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Distribution, Relative Abundance, and Reproductive Seasonality of Larval Fish in the Red River

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DISTRIBUTION, RELATIVE ABUNDANCE, AND REPRODUCTIVE SEASONALITY OF LARVAL FISH IN THE RED RIVER

by

Timothy James Resseguie
Bachelor of Science, Bowling Green State University, 1997

A Thesis

Submitted to Graduate Faculty

of the

University of North Dakota

in partial fulfillment of the requirements

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This thesis, submitted by Timothy J. Resseguie in partial fulfillment of the requirements for the Degree of Master of Science from the University of North Dakota, has been read by the Faculty Advisory Committee under whom the work has been done and is hereby approved.

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This thesis meets the standards for appearance, conforms to the style and format requirements of the Graduate School of the University of North Dakota, and is hereby approved.

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July 18, 2002
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Title Distribution, Relative Abundance and Reproductive Seasonality of Larval fish in The Red River

Department Biology

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ABSTRACT

Spawning habitat availability and reproductive timing are crucial factors that affect survival of larval fish. To understand temporal and spatial variation in larval fishes in the Red River, samples were collected from the Red River and North Dakota tributaries using ichthyoplankton nets. Collections were made during the spring and summer of 1999, 2000, and 2001. Spatial patterns were examined to uncover any variation in a cross section of the river. Common carp *Cyprinus carpio*, cyprinid spp. and white bass *Morone crysops* were more abundant near the surface than at mid-depth. Channel catfish *Ictalurus punctatus* were more abundant at mid-depth than at the surface. There appeared to be no difference between the shore and midstream sampling stations for any species.

Densities of larval fish were compared between each of five tributaries and the Red River near each confluence to determine whether species have greater preference for or spawning success in tributaries versus the main channel. *Moxostoma* spp., white bass, *Stizostedion* spp. and Hiodontid spp. were more abundant in the main channel of the Red River than North Dakota tributaries. None of the species examined were more abundant in the tributaries selected for this study.

Reproductive timing of the most common species (carp, white sucker *Catostomus commersoni*, freshwater drum *Aplodinotus grunniens*, and *Stizostedion* spp.) in the Red

River was examined using larval fish density to indicate peaks in spawning activity and identify probable spawning dates. Density was compared with water temperature and discharge to determine which of these is the predominant synchronizing cue, triggering spawning behavior. In all years, water temperature regimes were similar; however, discharge hydrographs differed substantially. The years 1999 and 2001 were more typical where peaks in discharge occurred in April and were related to snow-melt and heavy spring precipitation. In contrast, the 2000 peak in discharge occurred during the third week of June. The timing in reproduction of white sucker and *Stizostedion* spp. appeared to be associated primarily with temperature or photoperiod. Spawning for these species occurred at the same time during all three years of the study. Spawning in freshwater drum could be either temperature or discharge related. Estimated spawning times for carp appeared to be associated primarily with peaks in discharge. Peaks in carp reproduction occurred as discharge rates began increasing in 2000, indicating that discharge may act as the primary synchronizing cue for carp. The relationship between discharge and the initiation of spawning in carp may stem from their requirement of submerged vegetation for spawning habitat.

CHAPTER ONE: INTRODUCTION

There is a variety of reproductive strategies used by fishes. Almost all freshwater riverine fishes found in temperate climates produce relatively large numbers of small offspring that suffer extremely high mortalities until they develop fully into adults (Cushing 1990, Balon 1975, 1981). These characteristics make the early life stages of fishes the most sensitive for their survival. Although some individuals succumb to extreme abiotic factors (i.e. temperature, salinity, etc.), predation and starvation are often the two greatest sources of mortality of fish larvae (Cushing1990).

As with many organisms that live in variable environments, the timing of reproduction is crucial to riverine fish survival. Several hypotheses have been developed in an attempt to explain why annual reproductive cycles may have evolved in fishes. Cushing's match/mismatch theory describes how fluctuations in year-class strength could be determined by fluctuations in plankton production at the time of yolk-sac absorption and the beginning of exogenous feeding for fish larvae (Cushing 1990). High survivorship occurs when larvae hatch during peak levels of plankton production and lower survivorship due to starvation occurs if larvae hatch during a period of low plankton production. Thus, Cushing argued, reproductive timing might have evolved so that hatching would coincide with peaks in plankton production.

Another probable factor that affects recruitment to adult stages in temperate regions is over-winter survival. During winter, food is often limited and growth slows or stops. In these cases fish must rely on fat reserves to provide energy needed for metabolic processes, and in extreme cases, fish may absorb gonad tissue. Individuals that are able to grow to a larger size before the onset of winter often are less likely to succumb to starvation than their smaller cohorts (Conover 1992). It seems plausible that this evolutionary force would drive fish to spawn as early as possible to allow for longer periods of feeding and growth. Conover found bio-geographical evidence for Atlantic silversides (*Menidia menidia*) on the east coast of the United States indicating that populations at lower latitudes will spawn at higher temperatures and that their spawning season is longer than populations of the same species at higher latitudes (Conover 1992). He identified a number of other studies involving a variety of temperate fishes where this pattern was observed (Conover 1992). He attributed this pattern to higher over-winter mortality at higher latitudes within a species' geographical range, specifically affecting individuals hatched later in the spawning season.

A similar cycle has been described in tropical regions that have dry and rainy seasons but relatively little variation in temperature. Here, the dry season is often a period of reduced growth for aquatic species and the rainy season is a period of abundant resources (Junk et al. 1989). Many species spawn at the beginning of the rainy season giving them the greatest possible time for growth before the onset of the dry period when starvation and predation take a greater toll on larval and juvenile fish. Cushing's match/mismatch hypothesis and Conover's over-winter mortality hypothesis are probably both important in explaining how reproductive seasonality may have evolved in fishes.

Much of the debate surrounding reproductive seasonality in fishes concerns the endogenous rhythms and environmental cues that control fish reproductive cycles (DeVlaming 1971, Potts and Wooten 1984). In some marine crustaceans, as many as four environmental cycles (photo-period, tidal phase, tidal amplitude and lunar cycles) are thought to control the timing and duration of reproduction. Environmental cues operated in a hierarchy to ensure that crabs released their gametes synchronously and at a time when larval survival should be maximized (Morgan and Christy 1994). Similar reproductive patterns exist for other intertidal invertebrates and fishes.

In many temperate lentic systems, photoperiod and temperature are the most important cues in synchronizing reproduction (Munro 1990, Bye 1984). Many observational studies concerning spawning season identify the time of year that a particular species spawned or hatched, and some mention the water temperature as well (Yeager 1936, Walker and Frank 1952, Mraz 1957, Swee and McCrimmon 1966, Swedburg and Wahlburg 1970). Very few of these provide any indication as to which of these factors (photoperiod, temperature) most influences the timing of reproduction. DeVlaming (1971) reviewed a number of laboratory studies that cited either photoperiod or temperature as the exogenous factor that controls annual reproductive cycles in fishes. However, these short-term experiments often do not provide conclusive evidence that can exclude either temperature or photoperiod as the environmental cue that controls reproductive timing in fish. Reproductive timing, in most species is likely dependent on both photoperiod and temperature (DeVlaming 1971, Bye 1984, Munro 1990). Different aspects of reproduction (i.e. gonad recrudescence, gonad final maturation, spawning migration, release of gametes, gonad regression) are triggered or stimulated by photoperiod or temperature, and in many cases, probably a combination of both, working simultaneously to stimulate different events.

Balon (1974) recognized the importance of reproductive strategies to the survival of most fishes in a variety of different environments. The requirements of the early life history stages often limit the environments in which populations can become established (Balon 1974). He developed reproductive guilds that are often used to classify fish by their spawning behavior and substrate that they choose to deposit their gametes (Table 1) (Balon 1974, 1981). Fish that spawn on gravel or rocky substrates such as walleye *(Stizostedion vitreum)* and white suckers *(Catostomus commersoni)* are classified as egg scattering lithophils using Balon's system. In these species, photoperiod and temperature are likely to be the most dominant factors in triggering reproduction because of their annual predictability.

Hamel et al. investigated the relationship between water temperature and the onset of spawning in white suckers using both laboratory and *in situ* experiments. They concluded that spawning was triggered by a threshold temperature of 13° C in four of their warmer study sites and 10° C at two more northerly cold-water sites in Quebec (Hamel 1997, 1997).

Table 1. Fishes known to occur in the Red River, categorized according to Balon's (1974) Reproductive Guilds of Fishes

Nonguarders

Open substrate spawners

Pelagophils: Pelagic Spawners
- *Aplodinotus grunniens*
- *Notropis atherinoides*

Litho-pelagophils: Rock and gravel spawners with pelagic larvae
- *Acipenser fulvescens*
- *Hiodon tergisus*
- *Hiodon alosoides*
- *Lota lota*
- *Stizostedion vitreum*

Lithophils: Rock and gravel spawners with benthic larvae
- *Catostomus commersoni*
- *Moxostoma erythrurum*
- *Moxostoma anisurum*
- *Moxostoma macrolepidotum*
- *Moxostoma valenciennsi*
- *Notropis blennius*
- *Notropis dorsalis*
- *Notropis rubellus*
- *Platygobio gracilis*
- *Rhinichthys cataractae*
- *Percopsis omiscomaycus*
- *Stizostedion canadense*

Phyto-lithophils: Non-obligatory plant spawners
- *Hybopsis storeriana*
- *Notropis spylopterus*
- *Morone crysops*
- *Perca Flavescens*
- *Etheostoma exile*

Phytophils: Obligatory plant spawners
- *Esox lucius*
- *Cyprinus carpio*
- *Ictiobus cyprinellus*

Psammophils: Sand spawners
- *Carpiodes cyprinus*
- *Notropis hudsonius*
- *Notropis stramineus*
- *Percina carprodes*

Brood hiders

Lithophils: Rock spawners
- *Nocomis biguttaus*
- *Semotilus atromaculatus*
- *Percina maculata*

Guarders

Substrate choosers

Phytophils: Plant spawners
- *Pomoxis annularus*

Nest spawners

Lithophils: Rock spawners
- *Luxilus cornutus*
- *Ictalurus melas*
- *Ambloplites rupstrus*
- *Lepomis cyanellus*
- *Lepomis macrochirus*

Phytophils: Plant spawners
- *Pomoxis nigromaculatus*

Spelophils: Hole, burrow nesters
- *Pimepheles notatus*
- *Pimepheles promelus*
- *Ictalurus nebulosus*
- *Ictalurus punctatus*
- *Noturus flavus*
- *Noturus gyrinus*
- *Etheostoma nigrum*

Polyphils: Misc. substrate nesters
- *Lepomis gibbosus*

Ariadnophils: Gluemaking nesters
- *Culaea inconstans*

The walleye and sauger are other species that appear to require a threshold temperature to trigger spawning activity. They begin spawning most readily when the water temperature begins to warm in the spring and reaches 4° to 10° C depending on the geographical origin of the population (Koenst et al 1976, June 1977). These two species often spawn early in the spring to meet temperature and dissolved oxygen demands of their developing eggs. Temperature seems to play a crucial role in gonadal development and reproductive timing for a number of other species (De Vlaming 1971, Stacey et. al. 1979, Davies 1986, Hontella and Stacey 1990).

In lotic systems, stream or river flow regime is the cause of temporal and spatial variability. This plays a vital role in aquatic organisms' life history and is probably the most important abiotic factor in structuring these aquatic communities (Bain 1985, Schlosser 1985, Harvey 1987, Scheiddeger and Bain 1995). In smaller streams and rivers with relatively steeper gradients, floods are unpredictable and often shorter in duration compared with larger flood-plain rivers (Figure 1)(Junk et al 1989). There is often a quick rise in water level accompanied by fast current velocities. Sediment, sand, ice and woody material caught up in the current have a scouring affect. The onslaught of an erosive flood can be detrimental for the early life history stages of many species of fish (DeVlaming 1971, Harvey 1987). Not only can fast current and debris physically injure fish, but also fish larvae can be displaced long distances downstream, sometimes out of desirable habitat. Erosive floods following ice-out in arctic regions could be the reason why many fishes in these regions spawn during late summer or

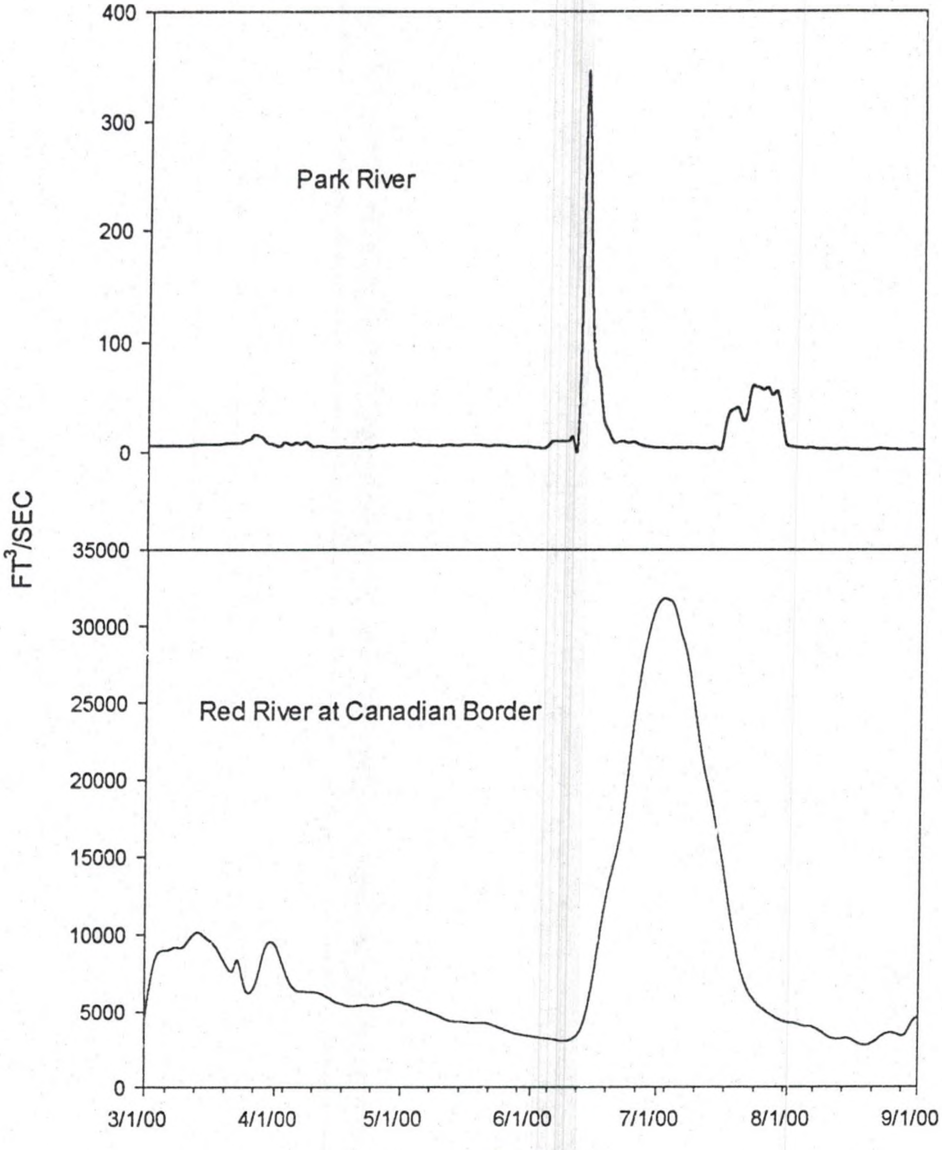


Figure 1. Hydrographs of a large river (Red River, near Emerson Manitoba) and a small river (Park River), during 2000, showing variation in flood pulse duration.

autumn (Conover 1992). In addition to this, increased turbidity can interfere with ability to locate prey (Mion et al. 1999, Henley et al. 2000).

Some species in these types of systems, such as longear and green sunfish (*Lepomis megalotis* and *L. cyanellus*), tend to spawn as the water is receding or shortly after, possibly to escape the detrimental effects of flooding in smaller streams (Harvey 1987). These species are nest builders that guard their offspring until they reach a size that is better able to escape predation. As one might expect, members of the centrarchid family--well known nest guarders--favor stable conditions that will not disrupt their nests and scatter their offspring. A number of investigations have shown that centrarchids and other nest builders tend to thrive in habitats or during years with a stable flow regime and are often affected negatively by flooding during their spawning season (Schlosser 1985. Harvey 1987, Copp and Penaz 1988, Scheidegger and Bain 1995). Many other species, especially some catostomids and cyprinids, have adapted well to these spring torrents and can effectively feed and reproduce under these conditions.

In watersheds with relatively flat gradients where floodwaters rise more slowly and drain at a slower pace, flooding is not so detrimental to fish reproduction. Flooding is often delayed following rainfall, especially in larger rivers. Annual floods in the lower Amazon sometimes occur 5-6 weeks after the beginning of the rainy season (Junk et al.1989). Similar patterns can also be seen in large temperate rivers, although man-made devices have caused some disruptions (Bayley 1995). Low areas adjacent to the river are gradually inundated and the mouths of tributaries become backed up, sometimes great distances, producing areas with little or no current. The zone that fluctuates between being aquatic and terrestrial, which Junk et. al. coined the ATTZ (aquatic terrestrial transition zone), is commonly known as and henceforth will be called the floodplain (Junk et al 1989, Bayley 1995). Water on the floodplain is often shallower and warmer than the water in the main channel of the river.

Many have recognized the how these floodplain systems differ from most rivers and streams described by Vannote's river continuum concept, which concentrates on the lateral transport of energy (Vannote 1980, Junk et al. 1989, Bayley 1995, Johnson et al 1995, Hogarth 1999). These flooding events have a different, more-often positive effect on the aquatic biota. Floods on rivers with flood plains make available, areas of complex habitat in the form of flooded vegetation and increase productivity for exploitation by river fishes (Junk et al 1989, Ross and Baker 1983, Welcomme 1979). The release of nutrients from flooded terrestrial zones is often associated with increased macroinvertebrate and plankton production (Eckbald et al. 1984). Junk et al. (1989) named this process the flood pulse concept and argued that it was the source of high aquatic productivity in flood plain ecosystems.

Many species that inhabit flood-plain rivers will spawn at the beginning or peak in a rise in water levels giving their offspring the ability to exploit the resources of the floodplain and avoid predation during the most vulnerable period of their lives. This behavior has been widely documented in fish species that inhabit large tropical rivers affected by wet and dry seasons (Hogarth 1999, Bayley 1995, Junk et al1989, Welcomme 1979). In northern, temperate climates, the flood plain waters also offer the advantage of being warmer than main channel waters, providing further benefits for developing larvae (Bayley 1995).

Many temperate fishes (e. g., northern pike, bigmouth buffalo and common carp) are classified as phytophils requiring vegetation as a spawning substrate (Table 1). The flood plain provides valuable spawning habitat in turbid rivers where insufficient light is available for plants to grow (Balon 1979). In addition to photoperiod and temperature, which are thought to be important in gonadal development prior to final maturation, a third environmental cue is needed to trigger spawning behavior, final gonad maturation, and the release of gametes in many phytophils that inhabit turbid rivers, (Munro, 1990). This could be the rising water, higher current velocities associated with flooding events, or the scent of recently inundated vegetation. These cues probably also work in a hierarchy along with photoperiod and temperature to ensure that fish spawn in a synchronous manner at a time when their offspring would exhibit the highest survival (Hontella and Stacey, 1990).

Several larval fish surveys involving cyprinids have documented increased larval fish densities in the drift during periods of high discharge (Nesler et al 1988, June 1977. For example, Colorado pike-minnow larvae were found by Nesler et al. to be associated with peaks in discharge (1988). Several species of Indian carp have larval densities that are highest during the initial rise in water associated with the monsoon season in the

River Jamuna in Bangladesh (De Graaf, et al 1999). The buffalo (*Ictiobus* spp.) members of the family Catastomidae are known to require aquatic or flooded vegetation to spawn and it is well documented that they require flood plain inundation or they will fail to spawn (Johnson, 1963; Walker et al., 1952; Yeager, 1936). Although they do not spawn directly on flooded vegetation like carp and buffalo fish, freshwater drum and quillback appear to be influenced to spawn by periods of increased discharge (Parker et al 1991, Swedburg and Walburg 1970). Walleye, sauger and white sucker do not depend on the floodplain to provide flooded vegetation for spawning; however, their larvae may benefit from the complex habitat and refuge from current provided on the flood plain. For most species in lotic systems, the link between reproductive timing and suitable spawning habitat availability is probably strong.

Larval fish studies have been used to document spatial distribution and abundance of larvae in the drift (Gale and Mohr 1978, Gallagher and Conner 1980) and estimate the number lost to entrainment through dams or other water uptake structures (Pitlo 1989, Calhoun 1953). Larval fish studies are sometimes used to predict year-class strength for fish populations (Sammons and Bettoli 1998; Johnston et al. 1995). There is evidence that larval fish studies can also be used to evaluate spawning habitat in river ecosystems (Brown and Coon 1994; Muth and Schmulbach 1984). Larval fish collections have also been used to describe and explain reproductive seasonality in fishes (Humphries and Lake, 2000, Nesler et al. 1988, Naesje et al, 1986).

Fish larvae have some means of locomotion, so their movements are not completely passive; however, they can only retard their eventual downstream displacement and tend to drift with the current in lotic ecosystems (Starnes et al. 1983).

Remaining near shore and out of the main channel of the river is one tactic fish can use to slow their downstream displacement rate. Houde (1969) calculated larval perch maximum swimming velocities at about 3 to 4 body lengths per second in larvae over 9.5 mm. Fish larvae can be assumed to have originated from upstream spawning activity in situations where the current is flowing in one direction and the velocity is swifter than the larvae's swimming ability. Larval fish in the drift are good evidence that fish of that species were successful in reproducing and that suitable habitat exists upstream from where the collections were made. As fish larvae develop into juveniles, their swimming ability increases rapidly and this assumption concerning their ability to move upstream should no longer be made (Harvey 1987, Starnes et al. 1983). Larval fish are better able to hold their position in habitats with lower current velocities (i.e. shore, structure on the bottom, backwater or floodplain habitat).

In large rivers that have high current velocities, many species take advantage of the slack current found in backwaters or areas off the main channel (Sabo and Kelso 1991; Holland 1986, Scott and Nielsen 1984). Small tributaries of large rivers often have similar characteristics to backwater areas, especially during periods of high water on the main channel of the river. High water levels on the main channel of the river can act as a barrier to the downstream flow of the tributary producing an impounding effect that results in slow current velocities at the confluence, and the flooding of low areas adjacent to the tributary (Brown and Coon 1994). In channelized rivers or rivers with few natural backwaters, flooded tributaries may provide the best spawning habitat for both floodplain (phytophilic) and main channel spawners (lithophilic and pelagophilic) because of higher temperatures, slower current in some areas, shallower depth and greater allochthonous production (Muth and Schmulbach 1984; Smith and Hubert 1989, Brown and Coon 1994, Robinson et al. 1998). Other species of fish take advantage of the gravel, rock and sand substrate found in riffle areas further upstream in these small tributaries. This makes tributaries potentially important spawning habitat for riverine fishes.

