velocity was not correlated significantly with numbers of carp in the drift ($r = -0.048$, $p = 0.164$, $n = 857$), indicating that other factors also might influence the number of larvae moving downstream with river current. The age distribution through the course of the season also supported our argument. The date when the first common carp larvae appeared in samples at our ten study sites ranged from 13

June 2000 to 27 June 2000. All larvae captured during this period (n = 2,263) were 1-or 2-day-old larvae (with the exception of one 4-day-old individual), indicating that the spawning events that produced these individuals occurred 4 to 6 days before. The larger, older individuals were captured only during the following weeks, even after the peak in discharge subsided.

The numbers common carp larvae in light traps set overnight during the 2000 season at our tributary sites coincided with those of plankton net samples (Resseguie 2002). Common carp larvae were absent in light trap collections until 20 June 2000 similar to plankton net collections. The lack of carp larvae in light trap samples until their appearance in drift net samples further supported our argument that common carp were reluctant to spawn before the rise in discharge.

We have attempted to investigate factors that trigger common carp spawning activity by observing larvae in the Red River. Our findings suggested that both temperature and discharge might work simultaneously or in a hierarchy to cue ovulation and spawning in common carp in the Red River. Although we did not attempt to quantify available spawning habitat (submerged vegetation) or its relationship to discharge, we suspected that the presence of flooded terrestrial vegetation might be the factor that directly stimulated spawning in common carp in the turbid Red River, which lacked true aquatic vegetation. Spawning synchrony has been documented for the widely distributed common carp in many types of aquatic habitats (Swee and McCrimmon 1966, June 1977, Phelps 2006). Photoperiod, water temperature, wind/wave action, and discharge have all been identified as possible cues or controlling factors in carp reproductive timing. Understanding the complex hierarchy of environmental factors that influence reproduction in common carp will aid in the management and control of carp populations.

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