To address some of questions proposed above, my objectives were to: (1) describe the cross channel, diel, spatial, and temporal variation of larval fishes in the Red River and selected major tributaries, (2) compare the relative larval-fish contributions of selected tributaries with contributions from the Red River main-stem at and between each confluence, and (3) associate estimated individual larva fertilization dates, abundance, distribution, and temporal variation with important environmental variables such as current velocity, temperature, photo-period, and flood events that may act as synchronizing cues. I hypothesized that a number of Red River fishes will fall into one of two categories: temperature cued spawners including percids and some catostomids (e. g., white sucker, *Catostomus commersoni*) or flood plain spawners, including carp *(Cyprinus carpio)*, and freshwater drum *(Aplodinotus grunniens)*. I tested this hypothesis by comparing timing of observed larval densities and estimated fertilization dates of larval carp with timing of predicted peak densities determined on the basis of either temperature or flood events. I adapted a model using degree-days (developmental rate increases linearly with temperature until hatching) to estimate incubation times to make predictions about the timing in reproduction for some of the more common Red River fishes including carp, white sucker, *Stizostedion* spp., and fresh water drum that were abundant in larval drift samples. I tested whether these species were triggered to spawn by the threshold temperature described in published laboratory experiments and observational studies. I also compared water temperature regimes with estimated spawn-date distributions for individual carp larvae and larval drift densities for white sucker, *Stizostedion* spp. (walleye and sauger), and freshwater drum. Alternatively, I examined discharge rates and estimated fertilization dates for carp and larval drift densities for white sucker, *Stizostedion* spp. and fresh water drum to determine if rise in water levels and inundation of the floodplain acts as a synchronizing cue for these species of fish.

CHAPTER TWO: METHODS

Study Area

The Red River of the North flows north and forms the border between Minnesota and North Dakota. Its origin is formed by the confluence of the Otter Tail and Bois de Sioux Rivers near Wahpeton North Dakota. It then flows into Lake Winnipeg in Manitoba and is part of the Hudson Bay drainage. Large rivers are ecosystems that are often difficult to classify (Pennak 1971, Johnson et al. 1995). Concepts that are useful on smaller streams such as stream order are often not as helpful when applied to larger rivers (Johnson et al 1995). Although not as large as well known floodplain rivers such as the Mississippi or Amazon, the Red River has some of the characteristics of a flood plain river including vast areas that are inundated for an extensive period of time.

The Red River has a drainage area of 40,200 mi^2 (including areas that are noncontributing) at the Canadian border (Harkness et al. 2000). It has a low gradient on the lake plain and high sinuosity (Koel 1997). Situated in the ancient bed of Pleistocene Lake Agassiz, the Red River has a wide, flat floodplain changing in elevation a mere 200 ft along its 394 mile course from Wahpeton to the Canadian border (Koel 1997, Stoner et al. 1993). Most of the watershed is used extensively for agriculture where sugar beets, wheat, potatoes and a variety of row crops are grown (Stoner et al 1993). The Red River and tributary channels and flow regimes are relatively unaltered, compared to other North

American rivers, especially the stretch of river that lies north of Fargo. A few low-head dams have been constructed to retain water during dry years and small reservoirs were constructed mostly in the headwater regions of some tributaries and far upstream reaches of the Bois de Sioux and Otter Tail Rivers. Systems of ditches also have been constructed to drain farmland and flood control devices have been constructed to protect cities and farmsteads. Spring flooding after snowmelt is characteristic of the Red River drainage basin with some floods reaching a catastrophic magnitude (e.g. 1950, 1979, and 1997). River levels sometimes reach flood stage after widespread heavy rains and thunderstorms in early summer as well (e.g. June 2000). Discharge is normally at lowest levels in the autumn and winter (Stoner et al. 1993).

A total of 77 native and non-native species of fish have been documented in the Red River basin during past surveys. However, some of these are only found in the headwater streams, particularly the clear headwaters and lakes of the Red Lake and Otter Tail Rivers in Minnesota (Koel 1997). In the main stem of the Red River, 58 species representing 15 families have been reported in the past, not including those that have not been collected in the last 50 years (Koel 1997).

Collection Sites

Because they have a slower current velocity and an often more heterogeneous channel morphology, tributaries were hypothesized to have more spawning adults and thus higher larval densities than the main channel of the Red River. All sampling was done within the Red River valley ecoregion (Koel 1997). Five pairs of sites were sampled during all three years (1999, 2000, and 2001) of this study. Sites ranged from south of Fargo near Rustad Minnesota to North of Pembina North Dakota, just south of the Canadian border (Figure 2). Six confluences were sampled originally, but site pair 4 at the Forest River confluence was eliminated because of heavy traffic on the bridge near Oslo Minnesota. At each of these five pairs of sites, one was situated upstream from the confluence on the Red and one was located upstream on the tributary. For access and safety during high water, which is characteristic during spring spawning, most collections were made from bridges. Bridges over the Red River nearest to the confluence of each tributary and the nearest bridge on the tributary were chosen as sites to be sampled because they were expected to provide the best representation of larvae for comparison between tributary and Red River main-stem. The five largest watersheds on the Red in North Dakota were sampled including the Wild Rice, Sheyenne, Goose, Park, and Pembina Rivers. Descriptions of these sites can be found in Appendix I

Ichthyoplankton Collections

Drift Samples

Peak densities of larval fish were assessed using ichthyoplankton samples collected with 0.5 m diameter twin-framed bongo nets. Mesh size for plankton nets was 500 micron and they had a 5 to 1 length to mouth ratio. Each net had a detachable sample bucket at the cod end of the net where current would naturally wash the majority of filtered material. To estimate the volume of water filtered through each net, General Oceanic Flow Meters were suspended in the center of the net opening. Samples were collected from May 13th until the end of July in 1999, from April 17th until the end of July in 2000 and from April 24th until the end of May in 2001. To enable sampling during

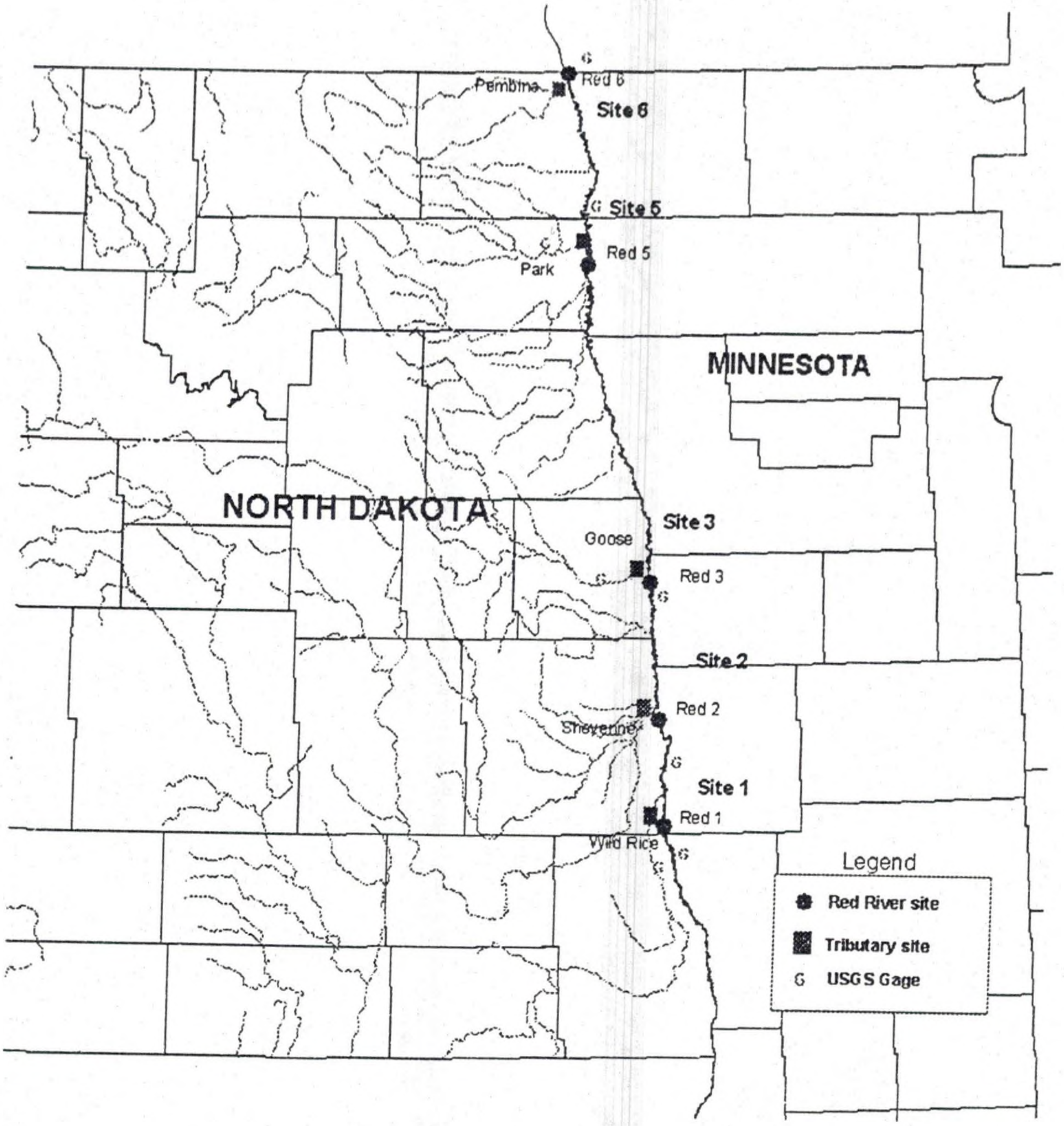


Figure 2. Map of study area showing five pairs of sites sampled on the Red River and North Dakota tributaries. Site pair 4 at the Forest River confluence was eliminated because of safety concerns.

flooded conditions, often involving fast current velocities and large floating trees and other objects, and because of limited access to boats on the Red River and tributaries, nets were deployed in the current from bridges using a winch and boom assembly with steel cable (Figure 3). Downrigger weights and plane shaped depressor weights (Wildco) were also attached to the steel cable to depress the nets against the current. Nets were set for 15 to 60 minutes depending on the current velocity and the amount of debris suspended in the water column, to attain a sample size of between 100 and 250 cubic meters. In some situations when current wasn't adequate and the channel depth was over 2 meters, the nets were towed behind a 12-foot aluminum john boat in an upstream direction as close to the sampling station as possible. Nets were rinsed on shore and the contents of the collection buckets were emptied into whirl-pack sample bags.

Cross channel spatial variation

Because of slower current velocities and refuge in the areas near shore, most species of fish were expected to be more abundant there. To determine the relative difference in larval fish densities in a cross section of the river channel and at different depths, nets were set at 3 different positions in 1999 (Figure 4). One net was deployed at the mid-stream location near the surface. Another net was deployed approximately at one half the depth of the water. The third net was deployed near the shore in slower current where the current velocity was still sufficient for the net to filter inflowing water.

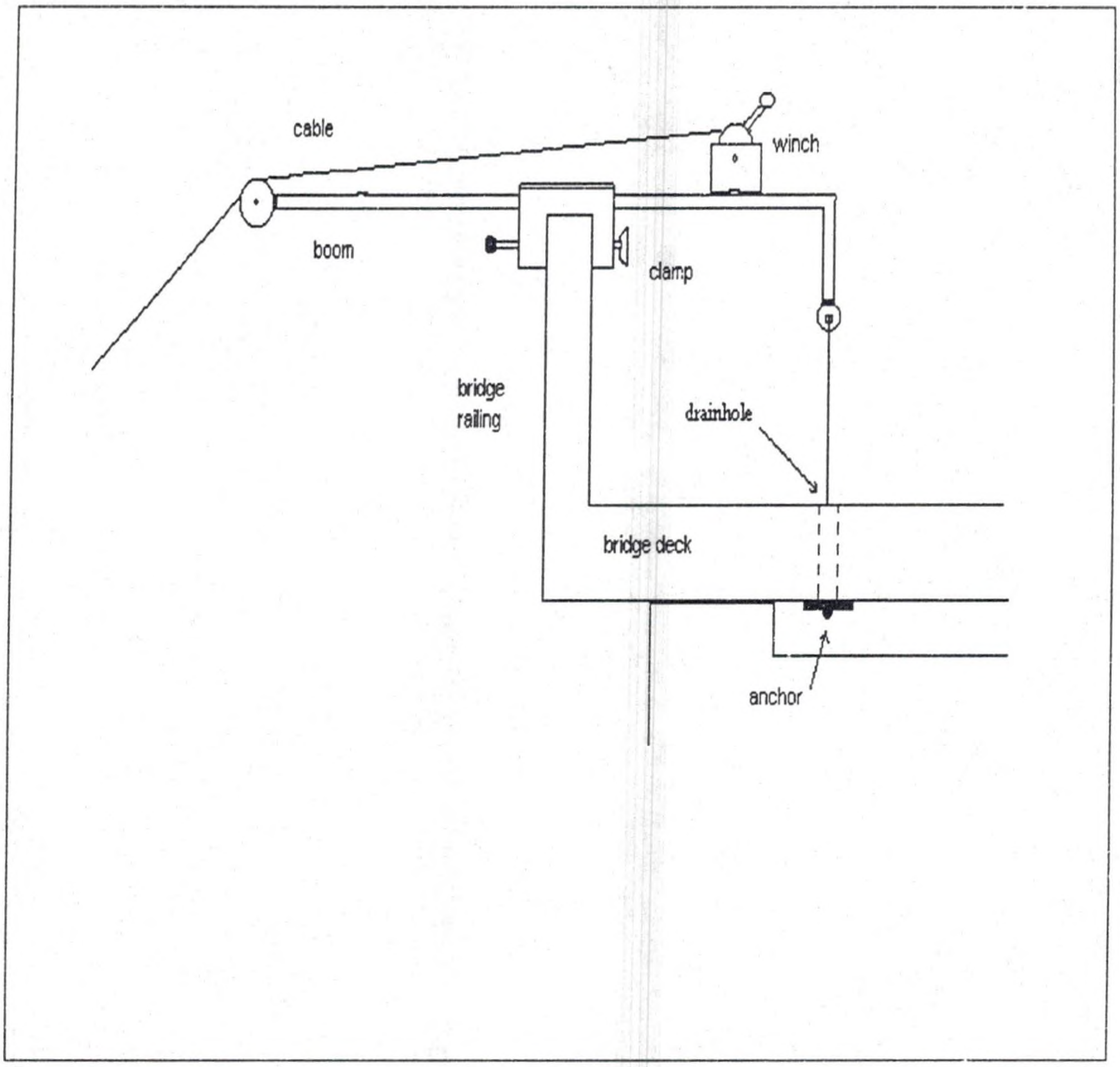


Figure 3. Winch and boom assembly used to deploy nets from bridges. Assembly was clamped to bridge railing and anchored through a drain-hole in the bridge.

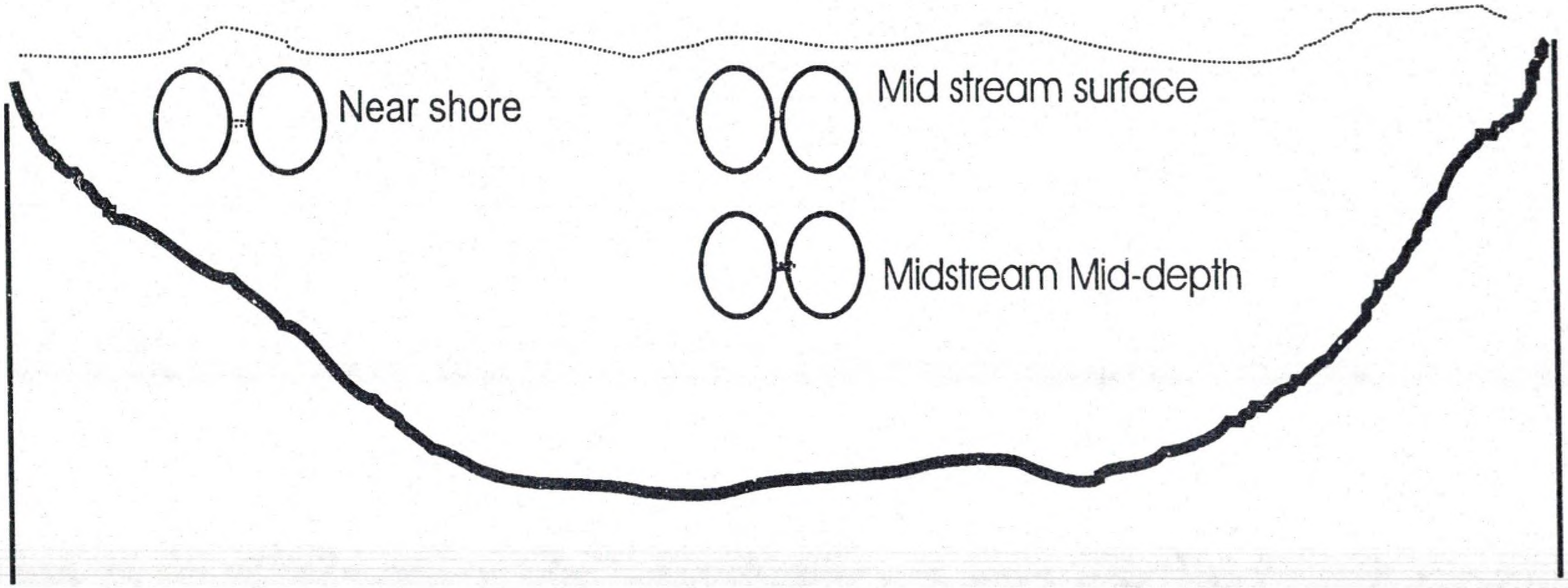


Figure 4. Position of bongo nets at 3 sampling stations in a cross section of the Red River.

Because of the small size of the Red River tributaries, only a midstream net was set in the tributary sites. In 2000 and 2001 nets were set only at the surface. During the 2000 season a second (replicate) net was set at the midstream surface position immediately following the first net set. A second (replicate) net was also deployed at the mid stream tributary site.

Drift net vs. Towed Net Comparison

An attempt was made to assess the levels of fine-scale spatial and temporal heterogeneity in larval fish drift in the main channel of Red River and to test the compatibility between samples collected from bridges and those collected by towing the drift nets behind a small boat. At the northern most site on the Red River near Pembina North Dakota, four tow (net towed behind a boat) samples were collected and four bridge (net deployed from bridge) samples were collected on July 19, 2000 to compare the amount of fine scale variation in larval fish densities between replicate nets.

Diel Variation

To assess larval fish drift variation during different times of a 24 hour diel period, collections were made during the day 9:00AM to 4:00 PM, at dusk 0.5 hours before sundown, and at night 11:00 PM to 1:00 AM during the 1999 season. Two tributary bridges, one on the Pembina and one on the Wild Rice, were chosen for this analysis because of their relative safety owing to a lower amount of automobile traffic. After the first two collection dates at each tributary site, the dusk sample was eliminated and only day and night samples were collected. After July 15th, only day samples were collected because the fish observed in each sample were becoming increasingly rare. A total of eight diel comparisons on the Wild Rice and seven on the Pembina River were made. The results of this were analyzed in a previous study that found no differences between night and day collections (Ryan Duffield, unpublished data).

Light Traps

Supplemental to drift net collections, during the 2000 season larval fish were also collected using modified Quatrefoil light traps between May 20 and July 15 (Floyd et al 1984). Two traps were set over night at sundown at each of the tributary sites on opposite banks of the river ideally in locations out of fast current but in a sufficient depth to allow complete submergence of the traps. Small identical flashlights supplied light with two AA batteries enclosed in the trap to attract larvae. Traps were set at dusk or shortly after and collected each morning prior to the setting of drift nets. Any fish larvae present in the traps were preserved and identified in the lab. Light traps were not as effective at capturing all species of larvae in the Red River and were excluded from most analyses. They were helpful in establishing the presence or absence of larval fish in a few locations and dates when drift sampling was impossible.

Laboratory Processing and Identification

Samples were fixed in a 5% buffered formalin solution in the field and placed on ice immediately (Markel 1984). In the lab formalin was drained from samples and they were washed under running water to remove additional formalin. This made samples less noxious and safer to process. Samples often contained large amounts of detritus, zooplankton, and macro-invertebrates, making sorting by hand very tedious and time consuming. However, other methods did not work because of the nature and consistency of these samples. Larval fish were separated from these other materials in the lab under a dissecting microscope and fish larvae were identified to the lowest taxa possible with the use of several identification guides (Auer 1982, Fuiman et al 1983, Holland-Bartells 1990). Different light settings and cross polarization filters were used to highlight larvae myomeres to aid in identification. Juveniles were included in analyses if they were determined to be age 0+. Fish larvae were then stored in vials in 70% ethanol.

Environmental Conditions

Physical parameters including temperature, DO, conductivity, turbidity, and pH were each measured with a Horiba model U-10 water quality checker. Depth measurements were made at mid-channel and the shore sites with a rope marked in 1-meter increments and large iron weight. Surface current velocities were estimated by measuring the time it took for a floating wooden object to travel a known distance (the width of the bridge). Current velocities were placed into 4 categories (nonexistent < 0.2 m/s, slow 0.2m/s -- 0.5 m/s, medium 0.5 --1m/s, and fast, > 1m/s). Weather conditions including air temperature and the percent of sky concealed by clouds were also recorded. The amount of shade on the river surface was recorded as well. During the 1999 season substrate samples were collected at each sampling station using a Ponar dredge and inspected visually to determine the type of substrate at that site. Daily mean water temperatures were obtained from the United States Geological Service gages on the Red River near Fargo and Halstad for 1999, 2000, and 2001. A USGS gage provided temperatures for the Sheyenne River near West Fargo as well. Discharge hydrographs for 1999, 2000, and 2001were also obtained from five USGS gages (Hickson, Fargo, Halstad, Drayton, and Emerson) on the Red and the nearest USGS gage on each of the five tributaries (Wild Rice at Abercrombie, Sheyenne at West Fargo, Goose at Hillsboro, Park at Grafton, Pembina at Niche). Each tributary sampled had at least one USGS gage located on it. However, some of these gages were located 30 kilometers upstream from the sample sites and so do not include runoff from the entire watershed.

Statistical Analyses

Towed vs. Drift Nets

For this analysis all species of fish were combined and a students T test was used to compare of drift-net samples taken from bridges with samples taken with the same net towed behind a boat.

Cross Channel Variation

Fish numbers were converted into fish densities (number of fish per 100 cubic meters) using data from flow meters to determine sample volume. This method was used to standardize samples because it was difficult to predict the amount of time needed to deploy nets to achieve a target sample volume. Variation at the three stations (mid stream surface, near-shore, and mid depth) across the river channel was examined for eight common species of fish including common carp *(Cyprinus carpio)*, *Ictiobus* / *Carpiodes* spp., white sucker *(Catostomus commersoni),* freshwater drum *(Aplodinotus gruniens,)* hiodontid spp., channel catfish *(Ictalurus punctatus)*, white bass *(Morone chrysops),* cyprinid spp., redhorse *(Moxostoma)* spp., and *Stizostedion* spp. Although these were the most abundant taxa, there were many samples where one or more of these taxa were absent. Such samples were excluded from the analysis for a species when none were captured during a sample date at a pair of sites. Even after all these samples were excluded, there were still many samples with zero densities. Because of this, along with unequal variances, normalizing the data was not possible; therefore, non-parametric statistics were necessary. The Kruskal-Wallace test, a nonparametric analog of a one-way ANOVA, was employed. Mann-Whitney U tests were used as a method of planned comparisons to test for differences between midstream surface stations and other stations (Day and Quinn, 1988). All sites, dates and years were included for the near-shore and midstream surface sampling stations. Because 1999 was the only year that the mid-depth net was deployed, this year was also analyzed separately using Kruskal-Wallace for all stations and a Mann-Whitney U test for planned comparisons between the shore and midstream surface nets. Fish densities at each site were correlated with current velocity for that site in an attempt to elucidate the effect of this variable on larval drift because current velocity generally increases the further with distance from shore.

Tributary Main-channel Red River Comparisons

To compare fish densities between tributary and Red River, the same methods were employed as described above for cross-channel variation. All sites and dates were combined. Only mid-stream and shore nets were used on the main stem of the Red River. A few dates were excluded on the Park River in 2000 because the Red River flooded on the main-stem and backed up several miles into the Park River, flooding the entire floodplain and making it impossible to differentiate between the Park and flooded Red River. A Kruskal-Wallace test was used to compare sites on the Red River with those on tributaries. Mann-Whitney U tests were performed to analyze differences between the tributaries and midstream surface nets. Differences between the five pairs of sites were also examined for each species using Kruskal-Wallace and Mann-Whitney U tests for unplanned multiple comparisons. Alpha was adjusted for experiment-wise error using the Dunn-Sidak method (Sokal and Rolf 1988).

Reproductive Timing in Common Species

It was hypothesized that most fish species in the Red River could be placed in two categories. Fish that use temperature as a synchronizing cue to trigger spawning, spawn soon after the water temperature reaches a minimum critical temperature. On the other hand, some fish, especially phytophils that spawn on aquatic vegetation would use water depth or discharge as a synchronizing cue and spawn at peaks in discharge. To test this hypothesis, a simple model using the reported threshold temperatures of carp, white sucker, freshwater drum and *Stizostedion* spp. was employed. Using USGS continuous water temperature data in conjunction with published values of threshold temperatures, predictions of spawning times were made (Auer 1982, Hamel et al 1997, Swedburg and Walburg 1970, Swee and McCrimmon 1966). These predictions were compared to observed distribution of larval drift. Densities of white sucker, freshwater drum, and Stizostedion species were also compared with the temperature data obtained from the USGS water temperature monitors to determine if water temperature and larval fish drift were related. Alternatively, larval densities were compared with USGS discharge hydrographs. The date when the first 5% of the larvae were procured for a species was used as an indicator to determine the beginning of the spawning season; although actual spawning took place a short time prior. These dates were compared between years. Peak densities of larvae were also considered. Drift densities were examined graphically both by site and combined to detect patterns and differences among years.

Carp Reproductive Timing

Better comparisons between the environmental conditions (i.e. temperature and discharge) and the intensity of spawning could be made if the date of fertilization and oviposition for each individual larva captured could be estimated to generate a frequency distribution. This distribution should reflect the dates that spawning took place and the intensity of spawning (Nesler 1988). Using available data not available for other species, a procedure was developed to estimate these dates for carp larvae captured during this study.

Fertilization dates for carp larvae (the date that a particular fish was fertilized) were determined by assigning stages to each individual captured using a key provided by Verma (1970). It can probably be assumed that fertilization took place immediately after oviposition. The fertilization date of each individual carp larva was estimated using a method similar to Nesler (1988) by back-calculating from the capture date, using the descriptions of lengths and morphological characteristics by age to first estimate hatch dates. From these hatch dates, fertilization dates were back-calculated by subtracting incubation times (in days) obtained from a day model where 67 degree days were assumed to be required for carp eggs to hatch. The 67 degree days estimated to be necessary for development was an average taken from several sources (Swee and McCrimmon 1966, Verma, 1970, Auer 1982). The degree day model was used to describe the relationship between developmental rate and temperature because it is easy to calculate and is shown to provide similar precision to other more complex models such as the thermodynamic or power law (Hamel et al 1997).

Hatch date = Capture date – Age at stage

Fertilization date = Hatch date – Incubation time

A fertilization date distribution was generated for carp for all three years. The spawning date distributions for 1999 and 2000 were compared using a Mann-Whitney U test. An average spawning temperature was determined for the individual larvae for both years as average daily mean temperature (from nearest USGS temperature monitoring station) on each fertilization date. These temperatures were compared using a Mann-Whitney test. Carp fertilization dates were correlated (Pearson Product Moment Correlation; fertilization dates were ln transformed) with a daily percent of average discharge (20 year average 1980-2000; used to standardize discharge for all sites) for each USGS gauging site nearest to the sampling site. Samples with no carp were excluded from this analysis. Dates on the tributaries collected when water levels rose because of backed-up water from the flooded Red River were excluded as well because the discharge rate measured at the upstream USGS gauging station did not reflect the depth of water on the river at the sampling site. Fertilization dates (ln transformed) were also correlated with the change in discharge (standardized as a percent of a 20-year mean).

CHAPTER THREE: RESULTS

Environmental Conditions

Eastern North Dakota received above average precipitation in 1999, 2000, and 2001. There was widespread flooding in the Red River Valley for periods in all three years during which this study was conducted, particularly along the stretch downstream from Grand Forks (Figure 5). In 1999 and 2001 peak discharge occurred in late April, which is typical because of spring snowmelt and spring rains. In 2000 there was very little snowfall in the Red River Valley and the spring was relatively dry. All sites had low discharge rates with no peaks during this time. Smaller tributaries such as the Park and Goose Rivers had no measurable current. The Park River, which has the lowest average discharge of all five of the tributaries, had a depth of only 20 cm and negligible current velocity. Passage upstream from the Red River appeared to be blocked to all but the smallest individuals. Conductivity was measured at the unusually high level of 18.7 mS/cm and salinity was measured at 1.09% at the Park River site on June 6, 2000. This may have prevented successful reproduction in some species. The absence of fish collected in light traps at this site seemed to confirm inadequate conditions for reproduction in this stretch of river. Peak discharge occurred in June after heavy rains

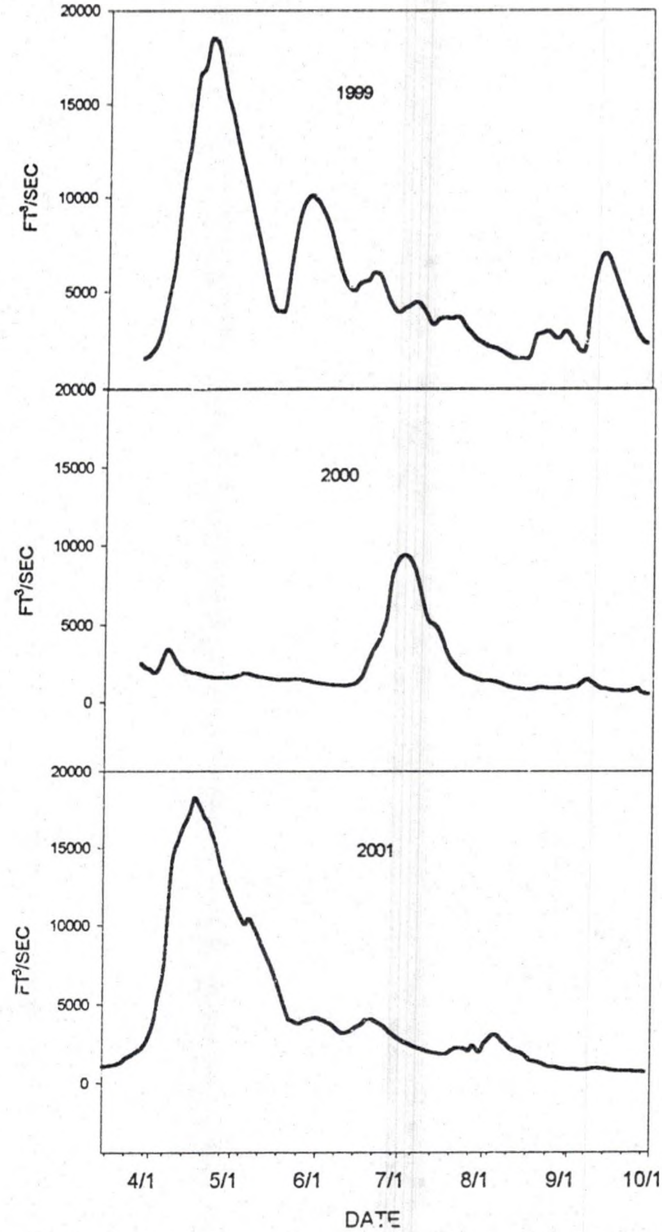


Figure 5. Average daily discharge rates for all United States Geological Service gaging stations located near sampling sites.

caused widespread overland flooding throughout the region, particularly in the Turtle and Sheyenne drainage basins. The river rose above flood stage at all sites north of Fargo North Dakota.

Water temperature did not vary by more than about two degrees Celsius among the three USGS stations with continuous water temperature monitoring. Average daily water temperatures were somewhat similar in 1999 and 2000 (Figure 6). The water in 2001 warmed at a slower rate until the end of April when temperatures increased rapidly. The accumulation of degree-days was also similar in 1999 and 2000 (Figure 7), with 2001 showing a slight delay.

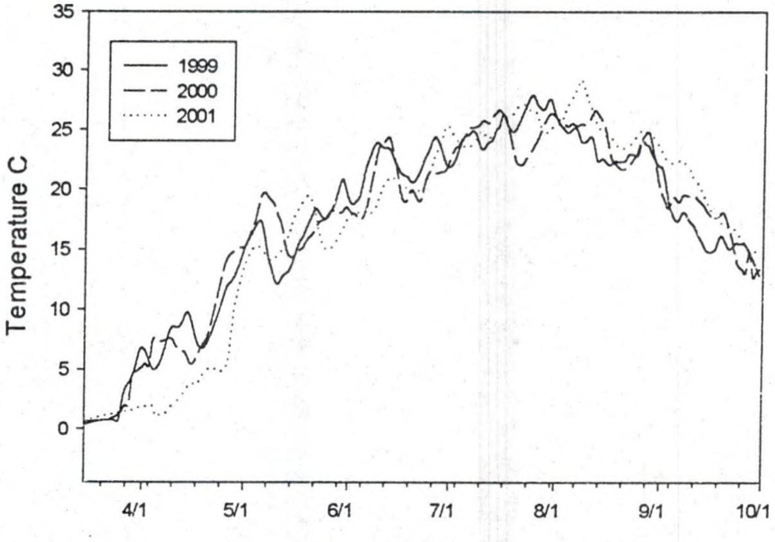


Figure 6. Average water temperatures at United States Geological Survey gaging stations over the period of study.

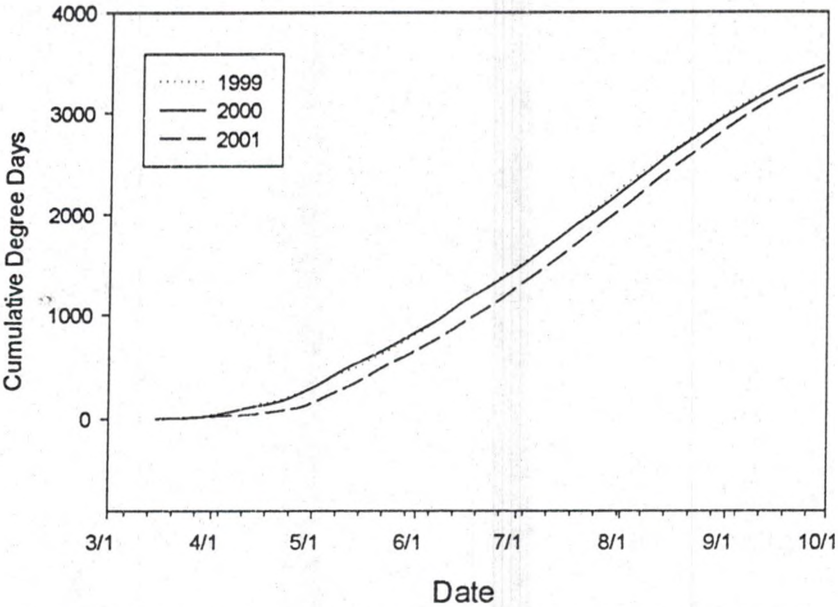


Figure 7. Cumulative degree days after ice-out based on average daily water temperatures at 3 USGS gaging stations on the Red and Sheyenne Rivers, 1999, 2000, and 2001.

Ichthyoplankton Collection

During 1999, 2000, 2001 a total of 11,184 individual fish larvae belonging to 10 families were captured in drift nets from the ten sites sampled in this study (Table 2). A total of 400 samples were collected and processed in 1999, 541 in 2000, and 160 samples in 2001. Taxa were identified to species when possible; however, a high degree of similarity and dramatic morphological changes through development made it impossible to identify all larvae to species. Among the cyprinids, only carp (which have distinct characteristics making identification possible) and some of the more-developed fathead minnows *(Pimepheles promelas)* and silver chubs *(Hybopsis storeiana)* could be identified to species. All cyprinids other than carp were lumped into one category (cyprinids) for analysis. Suckers (Catastomidae) are also difficult to identify to species. Three groups could be separated and identified. White suckers (*Catostomus commersoni*) could be identified to species; however, redhorse suckers could only be identified to genus *Moxostoma* and most *Carpiodes cyprinus*, *Ictiobus cyprinellus*, and *Ictiobus bubalus* were too similar to separate, so I lumped those into one category (*Ictiobus/Carpiodes*). Some of the more developed individuals in this category could be identified. Centrarchids were uncommon at all sites; most of the sunfish that were captured were probably *Lepomis gibosus*; however, these were lumped into one category (*Lepomis*). Both species of crappies are present in the Red River with black crappies (*Pomoxis nigromaculatus*) being more common. Crappies also were lumped by genus (*Pomoxis)*, as were *Hiodon* (goldeye and mooneye), *Stizostedion* (walleye and sauger), *Percina*, (logperch and blackside darter) and *Etheostoma* (johnny darter, Iowa darter*)*.

Carp larvae were classified into 8 categories or developmental stages (1, 2, 4, 7, 10, 15, 21 day old larvae, 1 month old larvae) using a key that examines length, fin development, yolk sack absorption and other morphological characteristics to age common carp developing at 20° Celsius (Verma, 1970). Seventy seven percent of carp captured in drift and towed nets were classified as 1, 2, or 4 day old larvae (Figure 8). These fish were classified as protolarvae because they have a portion of their yolk sack intact (Snyder 1976). By about the 4-day-old stage, much of the yolk sack is absorbed

Table 2. Species and number of fish captured in the Red River and tributaries by year

Family	Taxa	1999	2000	2001
Hiodontidae				
	Unidentified Hiodontids	9	22	44
Cyprinidae				
	Pimephales notatus	adults/juveniles only	adults/juveniles only	0
	Pimephales promelas	69	4	0
	Cyprinus carpio	2130	4142	316
	Hybopsis storeriana	0	2	0
	Notropis antherinoides	adults/juveniles only	adults/juveniles only	0
	Unidentified cyprinids	55	76	0
Catostomidae				
	Catostomus commersoni	181	39	226
	Ictiobus/Carpiodes spp.	339	777	383
	Moxostoma spp.	32	12	95
	Unidentified catostomids	0	0	7
Ictaluridae				
	Ictalurus punctatus	117	10	0
	Ameiurus spp.	5	0	0
	Noturus spp.	4	0	0
Gasterosteidae				
	Culea inconstans	1	1	0
Percopsidae				
	Percopsis omiscomyacus	0	1	3
Esocidae				
	Esox lucius	3	0	1
Percichthyidae				
	Morone chrysops	116	2	1
Centrarchidae				
	Pomoxis spp.	7	6	0
	Lepomis spp.	8	7	0
	unidentified centrarchids		1	1
Percidae				
	Etheostoma nigrum	5	0	0
	Percina spp.	8	3	0
	Stizostedion spp.	10	12	181
	Perca flavescens	0	adults/juveniles only	0
Sciaenidae				
	Aplodinotus grunniens	100	1838	0

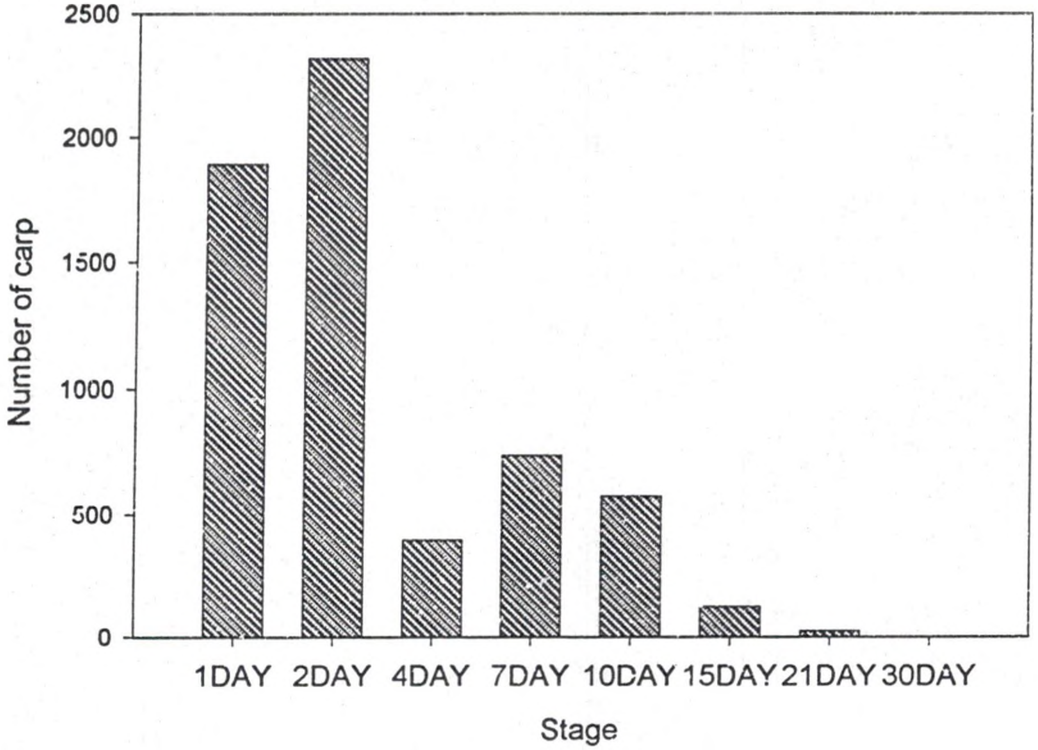


Figure 8. The number of carp larvae at each developmental stage as described by Verma (1970).

and endogenous feeding begins. There were relatively few fish (2.4% of total) in the 15-day-plus categories. Information to age other species of larval fish was not found.

Light Traps

A total of 104 individual fish were captured in light traps on the Red River and tributaries. Carp made up the majority of these (93 %). Other cyprinids, *Moxostoma* spp., and channel catfish were also captured using light traps. These devices were found to be effective in capturing larvae in clear streams (Floyd et al. 1984) and larger slow moving rivers (Turner et al. 1994). Waters of the Red River and its tributaries are highly turbid, often greater than 80 NTUs, perhaps making light traps less effective. The channels of these rivers are usually homogenous (i.e., morphology and current velocity), lacking the pools and riffles common in many streams, particularly those sampled by Floyd (1984). Very few larvae were captured in light traps when there was current flowing in the tributaries. Most were taken in the Sheyenne and Park Rivers when traps were set after the flooding incident in mid June. During this period, water levels rose to such a height on the main-stem of the Red River that water backed up in these tributaries flooding surrounding farmland and creating large areas with very little or no current. These flooded backwaters on the flood plain were the areas that I caught the majority of the carp with light traps, indicating that this species may be phototropic. Towed nets in these locations also produced some of the largest densities of carp compared to sites that had a faster current velocity.

Spatial Variability

Drift Net vs. Towed Net Comparisons

On July 19th, 347 larvae were captured at the Red River near Pembina North Dakota. Most of these larvae were carp, *Ictiobus/Carpiodes* spp., and freshwater drum. I conducted this study as the water level was receding after the mid June flood. In the eight drift samples 174 larvae were captured and 171 larvae were captured in the tow samples. With respective means of 21.3 and 22 larvae per sample for drift and tow samples, there wasn't a significant difference between samples taken with a drift net and samples taken with a towed net (T test: t=2.14, p= 0.864). Because there appeared to be little difference between drift and tow nets they were considered to be interchangeable. Differences between these two techniques were not, however, investigated at different current velocities. Lower current velocities could likely aid in larval fish's ability to avoid stationary plankton nets.

Diel Comparisons

We captured a total of 105 fish larvae during day, dusk and night comparison samples on the Pembina River and 47 larvae in the Wild Rice River. Larval fish densities were not different between day and night samples for either river. However, this may be the result of small sample size. Few fish were caught at the Wild Rice and Pembina River sites in 1999. Many studies have found significant differences in the diel distributions of fish larvae (De Graaf et. al. 1999, Brown and Coon 1994, Muth and Schmulback 1984, Pavlov et. al. 1978, Gale and Mohr 1978). Often, greater numbers of fish are found in the drift after dark and many species are believed to be nocturnal. However, larval fish studies examining the temporal variations in larval fish drift on relatively turbid waters do not tend to show this pattern (Pavlov et al 1978, Brown and Coon 1994, De Graaf et al 1999). The main stem of the Red and the downstream portions of the North Dakota tributaries are moderately to extremely turbid, perhaps accounting for a lack of diel differences and justifying my use of day sampling for much of the study.

Cross Channel Variation

Nine taxa were sufficiently abundant to compare cross-channel variation including: white sucker, *Moxostoma* spp. Hiodontids, *Ictiobus/Carpiodes* species, carp, other cyprinids, channel catfish, freshwater drum, and white bass (except for the 1999 comparison where *Stizostedion* spp. and hiodontids were excluded because of low numbers)(Table 3). Paired comparisons were made among near shore, mid-stream surface, and midstream mid-depth sampling stations in 1999, Cyprinid density was higher in the surface net compared to mid-depth (Z= -3.488, p< .001). More carp (Z= -2.018, p=.044) and white bass (Z=-1.984, p=.047) were found in the surface station compared to the mid-depth station; however, these differences were barely significant. Surprisingly, freshwater drum, which have larvae that contain an oil globule used for flotation, were not more abundant in the first half meter of the water column sampled by the surface net. Channel catfish larvae were more abundant in the midstream mid-depth samples compared to midstream surface samples (Z= -3.488; p < .001). There was no difference in density between the shore and mid-channel net for any of the 8 species of fish examined (Table 4).

Main Stem Red River Tributary Comparisons and Large-scale Spatial Variation

Four taxa (*Moxostoma*, Hiodontid, white bass, and *Stizostedion*) were significantly more abundant in the main stem of the Red River than in the North Dakota tributaries (Tables 5 and 6). Large densities of carp and freshwater drum were also captured in the static water of flooded tributaries, specifically the Park River, which was excluded from the analysis because of the possibility that the adults spawned in the main stem of the river and the larvae either drifted passively or swam into the static water of the flooded tributaries. When these samples were excluded, freshwater drum were also more abundant in the main channel sites than tributary sites (Z=-2.712, p= .009). There were differences between sites on the Red River (Figure 9). Sites north of Grand Forks appeared to be similar and the two sites near Fargo appeared to be similar in larval fish distribution. There were differences between tributary sites also, although no patterns were evident (Figure 10). Size of watershed, current velocity, riparian cover, and presence of low head dams may affect larval fish distributions in these rivers. Drift density at tributary and Red River sites were often similar for each sampling date (Figure 11).

Table 3. Paired cross-channel comparisons of fish densities (N/100m^3) using a Kruskal-Wallace test on collections made in 1999. * = significantly different at the .05 level. Different letters indicate significant differences. Numbers and densities in bold are significantly higher than those in regular type for a species.

	Kruskal Wallace (df=2)		Near Shore		Mid-stream Surface		Mid-stream Mid Depth	
	X^2	P	n	n/100m^3	n	n/100m^3	n	n/100m^3
Cyprinid*	12.44	.002	**48**	**.368a**	**37**	**.21a**	9	.064b
carp*	4.00	.135	**399**	**3.06a**	**515**	**2.9a**	97	.688b
Ictiobus / Carpiodes	1.04	.594	16	.123a	11	.062a	8	.057a
white sucker	.737	.692	42	.322a	44	.248a	20	.141a
Moxostoma	4.87	.087	19	.145a	8	.045a	2	.014a
channel catfish*	20.75	.000	15	.115a	11	.062a	**52b**	**.37b**
white bass*	4.28	.117	**26**	**.2a**	**55**	**.31a**	10	.071b
freshwater drum	.080	.961	28	.215a	36	.203a	34	.241a

Table 4. Cross channel variation. Fish numbers and density at near-shore and mid-channel surface stations, 1999, 2000, 2001. † = marginally significant

	Mann-Whitney		Mid-Channel Surface		Shore	
	Z	p	n	n/100 m^3	n	n/100 m^3
Hidontid	-1.335	.182	27	.053	33	.096
Cyprinid	-.927	.354	55	.143	17	.064
carp	-1.123	.263	1829	3.6	550	1.6
Ictiobus / Carpiodes	-.439	.661	276	.543	239	.471
white sucker†	-1.906	.057	142	.28	159	.463
Moxostoma spp.	-.723	.469	82	.118	39	.093
channel catfish	-.677	.498	11	.029	55	.209
white bass	-.870	.384	55	.143	10	.028
Stizostedion	-1.089	.276	65	.128	91	.265
freshwater drum	-.796	.437	67	.132	53	.241

Table 5. Density of fish (N / 100m^3) in main stem versus tributary, 1999, 2000, and 2001. Sampling halted on May 31 in 2001. * = significant at 0.05 Densities in bold lettering are significantly higher.

	Total Main channei	Total Tributary	Mann-Whitney U test		
	N/100M^3	N/100M^3	N	Z	p
Hiodontid*	**0.05**	0.008	**56**	**3.78**	**.000**
Cyprinid	0.099	.201	114	.99	.324
carp	3.07	5.39	135	-.478	.633
Ictiobus /Carpiodes spp.	0.546	1.31	104	-1.33	.183
white sucker	0.279	0.221	92	-.48	.607
Moxostoma	**0.106**	0.023	**51**	**-2.25**	**.025**
channel catfish	0.085	0.095	50	-.316	.752
white bass*	**0.093**	0.057	**47**	**-2.25**	**.024**
Stizostedion spp. *	**0.138**	0.076	**44**	**-3.13**	**.002**
freshwater drum	0.185	3.54	35	-1.72	.086

Table 6. Number of fish and density comparison between tributaries and the main channel of the Red River for all years

	Main Channel 99		Tributary 99		Main Channel 00		Tributary 00		Main Channel 01		Tributary 01		Total	
	n	n/100m^3	n	n/100m^3	n	n/100m^3	n	n/100m^3	n	n/100m^3	n	n/100m^3	n	n/100m^3
Hiodontid	8	.017	1	.006	19	.036	3	.01	44	.216	0	0	75	.044
Cyprinid	63	.141	54	.305	34	.064	41	.141	0	0	0	0	192	.11
carp	1007	2.25	1119	6.33	2349	4.41	1711	5.90	284	1.39	32	.61	6502	3.82
Iciobus/Carpiodes	35	.078	304	1.72	359	.674	254	.877	252	1.23	131	2.5	1425	.837
white sucker	106	.237	75	.424	18	.034	21	.072	206	1.01	20	.381	446	.26
Moxostoma spp.	29	.065	3	.017	5	.009	7	.024	92	.452	3	.057	139	.082
channel catfish	79	.177	39	.221	4	.007	6	.021	0	0	0	0	128	.075
white bass	91	.203	25	.141	0	0	2	.006	0	0	0	0	118	.069
centrarchid	13	.026	2	.141	11	.021	1	.003	0	0	0	0	27	.015
Stizostedion spp.	4	.009	6	.034	12	.022	0	0	147	.723	34	.648	203	.119
freshwater drum	98	.219	2	.011	83	.156	1668	5.76	0	0	0	0	1851	1.08

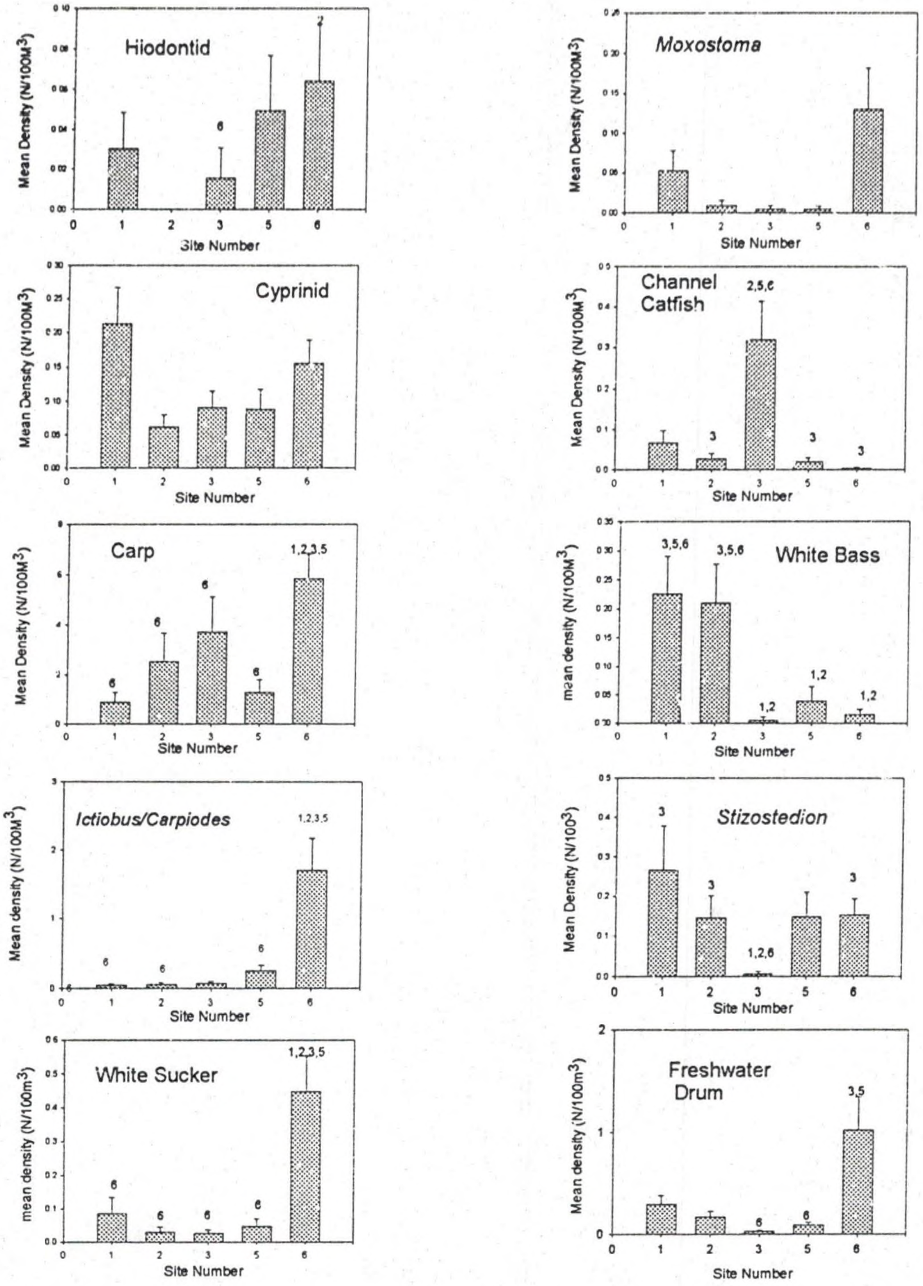


Figure 9. Comparisons of fish density between sites (1-6 in a south to north direction, excluding 4) on the Red River. Error bars = 1 standard error. Numbers above bars represent sites that are significantly different.

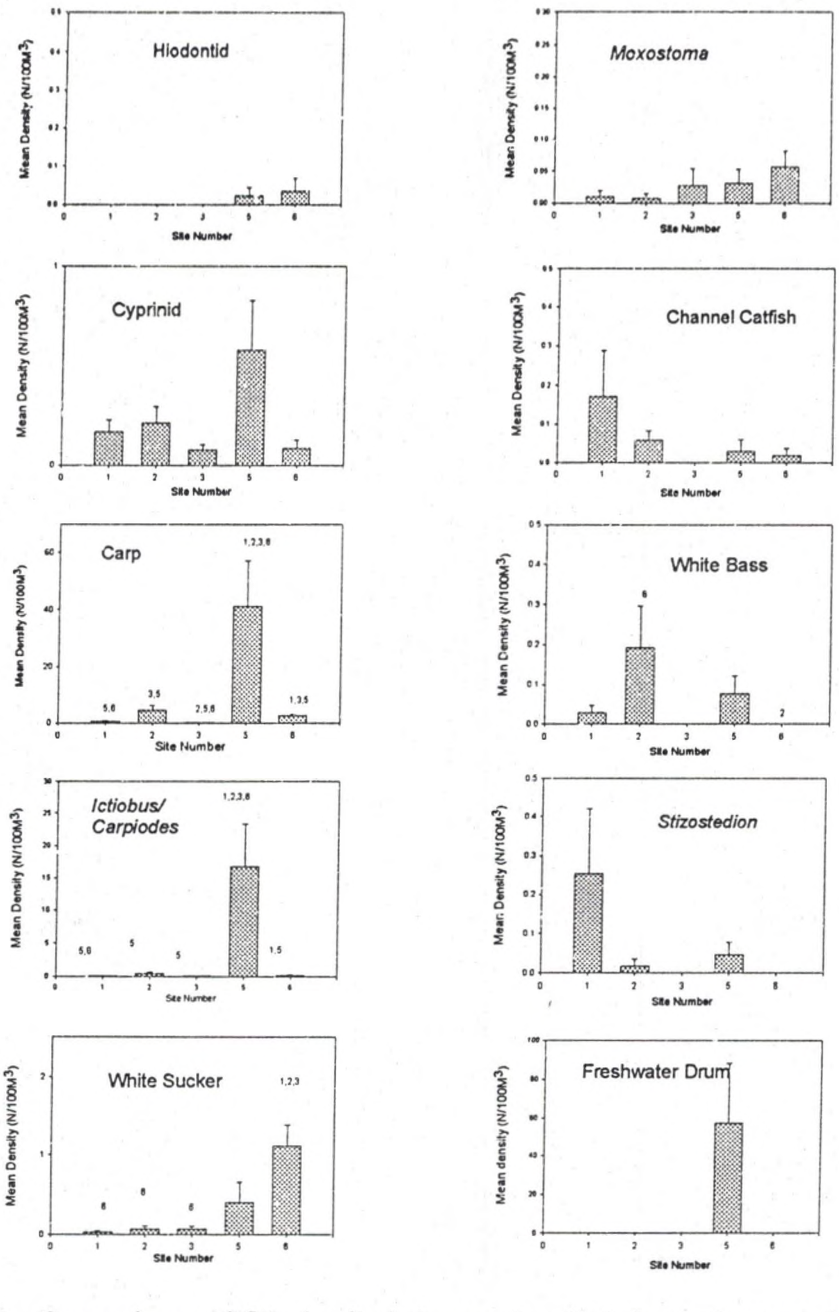


Figure 10. Comparisons of fish density between sites (1-6, in north to south direction excluding 4) on the tributaries. Error bars = 1 standard error. Numbers above bars represent sites that are significantly different.

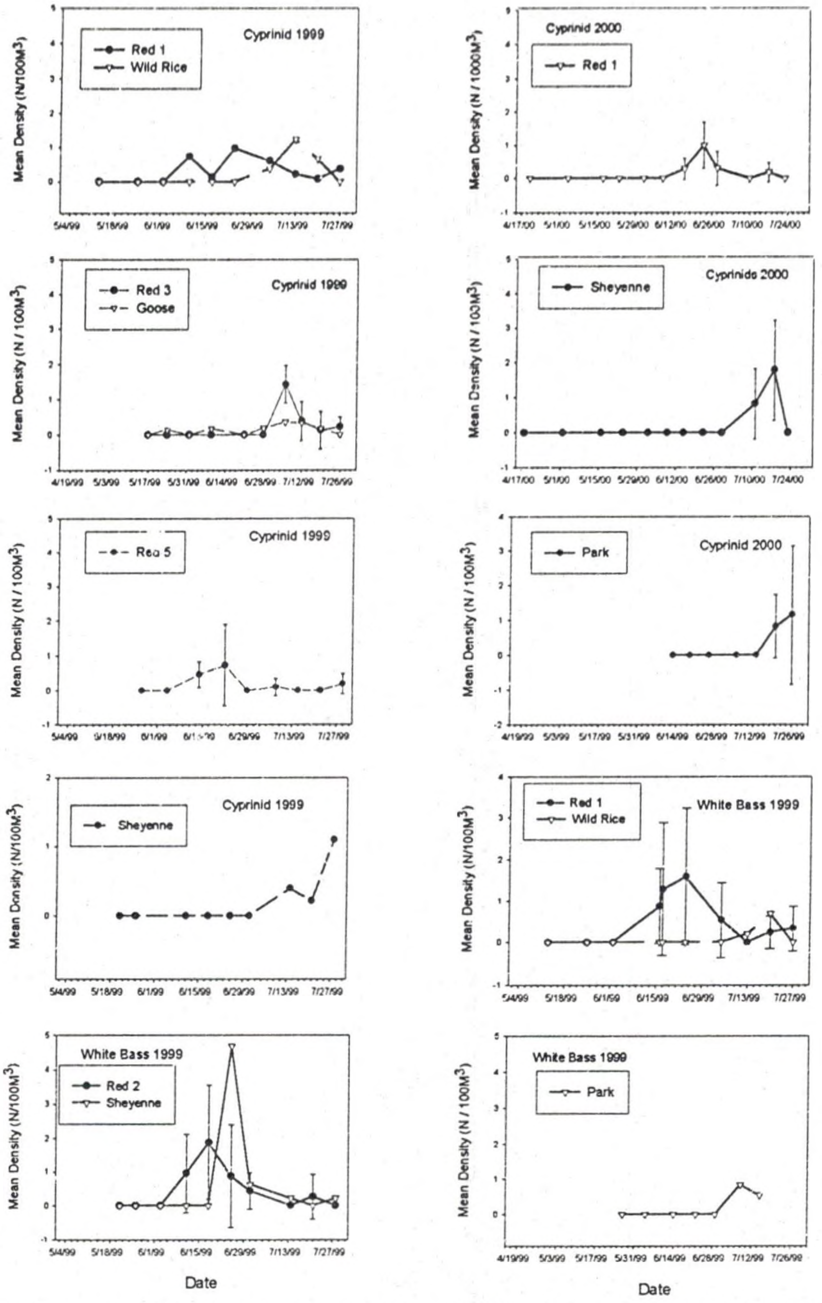
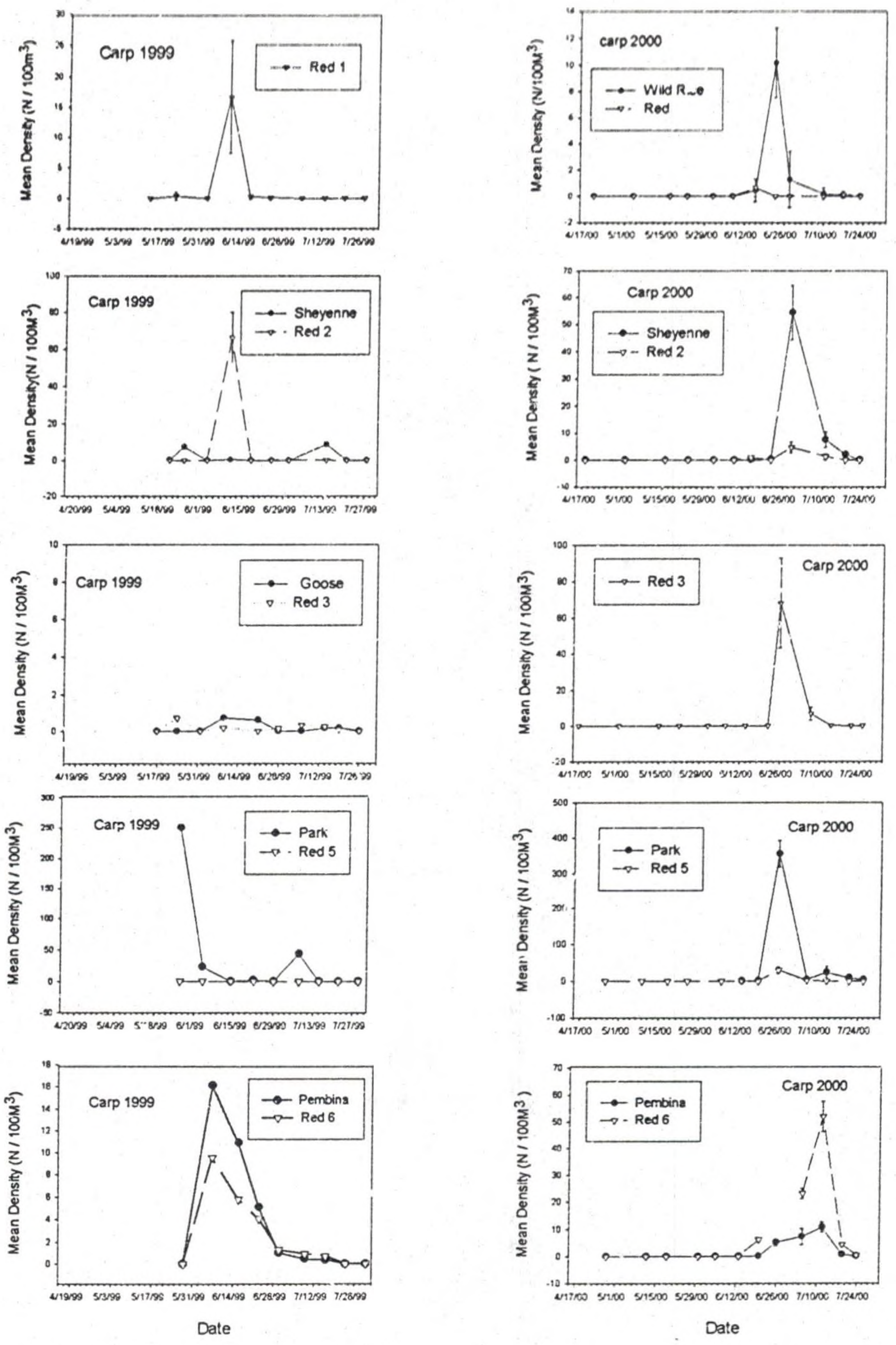


Figure 11. Tributary vs. Red River at each confluence; densities for carp, *Ictiobus / Carpiodes* spp., white sucker, *Moxostoma* spp., *Stizostedion* spp., freshwater drum, white bass, channel catfish, cyprinids and hiodontids for 1999 and 2000. 2001 densities for early spawning fish (*Stizostedion* and white sucker). Error bars = 1 standard deviation, (shown only at sites with at least 4 samples). Sites with densities less than 0.5 fish / 100m^3 for a season were excluded from graphs.



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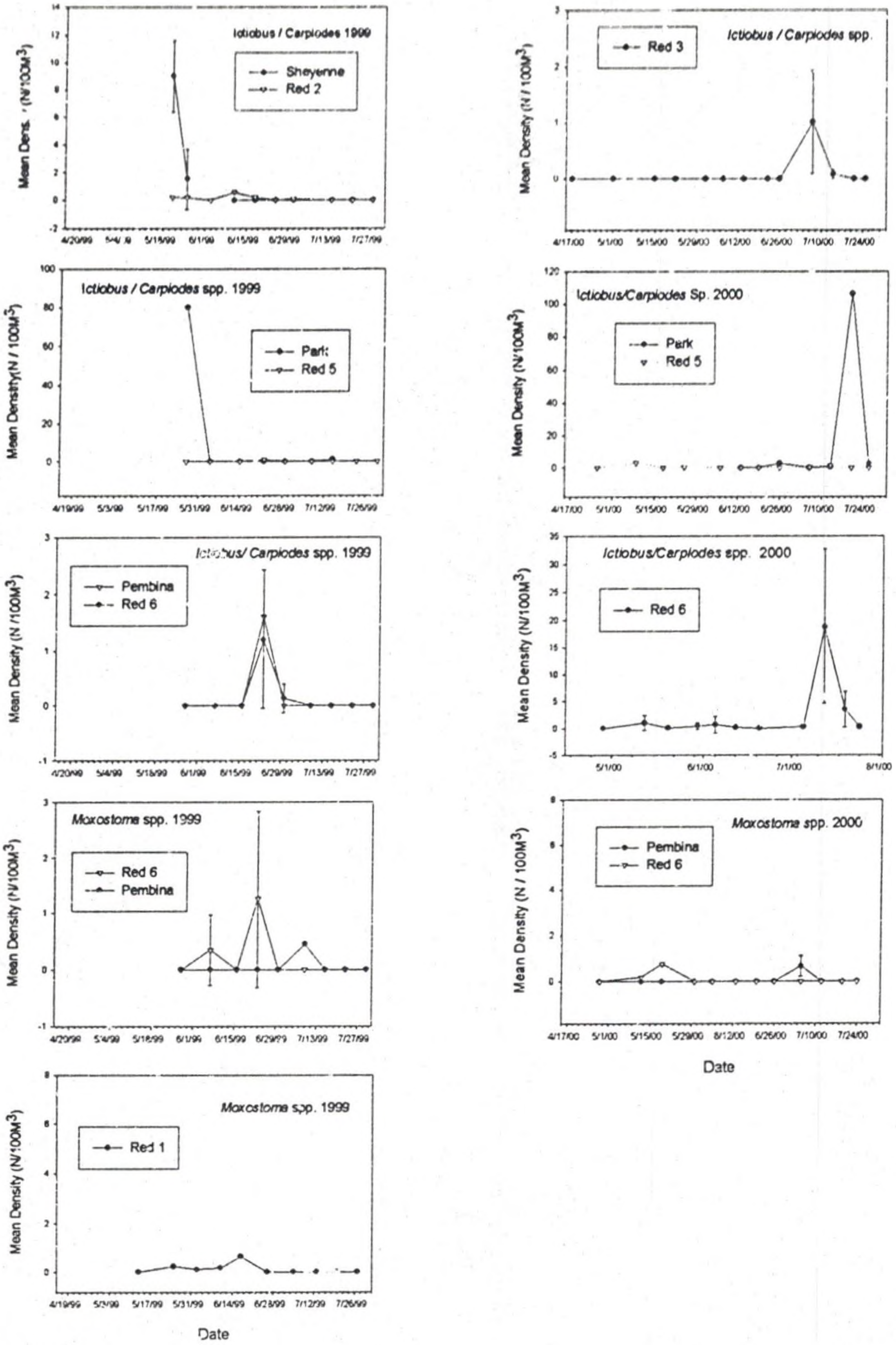

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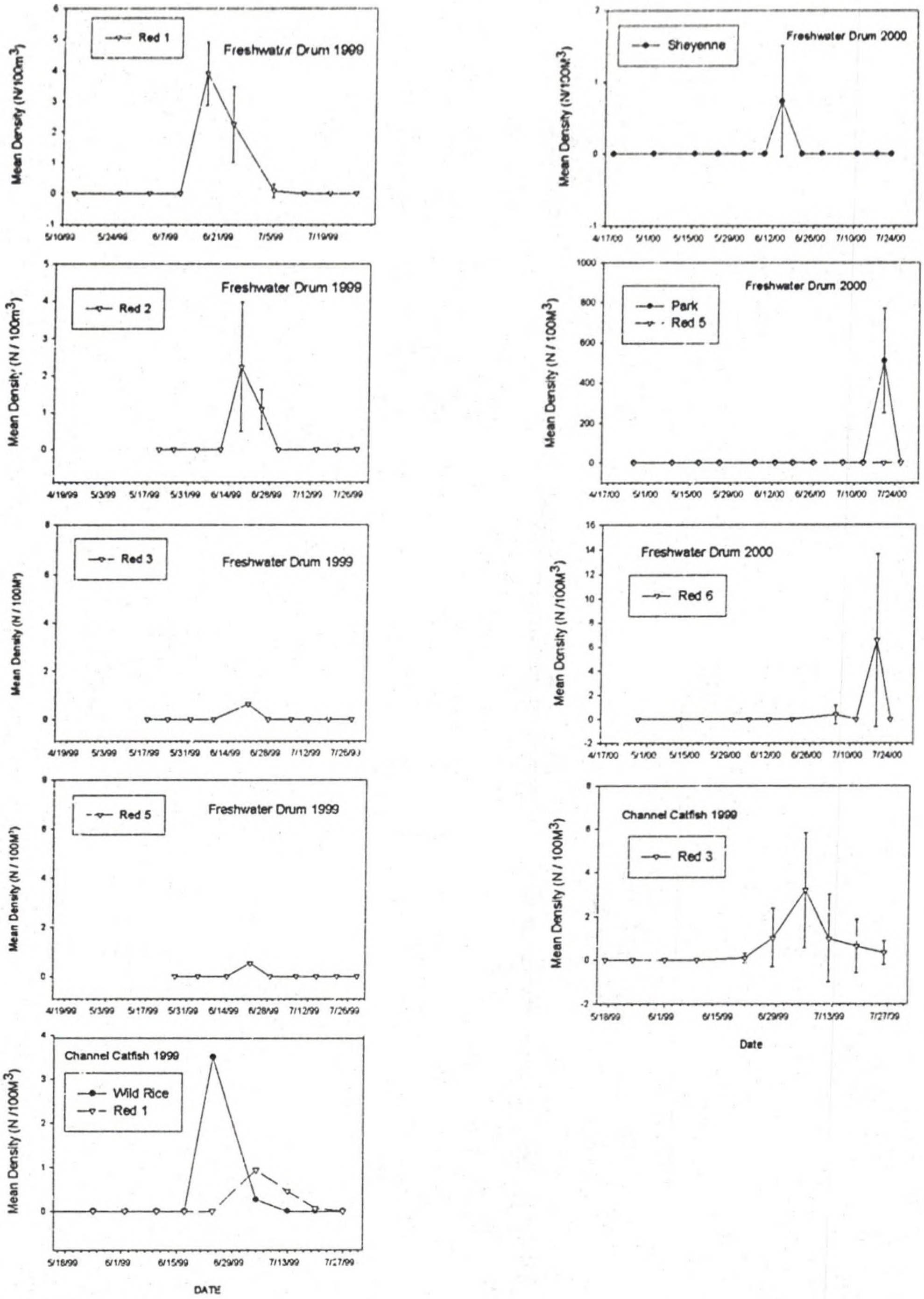

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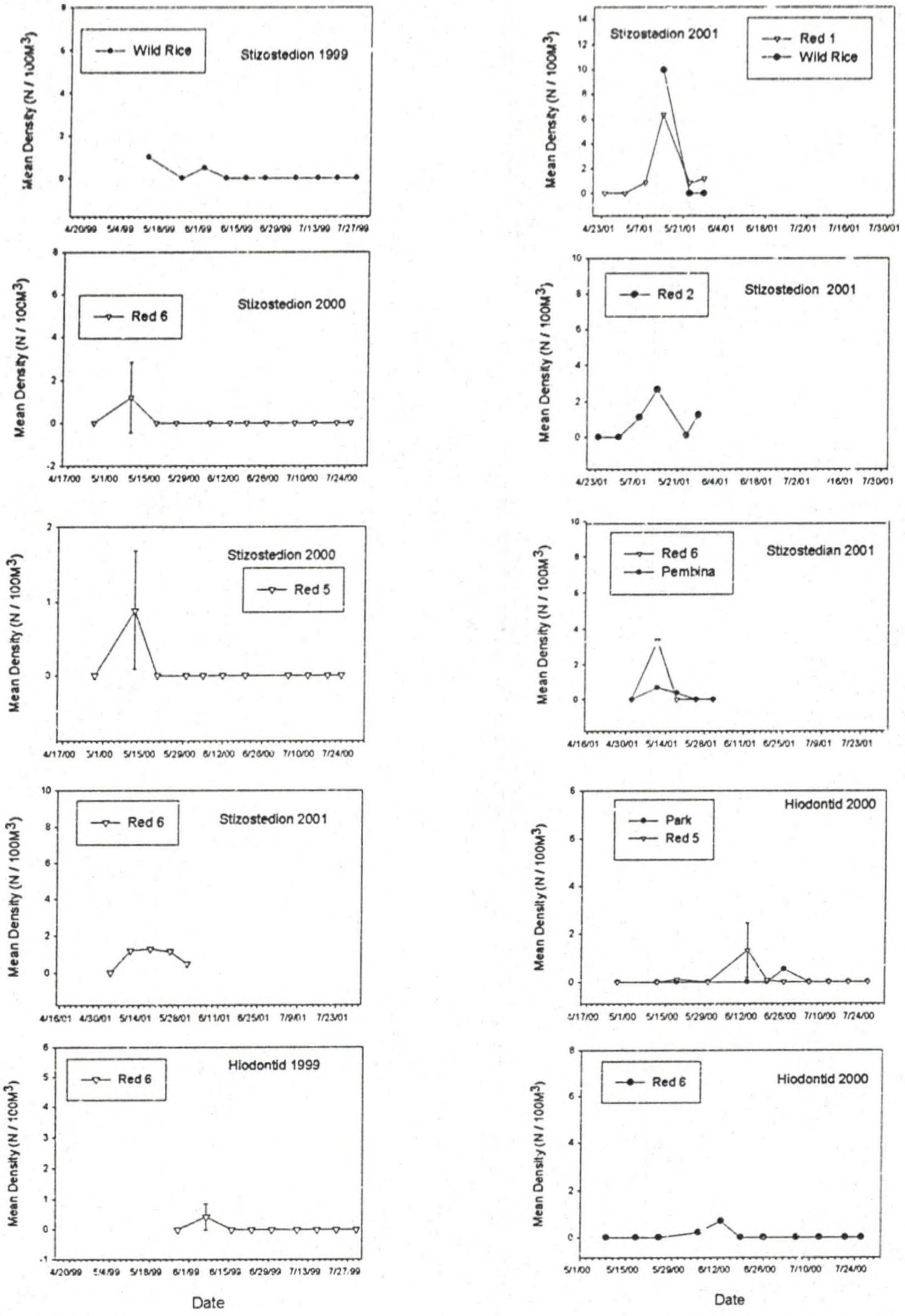

Figure 11. cont.

Reproductive Seasonality

Common Species (White Sucker, Freshwater Drum, *Stizostedion* spp).

White sucker, freshwater drum, and *Stizostedion* spp. (walleye and sauger) densities were examined to detect patterns in reproductive timing. Spawning dates were not back calculated for these species because information on developmental rates after hatching necessary to age larvae could not be found. White sucker and *Stizostedion* spawning was predicted to be triggered to spawn by temperature rather than by discharge because they require gravel or rock substrate to spawn over. Freshwater drum spawn near the water surface and reproduction by this species was hypothesized to be affected by discharge because larvae are buoyant and more subject to displacement.

White sucker density tended to be dispersed over a number of weeks in 1999 – 2000 (Figure 14, 15). White Suckers were captured in the drift between May 4 and July 15th. The entire white sucker spawning season may have only been sampled in entirety during 2000. Although they were not measured, it appeared that many individuals were larger in size and at a more advanced developmental stage than other species of fish such as carp and freshwater drum. Peak larval drift occurred towards the end of their spawning season in 1999 and 2000 (Table 7). The first 5 % of fish captured in all three years were caught during the second and third weeks of May.

Freshwater drum are one of the only pelagic spawning fishes found in the Red River Basin. Drum spawning was predicted to be more associated with discharge because they are reported to spawn at a range of temperatures between 18 and 25 degrees, much like carp (Auer 1982). The first drum appeared in the drift on June 11 in 1999 and on June 13 in 2000 (Figures 16, 17). Freshwater drum were not captured in 2001 because sampling halted after June 1st(just before the project termination date), before the date that drum began spawning in 1999 and 2000. Peak density in 1999 occurred about a week after the first larval drum was captured in the drift (Table 7). In 2000, peak density occurred about a month after the first larvae were captured. A substantial average density of 510.54 fish/100M^3 was taken in towed samples (N=4) from the flooded Park River (large areas of the floodplain were inundated by water backed up from the Red River) less that 1 km upstream from confluence on July 20, 2000. Freshwater drum were captured at this site the week prior and the week after suggesting that flooded tributaries may provide good nursery habitat for juvenile drum.

Stizostedion species were found in the drift during the same time each year 1999, 2000, and 2001 (Figures 18 and 19). Although few walleye and sauger larvae were captured during the 1999, 2000 seasons (10 and 12 respectively), they were captured during the same time, and were mostly prolarvae that had recently hatched (Table 7). In 2001, 203 *Stizostedion* larvae were taken in samples, indicating that this may have been a better year for walleye and or sauger reproduction compared to 1999 and 2000. *Stizostedion* were captured for the first time during the second week of May in 1999, 2000, and 2001. Peak drift dates occurred on June 2nd in 1999, much later than in 2000 and 2001, where peak drift occurred around the middle of May. However, with such low numbers of *Stizostedion* spp., where peak drift only involved 1 fish, it was hard to identify this as the peak drift time for walleyes and saugers. Peak drift occurred in 2001 on May 14th in the Wild Rice River with 31 individuals captured.

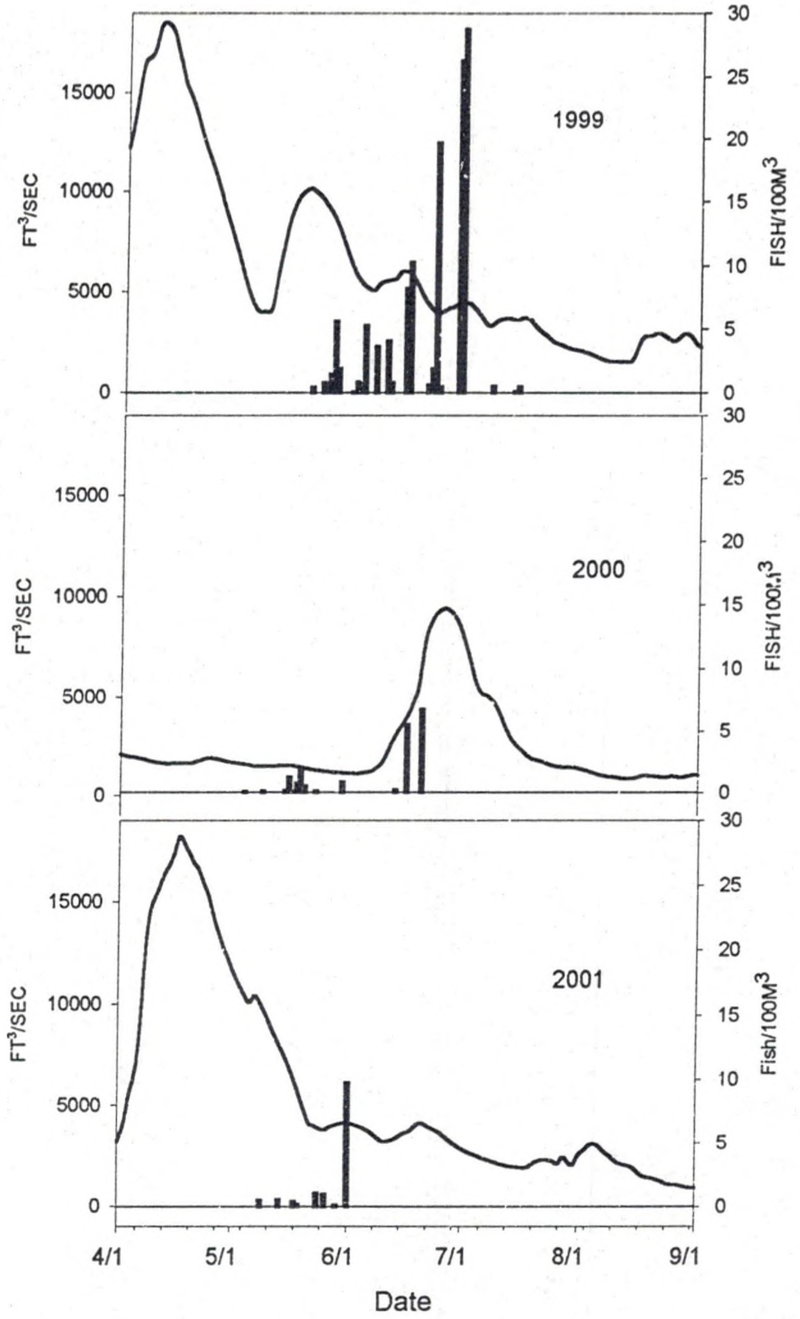

Figure 12. White sucker drift density (bars) and daily average discharge (line) for 1999, 2000, and 2001 for all sites combined.

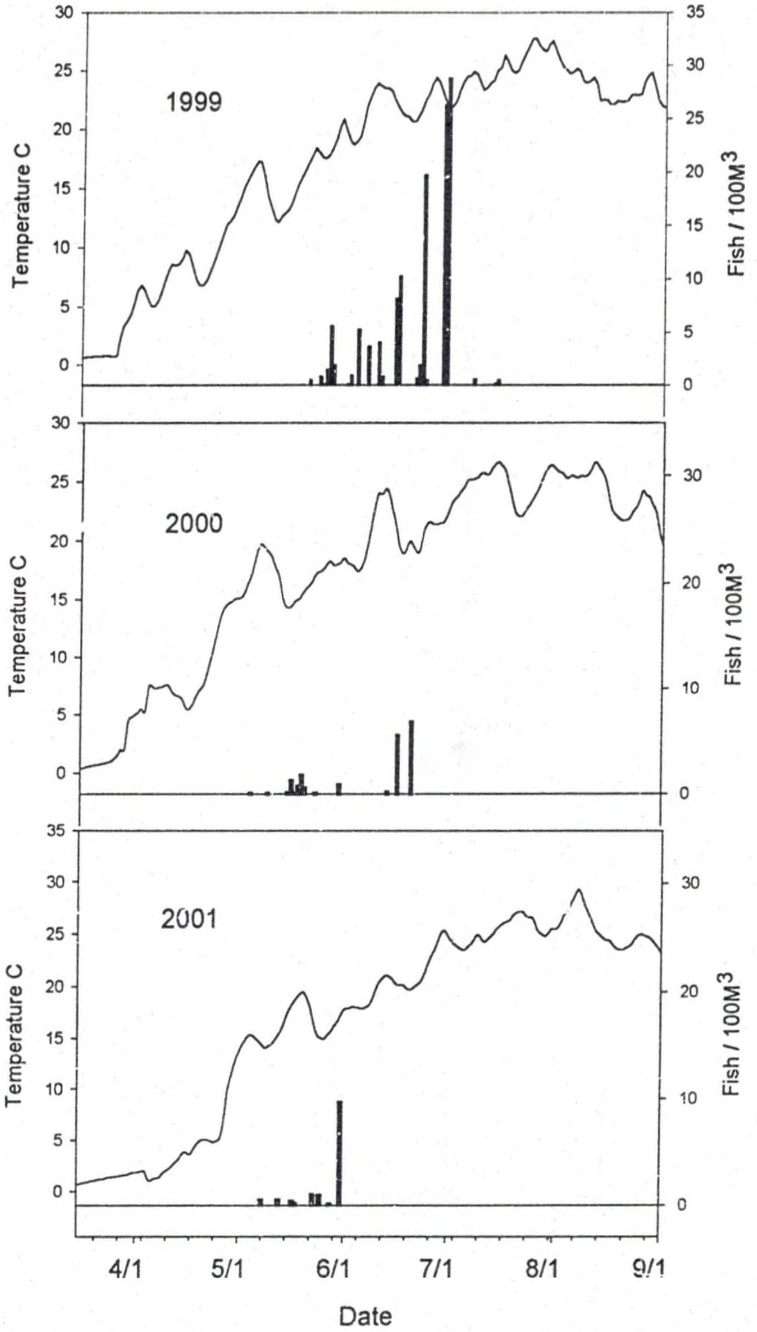

Figure 13. White sucker drift density (bars) and daily average water temperature (line) for 1999, 2000, and 2001 for all sites combined.

Common Carp

Common Carp were the most abundant fish captured in the drift of the Red River and lower reaches of most of the tributaries sampled. Carp spawned roughly four weeks later in the year in 2000 than in 1999 and 2001. The estimated fertilization date distribution was significantly different in 2000 than in 1999 (Mann Whitney U test; Z= -.808, p < .001)(Figure 20). The first 5% of carp captured in 1999 were oviposited on or before 5/22/99 (Table 7). In 2000, carp were not captured in the drift until the second week of June and first fertilization date was June 9th. The first 5% of carp captured in 2000 spawned on 6/21/00. In 2001 sampling ceased on June 1st probably well before the end of the spawning season, because carp were not the targeted species. However, a large number of carp (317) were captured between May 14th and May 31st, indicating that a significant number of carp were spawning during that time. In 1999, the carp fertilization date distribution was longer and there appeared to be a smaller second peak occurring in early June. Carp were found in the drift between May 21st and July 30th when sampling ended. Fertilization dates range between 5/15 and 7/09. In 2000 the carp spawning date distribution appeared to exhibit more of a normal distribution.

Mean carp spawning temperatures in 2000 (20.31) were only slightly higher than in 1999 (19.97) when carp spawned more than four weeks earlier (Figure 21). This small difference was, however, statistically significant (Mann Whitney U test; Z= -19.719, p<.001), but is probably coincidental rather than causal. At the continuous water temperature gages on the Red River in Fargo and the Sheyenne River in Horace North Dakota, water temperatures rose above 20 degrees C in the beginning of May (6th and 7th)

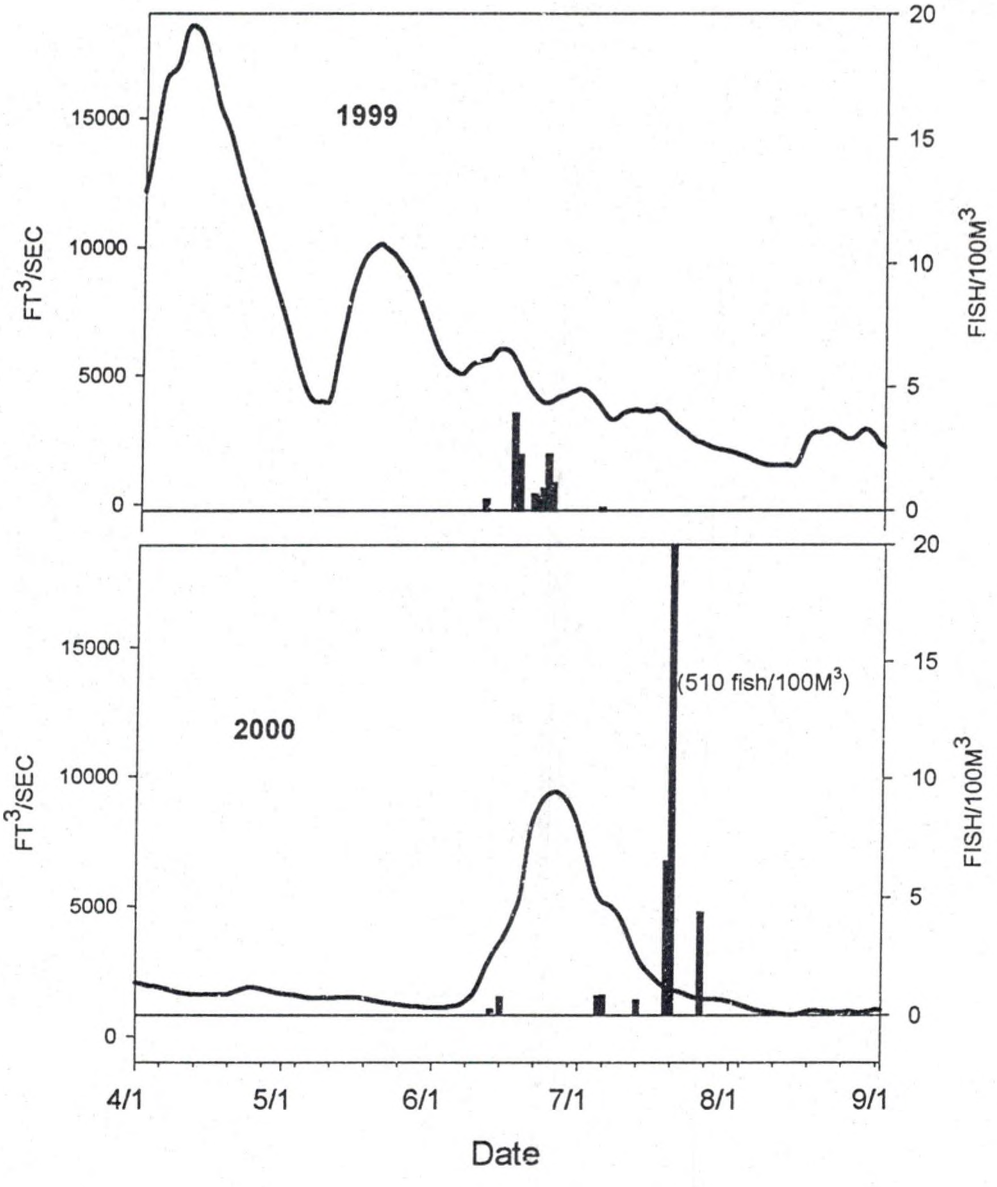

Figure 14. Freshwater drum drift density (bars) and discharge rate (line) for 1999 and 2000 all sites combined.

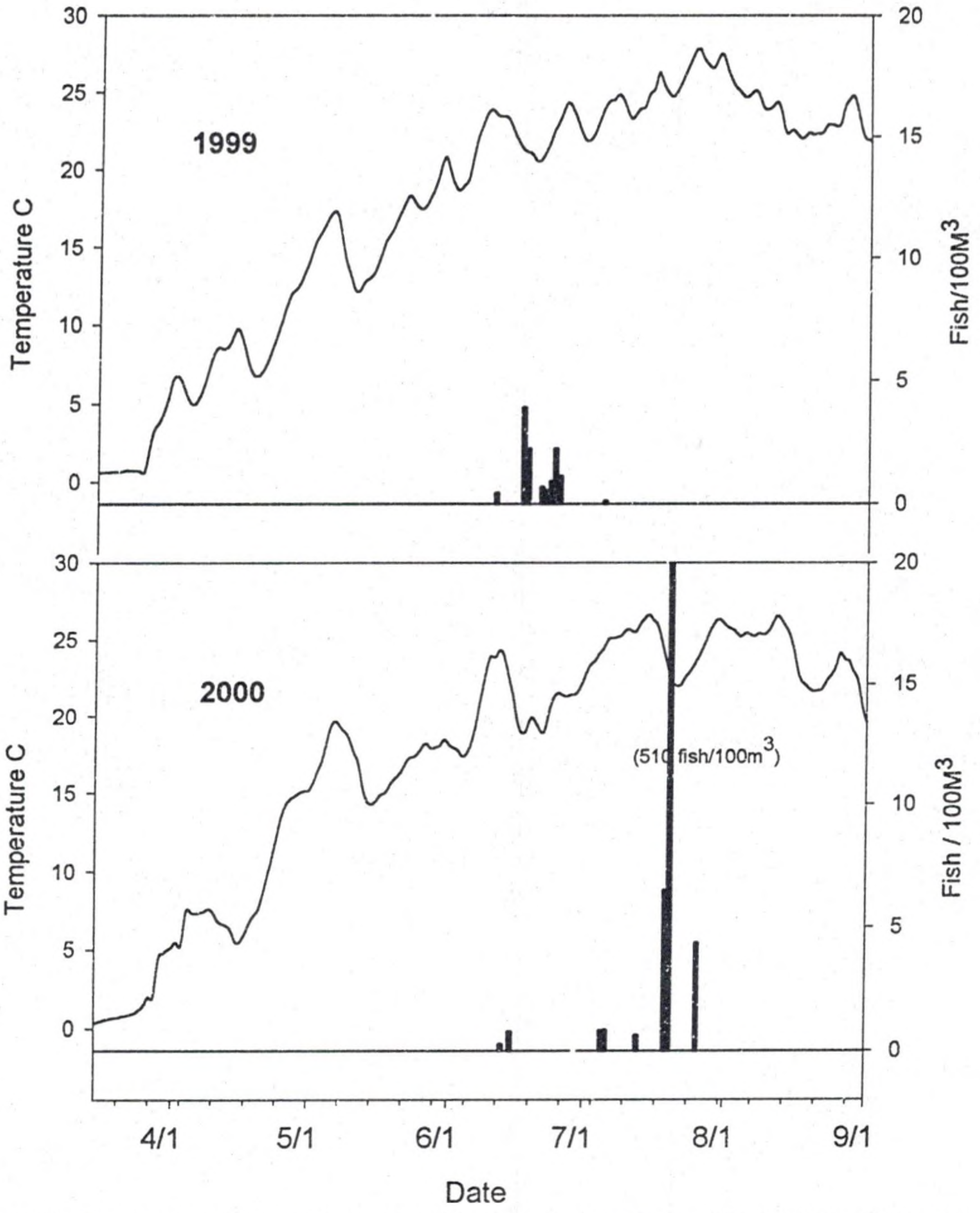

Figure 15. Freshwater drum drift density (Bars) and temperature (line) 1999, 2000, and 2001 for all sites combined.

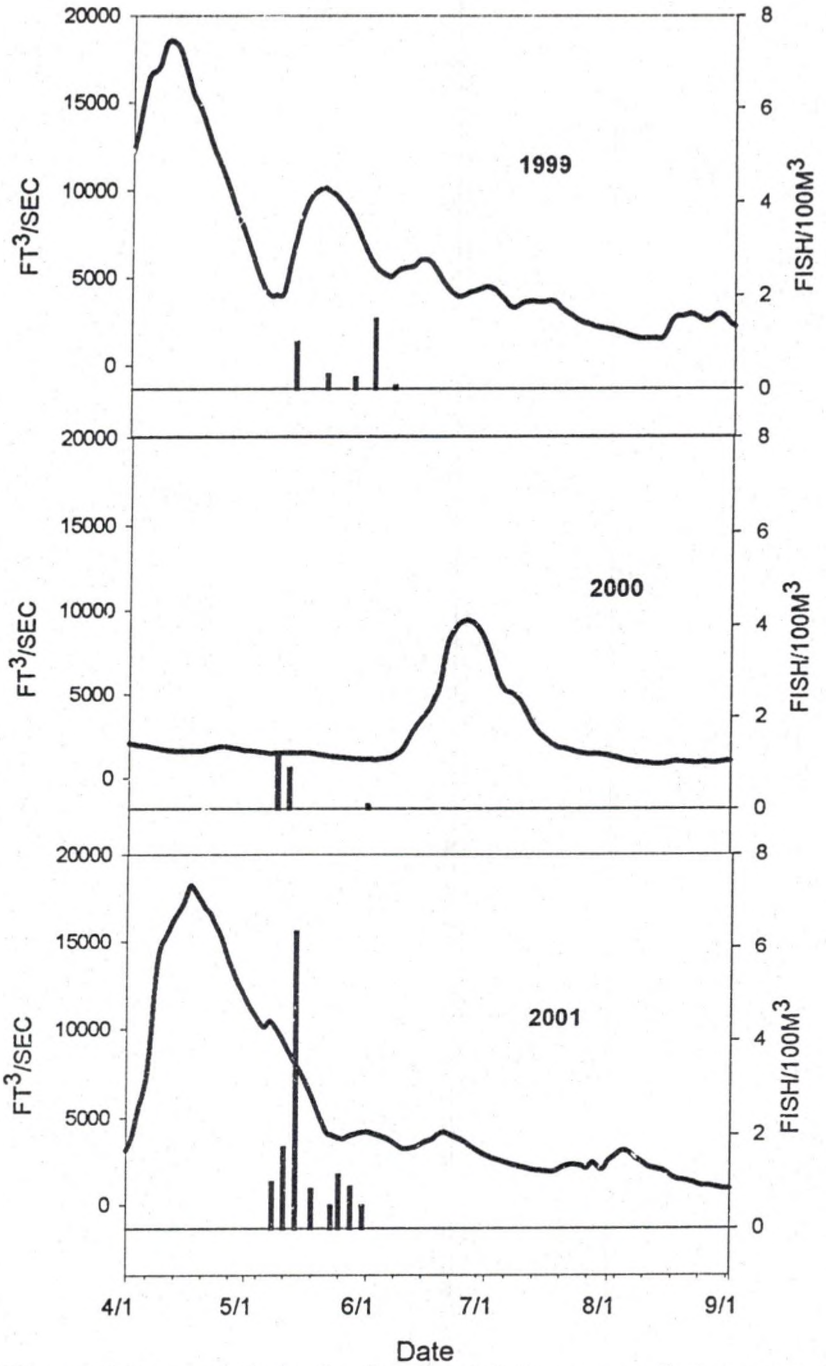

Figure 16. Stizostedion spp. drift density (bars) and daily average discharge rate for 1999, 2000, and 2001 for all sites combined.

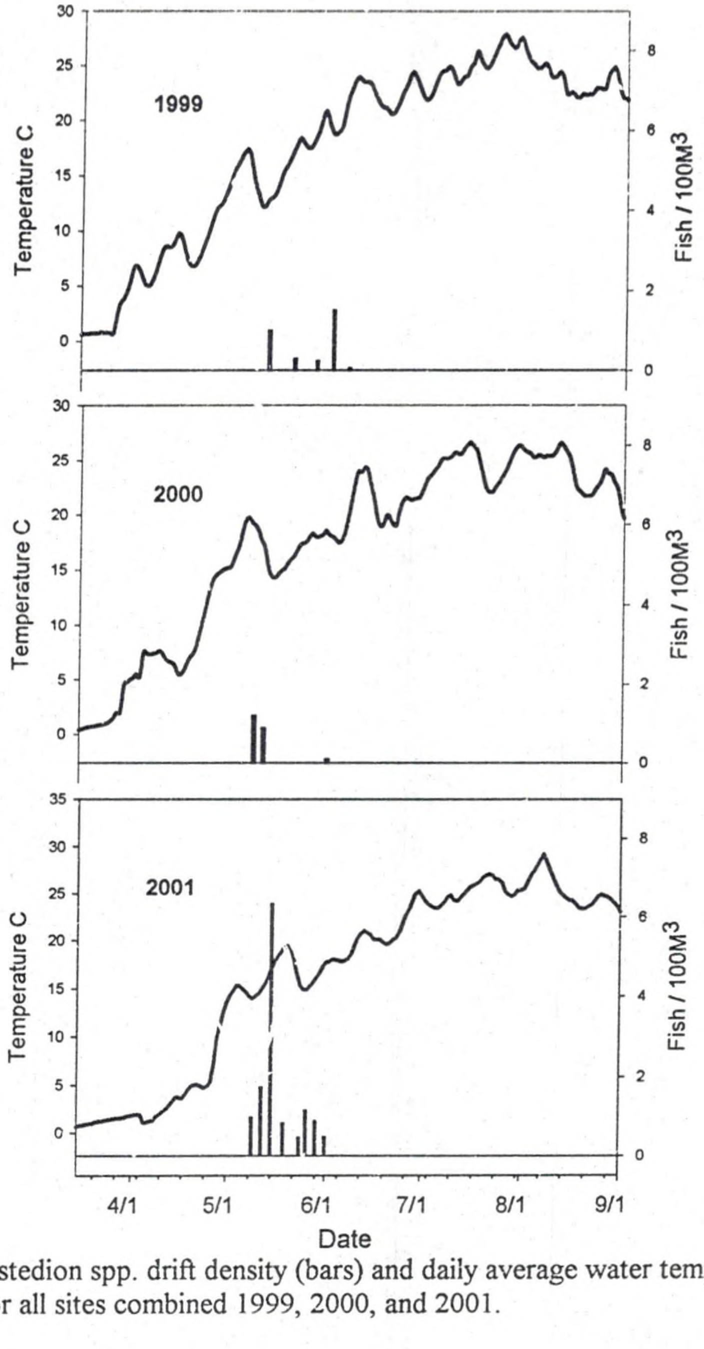

Figure 17. Stizostedion spp. drift density (bars) and daily average water temperature (lines) for all sites combined 1999, 2000, and 2001.

in 2000, which is close to the mean spawning temperature for carp for both 1999 and 2000 seasons. Peak (mode) spawning date in 2000 was on June 21st, nearly 7 weeks later. In 1999 daily mean temperatures reach 20 degrees on May 31st at all three USGS temperature sensors days after the peak (mode) spawning date (May 22) for the captured carp larvae. Spawning temperatures for carp ranged between 14.63 and 25.33 during the three years of this study. Although 14.63 seems too low for active carp spawning, higher water temperatures could probably be found in shallow flood plain areas that were exposed to sunlight. Water temperatures that carp spawn at have been reported to range between 15 and 25 degrees Celsius with an optimum between 18 and 23 degrees, which are close to the temperatures observed in this study. (Auer 1982, Swee and McCrimmon, 1966).

The derived carp fertilization dates seemed to be associated more with discharge rates than with water temperature in the Red River (Figure 22). In 2000, carp fertilization dates appeared to coincide with increasing discharge after heavy rainfall in mid June. When density of carp spawned on a date was compared with the percent discharge of the 20 year mean, there was a marginally significant correlation in 2000 (R_p= .340, p = .053). There was no correlation in 1999 (R_p = -.032, p = .851). Carp fertilization date densities were correlated with the percent increase in discharge in 2000 (R_p =.567, p =.001, Figure 21). In 1999, they were not correlated with increasing discharge (R_p = .090, p= .598), probably because water levels were high and falling at some sites when the minimum critical spawning temperature for carp was reached. Sites upstream from Fargo, North

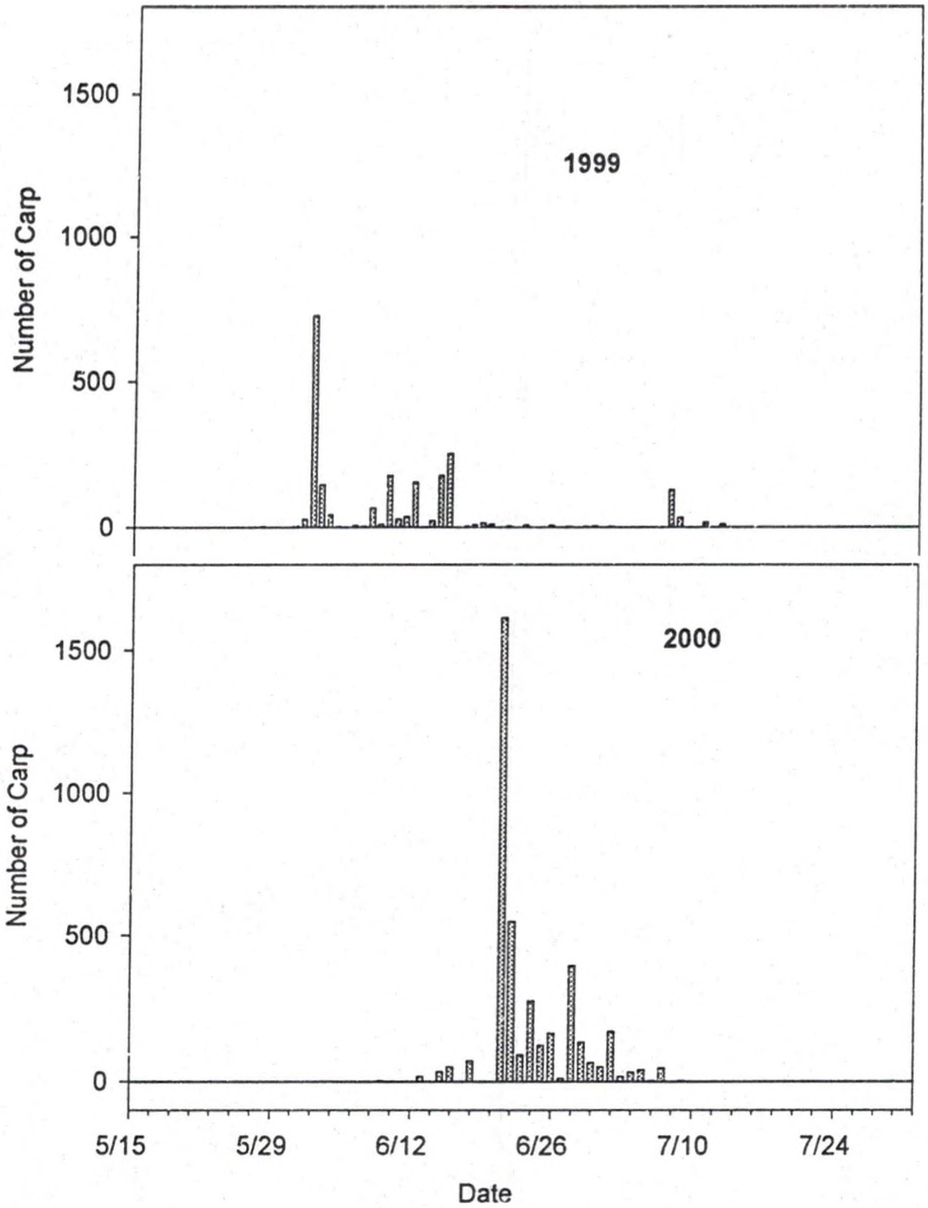

Figure18. Estimated carp fertilization date distribution (number of carp larvae oviposited) for1999 and 2000.

Table 7. Drift dates for first larvae captured, first 5% of larvae captured for season and peak drift dates for season

	1999			2000			2001		
	1st larva	1st 5%	peak	1st larva	1st 5%	peak	1st larva	1st 5%	peak
white sucker	5/21	5/21	6/27	5/4	5/16	6/20	5/8	5/8	5/30
freshwater drum	6/11	6/17	6/17	6/13	7/19	7/20	-	-	-
Stizostedion spp.	5/13	5/13	6/2	5/9	5/9	5/9	5/8	5/8	5/14
carp	5/26	5/26	5/27	6/13	6/26	6/26	5/14	5/18	5/18

Dakota, south of the point where the Sheyenne and Buffalo Rivers merge, did not receive the heavy summer rainfall like other parts of the watershed. These sites did not exhibit a noticeable spike in discharge inundating the floodplain like all other sites; and unlike most other sites, did not produce many carp larvae in samples (Figures 24, 25). In 1999, discharge peeked in early April with typical snowmelt and spring rainfall. River levels did not fall below flood stage until the end of May in much of the basin. Sampling did not begin until May 13th for the 1999 season. Carp appeared to begin spawning once the temperature approached the lower end of their optimal range (18° Celsius) in the third week of May. Water levels were probably sufficiently high in late May when temperatures rose to and remained above 18 degrees when carp most actively begin to spawn (Swee and McCimmon 1966). In 2001, the hydrologic regime was similar to that of 1999. Carp began to appear in samples by the middle of May in 2001.

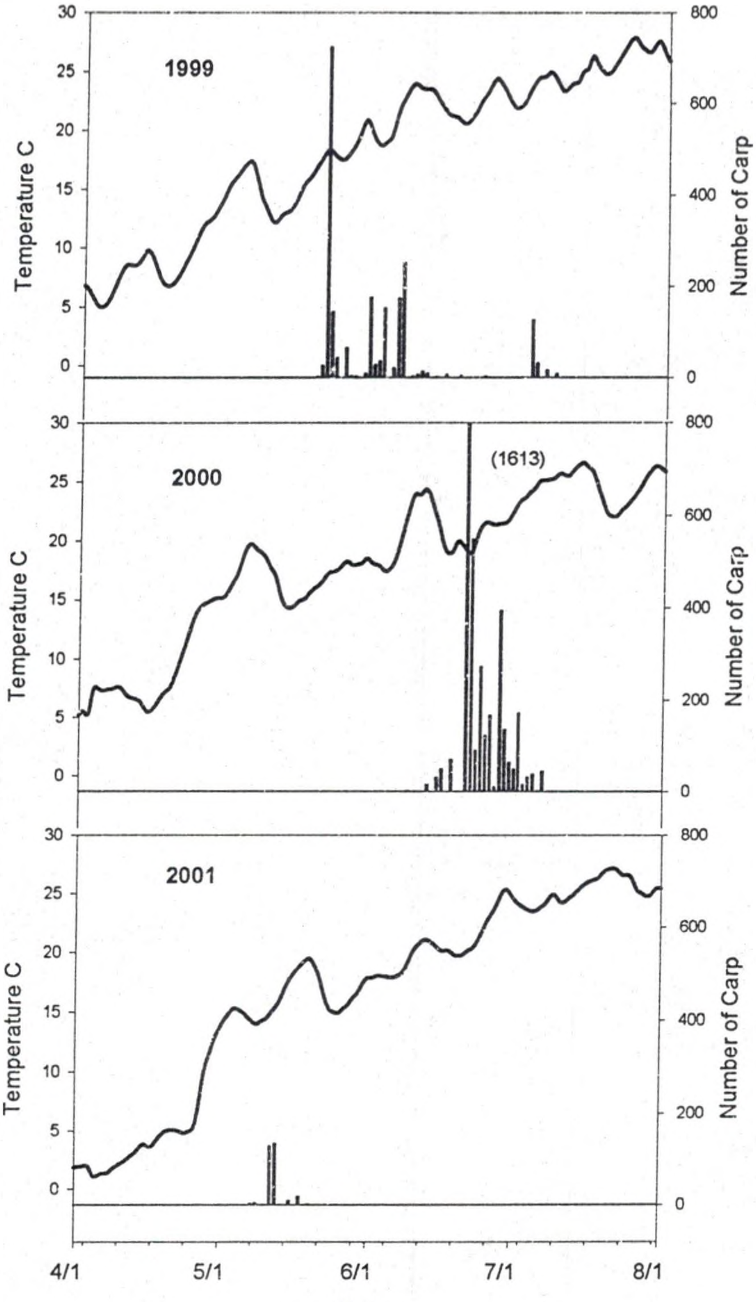

Figure 19. Estimated carp fertilization dates (bars) and temperature (lines) for all sites combined 1999, 2000, and 2001.

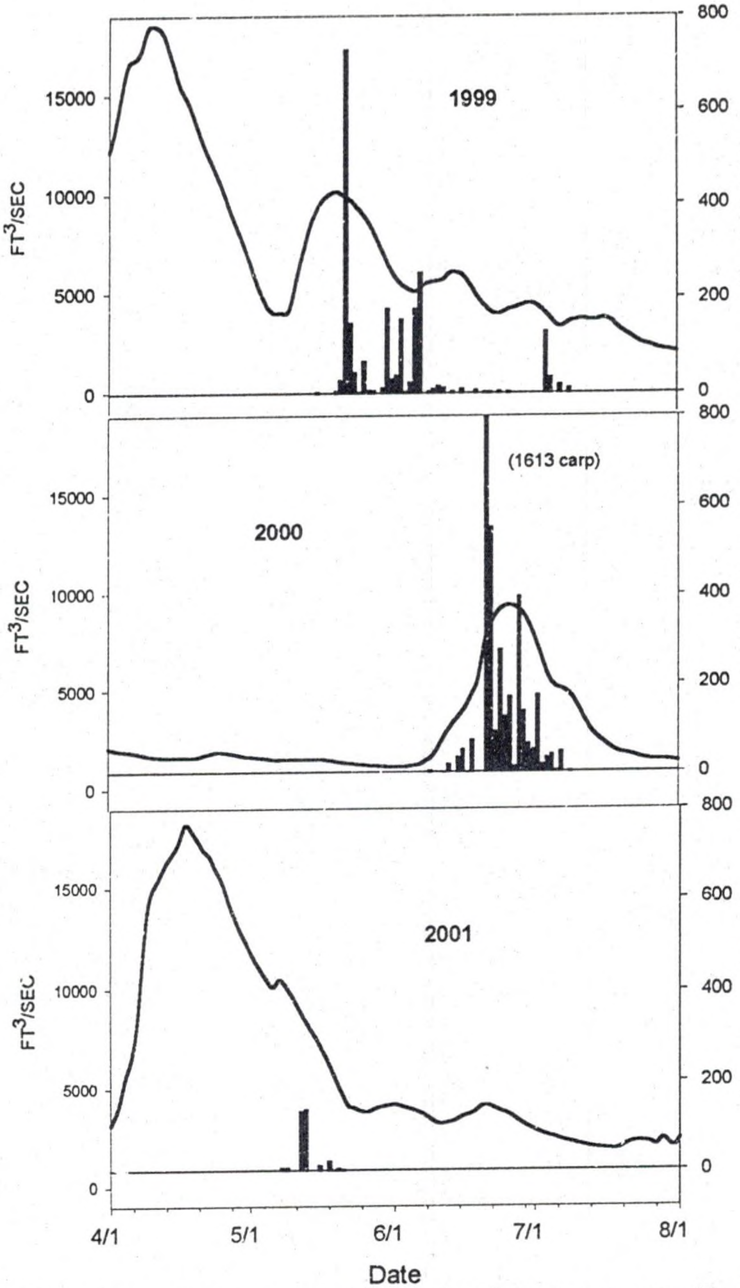

Figure 20. Estimated carp fertilization dates (bars) and discharge rates (lines) for all sites combined1999, 2000, and 2001.

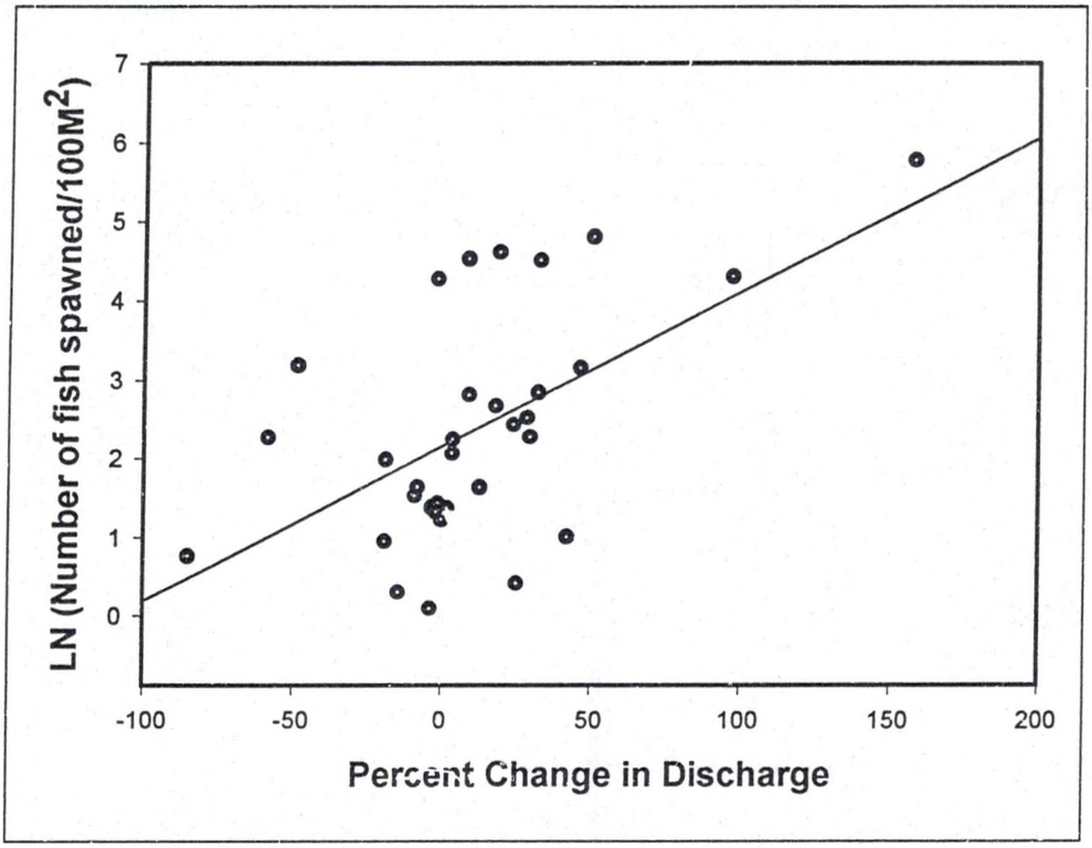

Figure 21. Correlation between the percent change of a 20 year annual average discharge and the log$_e$ number of carp oviposited and fertilized on date for the 2000 season. ($R_P = 0.567$, $p=0.001$).

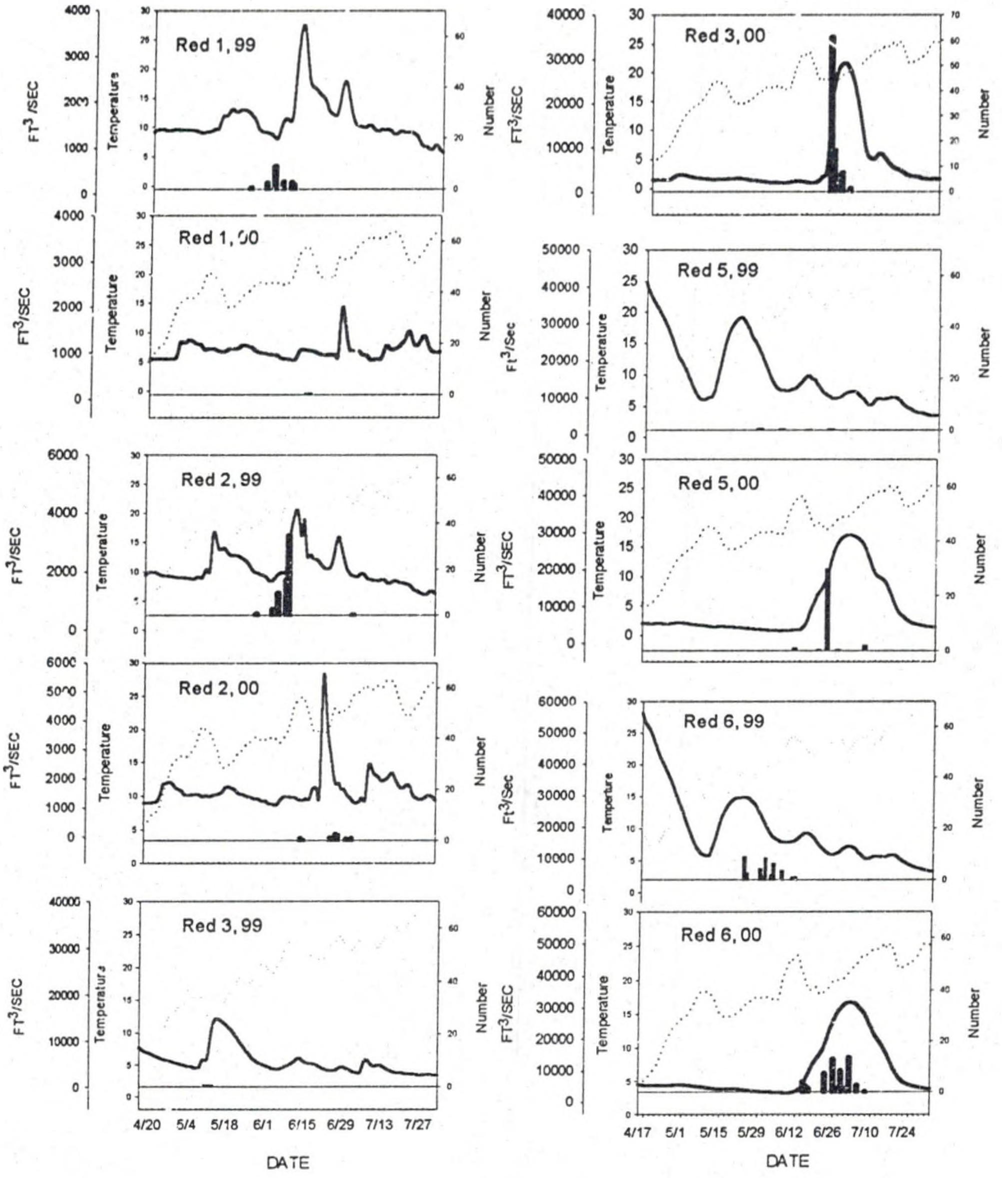

Figure 22. Carp fertilization dates (vertical bars) with corresponding temperature (dotted lines) and discharge rates (solid lines) for individual Red River sites, 1999 and 2000.

No carp caugth at Wild Rice in 1999

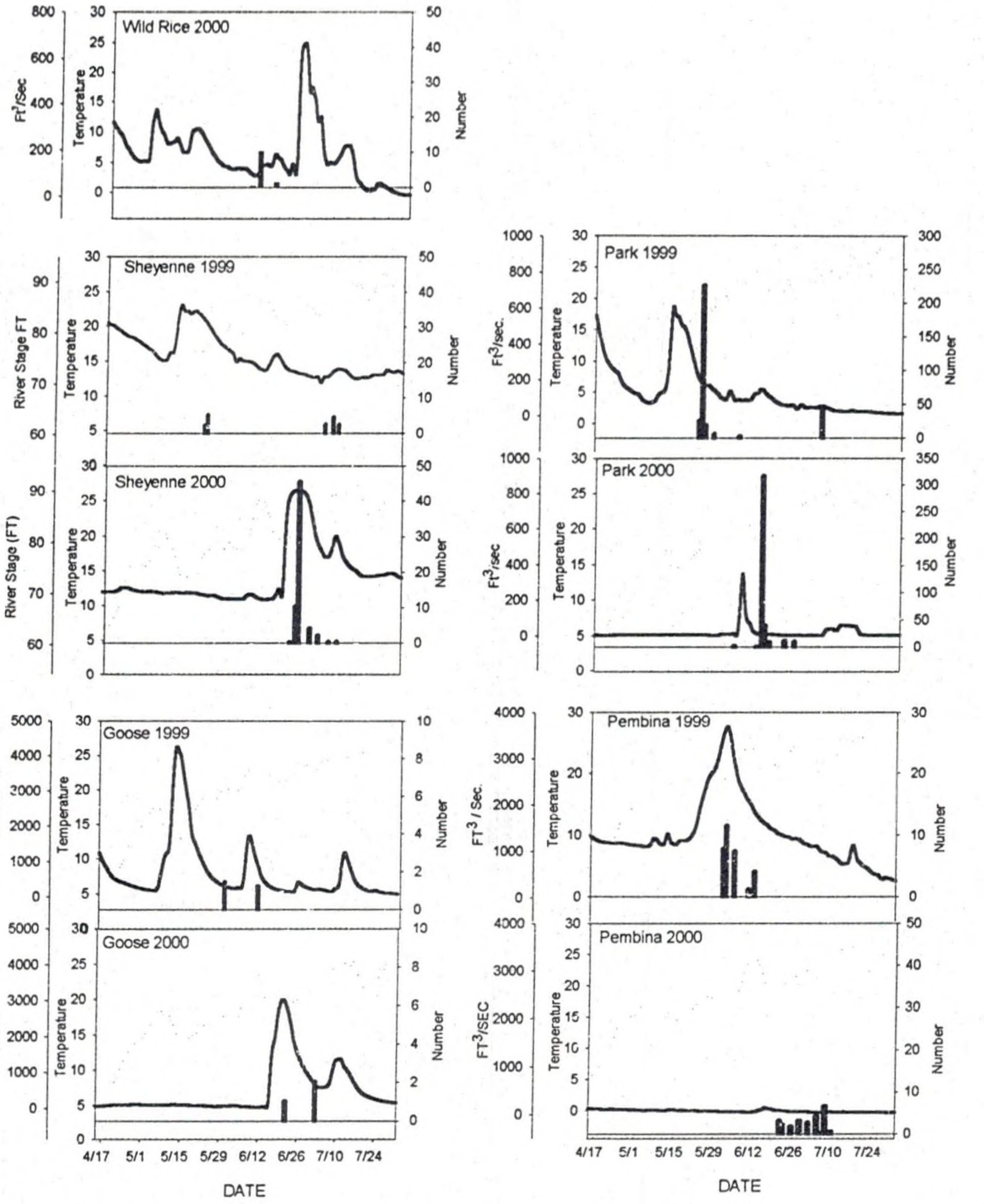

Figure 23. Carp fertilization dates (vertical bars) with corresponding temperature (dotted lines) and discharge rates (solid lines) for tributary sites, 1999 and 2000.

CHAPTER FOUR: DISCUSSION

Spatial variability

Cross Channel Variation in Larval Fish Abundance

Difference in larval fish abundance between ichthyoplankton nets deployed at the surface and those deployed near the bottom were observed for cyprinids, white bass, carp, *Moxostoma* spp., and channel catfish. The tendency for many larval fishes to drift close to the surface may be explained by the abundance of prey, zooplankton, feeding on phytoplankton near the surface (Brown and Armstrong 1985). Some species such as freshwater drum, white bass and hiodontids contain oil globules that add buoyancy, thus, keeping them near the surface (Auer 1982). Studies have established that freshwater drum, specifically the prolarvae, drift in the upper portion of the water column owing to their oil globules and phototropic behavior (Gallagher and Conner 1983, Muth and Schmulback 1984). As they attain a larger size they are found more often closer to the bottom during the day (Holland 1986). Walleye have been documented to drift in the top 1 meter of the water column, at least right after hatching, to take advantage of prey drifting in this region (Mion et. al. 1999). We caught few *Stizostedion* larvae (12) in 1999 when variation in density by depth was examined. Channel catfish were found to drift deeper in the water column (mid-depth nets had higher densities than surface nets). Channel catfish hatch at a larger size than many other species. They have fins that are relatively well developed at hatching, which may allow them to maintain a position near the bottom and avoid drifting passively downstream (Armstrong and Brown, 1983). Chironomids and other larval insects residing near the bottom are probably their main prey after their large yolk sac is absorbed, making it unnecessary to enter the upper part of the water column where zooplankton densities are highest (Armstrong and Brown 1983, Brown and Armstrong 1985).

Near-shore samples may have not differed significantly from midstream samples because of biased sampling gear. Lower current velocities near the shore (mean 0.62 m/sec for all shores samples) may have made it possible for fish larvae to avoid the plankton nets unlike larvae drifting in the mid channel where current velocities were higher (mean 0.82 m/sec for all midstream sites). Four species (Carp, white sucker, channel catfish and white bass) appeared to have densities that were positively correlated with current velocity (Kendall's Tau b; $\tau = 0.066$ $p = .012$, $\tau = 0.144$ $p < .001$, $\tau = 0.077$ $p = .012$, $\tau = 0.074$ $p = 0.016$, respectively) suggesting that either more larvae were present during periods of higher velocity or that the larvae may be less able to avoid nets at higher velocities. Some studies have documented that freshwater drum and other species were found in the midstream more often during the early developmental stages, but as they got larger and their swimming ability increased, they became more abundant in near shore areas (Holland 1986). Other studies using only towed nets found that for some species, densities varied between sampling stations near shore or with lower current velocities versus sampling stations in the middle of the channel depending on species (Gallagher and Conner 1983, Gale and Mohr 1978, Rider and Margraf 1997). Gallagher and Mohr found densities of drifting freshwater drum to be highest in the middle of the channel in the lower Mississippi River, whereas, gizzard shad were more abundant in back water habitats with lower current velocities (1983). Cross channel densities were highly variable in the upper Mississippi River as well (Holland, 1982).

Tributaries Compared with the Main Channel of the Red River

Stizostedion spp., Hiodontids, white bass and *Moxostoma* spp. were more abundant in the main stem of the Red River compared with the tributaries. These species are mostly lithophils (rock and gravel spawning fish) with the exception of white bass, which spawn on vegetation and other substrate as well. Suitable rock and gravel habitat may be more available in the main stem of the Red River or possibly Minnesota tributaries. Two Minnesota tributaries of the Red River; the Buffalo and Sandhill rivers have larval fish distributions similar to North Dakota. Carp and fathead minnows dominated larval fish collections in these rivers (Menaks 2000). For the other species, there were no apparent differences in density between tributaries and their corresponding main stem sites. In the Red River, the extreme downstream reaches of tributaries are similar morphologically to the Red River itself. All sites on all tributaries were part of the Red River flood plain at some point during this study and were flooded by water flowing from the Red. Several times on the Park and Turtle Rivers, water was observed to be flowing upstream because of high water in the Red River (personal observation). These flooded tributary confluences are similar to back water areas that have been identified as important nursery habitat on other rivers (Muth and Schmulback 1984, Holland 1983). Sampling these flooded habitats was impossible using the drift net sampling method. Sampling these habitats using plankton net towed by boat was possible when the water was deep enough and there were few obstructions (i.e. logjams, silt bars) on a stretch of river. During periods when floodwater from the Red reached the tributary sites forming, large lentic areas, I recorded some of the highest densities of carp, *Ictiobus / Carpiodes*, and catastomids, indicating their preference of this type of habitat.

Highest densities recorded overall were of freshwater drum (871 fish/100m^3, 1 net on 7/20/2000) captured from a flood plain lake formed on the Park River in July. This seems to contradict other studies that have reported highest densities of freshwater drum larvae in the main channel of rivers and few in back water areas (Holland 1983, Gallagher and Conner 1983). The individuals that were collected in this sample, however, had completely developed fins making them juveniles that were probably several weeks old (Snyder 1977). Because of their more advanced stage, it is possible that they originated in the main channel of the Red River but congregated in this temporary floodplain lake to feed on the abundant zooplankton (personal observation) commonly found in these waters. Holland noted that freshwater drum seamed to move into backwater areas on the Mississippi, as they became juveniles (1986). Larval freshwater drum were, in fact more abundant in the main channel when that particular park river site collection was eliminated from the statistical analysis.

Reproductive Timing

Reproductive strategies and tactics are described as the "complex of reproductive traits that an organism will attempt to manifest so as to leave some offspring" (Wootton, 1984). Habitat selection and timing are two important components of a reproductive strategy because they have such profound effects on the survival of offspring. In rivers these two components are closely associated because spawning substrate may only be available at certain times. Choosing the right time and place to spawn can reduce predation on offspring and maximize growth through increased prey availability (Cushing 1990). Spawning as early as possible will allow young to reach a larger size to maximize over winter survival (Conover 1992); however, spawning too early can expose eggs and larvae to lethal temperatures and low prey densities. Timing of reproduction is no doubt crucial to survival of offspring. A synchronizing cue that triggers final maturation of gonads and ovulation in females is necessary to inform the fish that conditions are suitable to begin spawning (Munro 1990),

Unlike many fish, including other cyprinids, maturation of gonads in carp begins immediately after spawning in early summer (Hontella and Stacey 1990). Gonad recrudescence including vitellogenesis is completed approximately 2 months before a minimum threshold temperature is reached in the autumn. A temperature of 14° Celsius is required for gonadal growth so gonad growth must be complete before water temperatures fall below this temperature (Hontella and Stacey 1990). Photoperiod and water temperature both appear to stimulate growth of gonads in carp (Davies 1986). Many studies identify temperature as the synchronizing cue that stimulates final maturation and ovulation in carp and close cyprinid relatives such as goldfish (Hontella and Stacey 1990, Davies 1986, DeVlaming 1972, Stacey et al. 1979).

Carp in the Red River basin probably depend on the rise in water levels associated with high discharge because of their spawning substrate requirements. Carp are categorized as obligate vegetation spawners (Balon 1974, 1984). Because of high turbidity throughout most of the year, little aquatic vegetation can grow in the river (Hegrenes 1992 personal observation,). Vegetation is only available to carp and other species of fish with this spawning substrate requirement when water levels rise and flow out of the bank, inundating terrestrial vegetation on the river floodplain. The importance of flooded vegetation was noted in a large reservoir where the abundance of young of year carp was observed to be high only during years of high water when large areas of grass were flooded (June 1977). During 1999 and 2001, the rise in water temperature above a critical spawning temperature of 16 or 17°C was most likely the synchronizing cue that triggered reproduction for carp. During these years there was an abundance of flooded vegetation throughout the basin in late spring when water temperatures first begin to climb to levels that carp can reproduce. Highly contrasting years in carp reproductive timing and flow regime made it possible to demonstrate the importance of high water to successful carp reproduction in turbid waters. In 2000, it appeared that carp delayed spawning until aquatic vegetation became available even after temperature climbed as high as 23°C. In carp at least, it appeared that that both a critical temperature and the presence of spawning substrate work simultaneously to cue final maturation of gonads ovulation and spawning in this species. It is unclear if it is the olfactory cues produced and released by the inundated vegetation or visual or tactile cues received from the vegetation. Goldfish *Carassius auratus*, a close relative of the common carp, readily spawned over plastic vegetation, so for this species at least, olfactory cues from natural vegetation is not required (Stacey 1984). Petrichor a mixture of organic substances released by the inundation of previously dry ground may act as an olfactory cue for some catfish and possibly other floodplain spawning fishes (Lake; as cited in Potts and Wootton 1984). Changes in water chemistry, current velocity, depth or perhaps a drop in water temperature caused by runoff could act as the discharge related cue as well. Male carp seem to respond to olfactory cues produced during ovulation in female carp by increasing amount of sperm. This may act as synchronizing cue for males. In 1999 a smaller peak in carp spawn date occurred at the beginning of July. This peak might represent a second spawning event for carp that had spawned once before. Fractional spawning has been observed in this species, although at some point female carp must begin developing next years ova while temperatures are still above the minimum critical temperature for gonad development (Swee and McCrimmon 1966).

It is unclear from this study what environmental cue triggers white suckers to spawn because many of the drifting larvae were at a more-advanced stage of development and were not prolarvae. White suckers spawn on rock or gravel substrate, which is often available during periods of low water as well as periods when water is out of the banks. Temperature has been suggested to be the synchronizing cue for this species, with temperatures between 10 and 13 ° C reported as threshold spawning temperatures (Hammel et. al. 1997, Corbett and Powles 1983, Curry and Spacie 1984).

Drift appeared to begin several weeks after this temperature was reached in all three years of this study. Discharge does not appear to be a synchronizing cue for white suckers. White suckers spawned in 2000 when water levels were relatively low before the discharge pulse that occurred in late June and early July.

The environmental cue that triggers spawning in freshwater drum is undetermined, but more than likely it is reaching a critical temperature since they do not have the requirement of flooded vegetation. Freshwater drum were reported to be fractional spawners once the water temperature reached 18 ° with one third of their ova maturing at once (Swedburg and Wahlburg 1970). June suggested that freshwater drum may be more influenced by photoperiod or endogenous rhythms because they tend to spawn at the same time each year (1977). In lake Oahe, North and South Dakota peak spawning dates for drum varied only slightly ranging between June 13 and June 21st from 1964-1971.

Spawning for walleye and sauger (*Stizostedion* spp.) and other percids appeared to be more closely associated with temperature than other families. Water temperature regimes were similar across the Red River basin in 1999 and 2000. Water temperatures were slightly cooler in 2001 (Figure 7), exhibiting a sharp increase at the end of April (Figure 6). During all three years water temperature warmed to the reported threshold spawning temperature of 4.4 and 10°C, rapidly after ice out (Auer 1982). Spawning probably occurred during this brief period, although this cannot be verified because spawn dates were not back calculated for this species. I cannot rule out the influence of photoperiod or endogenous rhythms either, with larval drift occurring at the same time each year. Discharge, however, does not appear to act as a synchronizing cue for this *Stizostedion* spp., although discharge may play an important role in larval survival (Mion et. al. 1999).

Management Recommendations

Many rivers, particularly large rivers with extensive floodplains in temperate regions of the world, have been modified by dams, levees, and flood control structures (Bayley 1995). These structures have the effect of isolating the floodplain from the river (Junk et al 1989, Bayley 1995). This can have damaging effects on the river's aquatic inhabitants. Very few attempts have been made to restore large rivers to their original function (Gore and Shields, 1995). Only low head dams exist on the main stem of the Red River and the lower reaches of North Dakota tributaries. These low head dams were observed to be breached by high water at some point during all three years of this study. This makes it difficult to assess whether these structures may be blocking spawning migration. In 1999 and 2001, most low-head dams were under water during April and May when early spawners (i. e. *Stizostedion* spp., white sucker, and northern pike) are reproducing. In 2000 most of these dams were impassible until high water occurred in late June and July possibly blocking migrations of some species. The rubble below some of these low head dams may provide spawning substrate for some gravel spawning species. One observation on the Wild Rice River that may support the value of such substrate for spawning, is the higher relative abundance of *Stizostedion* spp. collected from our site downstream (approximately 1 km) from the dam in the town of Wild Rice in 2001 where 31 larvae from this taxon were collected. In 1999 three of the 10 collected throughout the basin were also collected at this site. In 2000, larvae were absent, although, more samples were collected from this site. This could have resulted from the temporary damming of the river downstream from the sampling site during construction of a bridge. Several low head dams have been modified in Fargo and Grand Forks by adding rocks and rubble below the dams making them passable to fish migrating upstream. These modifications may also be helpful to fish movements on some of the Red River tributaries where fish migration could be blocked during years when spring discharge is low.

The flood plain of the Red River appears to be important for spawning in carp, habitat for carp, and probably other flood plain vegetation spawning species like bigmouth buffalo and northern pike. The occurrence of regular flooding on the Red River during the 1990s and early 2000's raises questions as to whether these species of fish are becoming more abundant in the drainage and what ecological impacts this may have. Although carp are considered a nuisance species, they have been found to be prey for adult channel catfish in the Red River (Hegrenes 1992). Because of their high abundance, larval carp also may be an important prey source for other species of fish. It is doubtful that carp have a major impact on the water clarity in the Red River like they have had in other watersheds in North America (Moyle 1984). The Red River exhibits high turbidity because of the soil types and extensive agriculture in the watershed.

The importance of the floodplain to adult riverine fishes has been documented (Halyk and Balon 1983, Ross and Baker 1983, Kwak 1988, Sabo and Kelso 1991). Many species of fish exploit the floodplain for feeding and reproductive. Fishes that do not move onto the floodplain to feed or spawn can benefit from the nutrients and increased production provided by flood-plain habitat (Junk et al. 1989, Halyk and Balon 1983).

Sometimes regulated floodplains or flood diversions are constructed as an alternative to the use of levees and dams to control seasonal flooding. These bypass structures divert water onto a diked, controlled floodplain during periods of high discharge retaining some of the function of the original floodplain (Sommer et. al. 2001). This may better flood control alternative to dams and levees in the Red River Valley.

APPENDIX I. SITE DESCRIPTIONS

Sites one through six were oriented in an upstream to downstream (North to South) direction on the Red. Corresponding tributary sites were located close to the confluence between several hundred meters to several kilometers.

WR1, Wild Rice River.

This site is located 7km south of Fargo off of Highway 81 near Wild Rice in Cass County. GPS: 46, 45.665; 96, 47.815. This site is about 1.5km upstream from the confluence with the Red. The River ranged from 17 m in width to several hundred when flooded in April 2001. Substrate at bridge was mostly cobble and organic material.

RE1, Red River site 1.

This site is located 10 km south of Fargo Cass County 16 Bridge. GPS: 46, 43.867N; 96, 47.049W. This site is 3km upstream from the confluence with the wild rice. Width ranged from 40 to 50 meters. Substrate under bridge was mostly silt and sand. RE1 was the furthest site upstream on the Red river.

SH2, Sheyenne River

Located 5miles NE of Harwood on county rd 31 in Cass Co. GPS: 47, 01.842N; 96, 50. 201 W. This site is about 0.5 km upstream from the confluence with the Red. It is the Red's largest tributary in North Dakota. Width ranged from 21 meters to completely inundated by floodwater from the Red, covering more than a kilometer of area in April 2001. The substrate at this site was mostly sand.

RE2, Red River site 2.

This site is located 4 miles East of Harwood on Clay County 26 north of Fargo. GPS: 46, 58.651 N.; 96, 49.199 W. This site is about 7 km upstream from the confluence with the Red. The river's width ranged from 44 m to over 100 m during this study. Substrate was largely silt and sand.

GO3, Goose River

This site is located near Caledonia on County rd 2 in Trail co. GPS: 46, 43.859 N.; 96, 47.052 W. This site is 1.5 km upstream from the confluence. This river's width ranged from 10m to 40m. Substrate consisted mostly of gravel and sand.

RE3, Red River site 3.

This site is located near Caledonia on County rd 13 in Trail Co. GPS: 46, 43.859 N.; 96, 47.052 W. This site is 1 km upstream from the confluence. The bridge at this site was situated at a bend in the river. The Rivers width ranged from 50 to 80 meters. Substrate was coble and silt.

FO4, Forest River

This site was eliminated after the first week of sampling in May 1999

RE4, Red River site 4

This site was eliminated after the first week of sampling in May 1999 because of heavy traffic on the bridge in Oslo Minnesota.

PA5, Park River.

This site is located 10 miles E. of Grafton on County Rd. in Walsh Co. GPS: 48, 26.268 N.; 97, 14.032 W. This site was on the smallest tributary that we sampled. It is 3 km upstream from the confluence with the Red. Width ranged from 10 m and no noticeable current velocity to being completely inundated by the Red River. Floodwater from the Red backed up on the Park River nearly 25 k in April 2001. Substrate was exclusively silt.

RE5, Red River site 5

This site is located 12 miles E. of Grafton on County Rd. 17 in Walsh Co. 48, 25' N. 97,09'. This site is situated about 20 km upstream from the confluence with the Park River. Width ranged from 70 m to several km. Substrate was mostly silt and sand.

PE6, Pembina River.

This site is located 5 miles SW. of Pembina at 156th in Pembina Co. GPS: 48, 56.200 N.; 97,17.462 W. This tributary was the most northerly of the tributaries we sampled Situated about 6km upstream from the confluence with the Red. Width ranged from 18 m to about 25 m. Substrate was sand and cobble.

RE6, Red River Site 6

This site is located in the town of Pembina North Dakota on Highway 75. GPS: 48'56.118 N.; 97' 17.46 W. 2 km south of the Canadian Border this site was the most northerly site on the river and the Red was widest and deepest at this point. It is 0.5 km downstream from the confluence with the Pembina. Width ranged from 105 m to several hundred meters. Substrate was mostly silt and sand.

APPENDIX II.

WATER QUALITY MEASUREMENTS

Table 8. Water quality measurements.

		Velocity(m/s)			Temp C°			D.O.(mg/L)			pH			Cond.(ms/cm)			Turb (neph.)			Depth(M)		
		Mean	Range		Mean	Range		Mean	Range		Mean	Range		Mean	Range		Mean	Range		Mean	Range	
1999	Red1M	.86	.65	1.1	21.77	7	27	6.76	4.85	8.3	7.34	7.02	7.9	.496	.345	.642	219	94	439	2.77	2	4.5
	Red1 S	.635	.47	.85	21.77	13.6	27.2	6.5	4.68	8.3	7.34	7	7.67	.508	.344	.642	244	156	454	2.45	1.5	4
	Red2 M	.952	.75	1.14	21.88	17.1	26.4	6.76	4.73	8.5	7.49	7.23	7.9	.609	.426	.609	350	201	833	3.5	2.5	5
	Red2 S	.638	.46	.94	22.12	17.1	27	6.72	5.35	7.87	7.47	7.27	7.9	.617	.426	.717	364	208	844	2.57	1.5	5.5
	Red3 M	1.023	.77	1.6	21.47	15	26.1	6.46	5.8	7.16	7.34	7.1	7.6	.604	.42	.757	508.9	290	999	4.75	3	9
	Red3 S	.775	.57	1.01	21.23	15	26	6.65	4.67	7.8	7.35	7	7.72	.623	.41	.96	493	310	999	2.1	1.5	4.5
	Red5 M	.74	.59	.85	22.45	17.6	26	6.66	5.6	8.1	7.45	7.16	7.96	.588	.497	.75	375	24	571	5.55	3.5	8.5
	Red5 S	.508	.35	.61	22.38	17.6	26.5	6.59	5.86	6.69	7.43	7.12	7.96	.571	.495	.641	430	71	692	3.03	1.5	5.5
	Red6 M	.825	.5	1.02	22.26	18	27.7	6.81	6.26	7.21	7.43	7.06	8.08	.582	.4	.75	393	206	563	8	5	11
	Red6 S	.538	.41	.634	22.11	18.3	26.8	7.02	6.61	7.5	7.41	7.02	8.9	.588	.515	.678	488	310	641	4.66	2.5	7.5
	Wild Rice	.36	.14	.54	22.75	12.9	27.5	7.87	6.27	9.15	7.31	7.2	7.74	1.37	.5	1.69	243	10	703	2.67	2	4
	Sheyenne	.91	.47	1.39	22.41	17	26.8	7.51	6.75	8.6	7.5	7.18	7.84	1.02	.62	1.39	424	120	767	3.21	3	6
	Goose	1.09	.51	1.42	21.11	14	25.3	7.79	6.4	9.03	7.32	6	7.65	1.12	.6	1.54	333	10	999	1.85	1	3.5
	Park	.387	.14	1.15	21.69	18.1	28	8.68	6.89	11.3	7.56	7.3	7.8	2.32	1.08	5.68	875	403	999	1.92	1	2.9
	Pembina	1.127	.8	1.24	20.31	17	26.3	7.65	6.5	8.4	7.41	6.85	8.05	.605	.1.	1.1	875	403	999	3.67	2.5	5.5
2000	Red1 M	.734	.68	.79	19.39	9.7	19.4	8.57	6.55	11.2	7.71	7.4	7.91	.41	.31	.563	235	27	414	2.08	1.5	3
	Red1 S	.613	.55	.69	19.8	9.7	20	8.87	6.7	11.3	7.76	7.41	7.94	.407	.306	.537	259	46	454	1.52	1	2
	Red2 M	.654	.36	.91	19.01	9.1	25.7	8.38	4.54	12.2	7.54	6.9	8.01	.511	.184	.65	382	56	999	3.63	2.25	10
	Red2 S	.52	.34	.74	18.48	8.4	25.8	9	6.1	13	7.72	7.3	7.9	.532	.449	.658	380	192	628	2	1	2.75
	Red3 M	.885	.65	1.4	18.9	6.8	26.8	8.46	3.2	12.6	7.57	6.84	8.01	.533	.158	.637	404	93	999	3.82	2	9.75
	Red3 S	.65	.53	.85	18.51	7.7	26.7	8.68	3.85	11.6	7.57	7.1	7.98	.524	.255	.639	368	14	999	2.26	.5	8.5
	Red5 M	.72	.65	1.42	19.42	14.1	24.6	7.84	5.3	12	7.75	6.86	8.05	.521	.52	.607	375	18	816	4.5	3	8
	Red5 S	.539	.5	.77	19.34	14.6	24.6	8.15	5.3	11	7.68	7.15	8.04	.527	.497	.592	344	38	864	3.15	1	7

Table 8. cont.

		Velocity(m/sec)			Temp C°			D.O. (mg/L)			pH			Cond.(ms/cm)			Turb (Neph.)			Depth (M)		
		mean	range		mean	range		mean	range		mean	range		mean	range		mean	range		mean	range	
	Red 6 S	.546	.28	.86	18.9	13.7	23.8	8.3	3.84	11.9	7.64	7.1	8.07	.52	.51	.572	340	17	974	4.15	2	9
	Wild Rice	.438	.33	.54	19.8	9.8	26.5	8.92	5.85	12.2	7.65	7.0	7.97	1.2	.51	1.81	283	54	656	2.29	1.75	3.5
	Sheyenne	.883	6.14	1.3	19.3	9.2	25.8	8.11	4.4	12.7	7.63	7.0	7.99	.82	.506	1.21	398	12	999	3.74	2.2	9.5
	Goose	1.04	.57	1.9	20.2	16	25.3	10.4	7.75	14.2	7.59	7.2	7.77	1.1	.59	1.38	291	10	608	1.52	.4	7
	Park	.24	0	1.3	20.4	17	23.4	5.4	3.5	6.06	7.21	6.8	7.95	3.3	.295	20.0	697	270	999	3.1	1	5.5
	Pembina	.355	0	.5	19.9	14.7	27	9.42	7.42	12	7.85	7.7	7.96	1.2	.51	1.81	283	54	654	2.29	1.75	3.5
2001	Red1 M	.983	.9	1	14.1	7.5	17.2	8.18	7.5	9.03	7.23	7	7.49	.53	.46	.58	172	10	340	4.5	3	6
	Red1 S	.667	.6	.7	14.2	7.6	17.5	8.26	7.6	9.03	7.28	7.1	7.43	.51	.448	.559	176	10	341	4	2.5	6
	Red2 M	.883	.7	1	14.3	7.7	18.7	8.55	7.4	9.4	7.36	7.2	7.53	.67	.601	.686	266	30	604	5.83	3	9
	Red2 S	.62	.5	.7	14.3	7.7	18.3	8.43	7.4	9.2	7.4	7.2	7.58	.66	.628	.733	239	30	378	5	3	7
	Red3 M	.98	.9	1.1	14.6	9.2	18.3	8.38	7.3	9.4	7.49	7.3	7.64	.7	.58	.95	429	204	604	5.95	3	9.5
	Red3 S	.76	.6	1	14.6	9.2	18.3	8.9	7.6	9.5	7.53	7..3	7.65	.71	.583	.95	416	204	510	5.1	3	9.5
	Red5 M	.98	8	1.1	16.0	13.5	19.3	7.53	7.31	7.67	7.53	7.3	7.67	.68	.575	.94	307	122	468	10	8	13
	Red5 S	.675	.3	1	16.5	13.5	19.4	8.02	7.6	8.4	7.51	7.3	7.65	.69	.575	.95	239	122	315	10.33	6	13
	Red6 M	1.26	1.1	1.4	15.3	13.7	17.8	8.52	7.5	9.5	7.43	7.3	7.36	.60	.53	.678	242	69	397	11.8	7	16.5
	Red6 S	.64	.6	.7	15.3	13.1	17.6	8.54	7.5	9.2	7.52	7.44	7.63	.6	.514	.678	282	189	397	11.8	7	16.5
	Wild rice	.466	.4	.5	15.7	12.9	18.3	8.9	8.3	9.2	7.36	7.26	7.42	1.4	1.3	1.5	237	23	425	3.82	3	4.5
	Sheyenne	.68	.4	.8	15.0	12.3	19.2	8.96	8.14	9.6	7.54	7.37	7.68	1.0	.523	1.23	520	260	999	6.5	5	8
	Goose	.82	.5	1.2	15.7	11.4	18.9	9.19	8.22	10.0	7.63	7.49	7.75	1.6	1.25	1.73	281	10	852	3.1	1.5	5
	Park	.68	.3	1.5	16.7	14.8	20.7	9.15	8.29	10.2	7.64	7.39	7.81	1.7	1.06	2.75	417	10	999	2	1	3
	Pembina	.99	.8	1.3	15.1	12.1	18	8.67	7.3	9.87	7.51	7.39	7.68	.60	.48	.721	906	698	999	5	3	8

APPENDIX III.

NUMBER OF INDIVIDUALS OF EACH SPECIES BY SITE DURING ALL YEARS OF THE STUDY

Table 9. Species codes used.

Code	Taxon	Scientific name
HIOD	Hiodontid	Hiodonidae
CYP	Cyprinid (other than carp)	Cyprinidae
CARP	common carp	*Cyprinus carpio*
ICT	Ictiobus /Carpiodes spp	*Ictiobus /Carpiodes* spp
RDH	Moxostoma spp.	*Moxostoma* spp
WS	white sucker	*Catostomus commersoni*
CC	Channel Catfish	*Ictalurus punctatus*
BHD	bulhead	*Ameirus* spp.
NOP	northern pike	*Esox lucius*
TP	trout perch	*Percopsis omiscomaycus*
WB	white bass	*Morone crysops*
LEP	Lepomis spp.	*Lepomis* spp.
POM	Pomoxis (crappies)	*Pomoxis* spp.
STIZ	Stizostedion spp.	*Stizostedion* spp.
DART	darters	*Etheostoma/Percina* spp.
FWD	freshwater drum	*Aplodinotus grunniens*

Table10. Number of fish of all species at each site.

site	HIOD	CYP	CARP	ICT	RHS	WS	CC	BHD	NOP	TP
RED RIVER 1999										
RED6 1999	5	14	362	12	15	88	1	0	0	0
RED5 1999	1	12	10	3	1	0	4	0	0	0
RED3 1999	0	0	16	3	0	4	54	2	0	0
RED2 1999	0	8	433	9	1	4	5	1	1	0
RED1 1999	2	29	186	8	12	10	15	1	0	0
SUM	8	63	1007	35	29	106	79	4	1	0
TRIBS 1999										
PEMBINA 1999	0	4	64	4	1	48	1	0	0	0
PARK 1999	1	21	972	240	1	10	0	0	1	0
GOOSE 1999	0	7	9	1	0	10	0	0	0	0
SHEYENNE 1999	0	9	74	59	0	7	2	1	0	0
WILD RICE 1999	0	13	0	0	1	0	36	0	0	0
SUM	1	54	1119	304	3	75	39	1	1	0
RED RIVER 2000										
RED 6 2000	9	3	972	317	4	2	0	0	0	0
RED5 2000	4	3	275	29	0	9	0	0	0	0
RED3 2000	3	8	1053	11	1	2	3	0	0	0
RED2 2000	0	5	42	1	0	2	1	0	0	0
RED1 2000	3	15	7	1	0	3	0	0	0	0
SUM	19	34	2349	359	5	18	4	0	0	0
TRIBS 2000										
PEMBINA 2000	3	4	106	3	3	15	0	0	0	0
PARK 2000	0	8	1050	342	1	0	1	0	0	0
GOOSE 2000	0	4	3	1	1	0	0	0	0	0
SHEYENNE 2000	0	19	486	5	2	2	5	0	0	0
WILD RICE 2000	0	6	66	3	0	4	0	0	0	0
SUM	3	41	1711	354	7	21	6	0	0	0
RED RIVER 2001										
RED6 2001	27	0	280	23	17	173	0	0	0	1
RED5 2001	3	0	0	1	1	6	0	0	0	0
RED3 2001	2	0	0	1	1	7	0	0	0	0
RED2 2001	0	0	3	16	22	7	0	0	0	1
RED1 2001	12	0	1	211	51	13	0	0	0	0
SUM	44	0	284	252	92	206	0	0	0	2
TRIBS 2001										
PEMBINA 2000	0	0	0	1	0	16	0	0	0	0
PARK 2001	0	0	26	20	0	0	0	0	1	1
GOOSE 2001	0	0	0	8	0	0	0	0	0	0
SHEYENE 2001	0	0	0	1	1	0	0	0	0	0
WILDRICE 2001	0	0	6	101	2	4	0	0	0	0
SUM	0	0	32	131	3	20	0	0	1	1
GRAND SUM	75	192	6502	1435	139	446	128	5	3	3

site	WB	LEP	POM	STIZ	DART	FWD	OTHER	TOTAL
RED RIVER 1999								
RED6 1999	3	0	1	3	0	0	0	504
RED5 1999	6	1	2	0	0	3	1	44
RED3 1999	1	0	0	0	0	6	2	98
RED2 1999	37	3	1	0	6	32	0	541
RED1 1999	44	4	1	1	2	57	0	372
SUM	91	8	5	4	8	98	3	1559
TRIBS 1999								
PEMBINA 1999	0	0	0	0	0	1	3	126
PARK 1999	5	0	0	0	0	0	0	1251
GOOSE 1999	0	0	0	0	4	0	1	32
SHEYENNE 1999	17	0	0	3	0	1	1	174
WILD RICE 1999	3	0	2	3	1	0	2	61
SUM	25	0	2	6	5	2	7	1644
RED RIVER 2000								
RED 6 2000	0	0	1	4	0	70	0	1382
RED5 2000	0	0	0	7	1	12	1	341
RED3 2000	0	0	0	0	0	0	2	1083
RED2 2000	0	3	0	0	0	0	0	54
RED1 2000	0	3	4	1	2	1	1	41
SUM	0	6	5	12	3	83	4	2901
TRIBS 2000								
PEMBINA 2000	0	0	0	0	0	1	0	135
PARK 2000	0	1	0	0	0	1668	2	3073
GOOSE 2000	0	0	0	0	0	0	0	9
SHEYENNE 2000	2	0	0	0	0	5	0	526
WILD RICE 2000	0	0	0	0	0	0	0	79
SUM	2	1	0	0	0	1674	2	3822
RED RIVER 2001								
RED6 2001	0	0	0	38	0	0	7	566
RED5 2001	0	0	0	20	0	0	0	31
RED3 2001	0	0	0	2	0	0	0	13
RED2 2001	0	0	0	38	0	0	1	83
RED1 2001	1	0	0	49	0	0	0	338
SUM	1	0	0	147	0	0	8	1036
TRIBS 2001								
PEMBINA 2000	0	0	0	0	0	0	0	17
PARK 2001	0	0	0	3	0	0	0	51
GOOSE 2001	0	0	0	0	0	0	0	8
SHEYENE 2001	0	0	0	0	0	0	0	2
WILDRICE 2001	0	0	0	31	0	0	0	144
SUM	0	0	0	34	0	0	0	222
GRAND SUM	119	15	12	203	16	1857	24	11184

REFERENCES CITED

Armstrong, M. and Arthur Brown. 1983. Diel drift and feeding of the channel catfish alevins in the Illinois River, Arkansas. Transactions of the American Fisheries Society 112: 302-313.

Auer, N. A. (ed.). 1982. Identification of larval fishes of the Great Lakes Basin with an emphasis on the Lake Michigan drainage. Great Lakes Fishery Commission. Ann Arbor, MI 48105. Special Pub. 82-3: 744 pp.

Bain, Mark. 1985. Fish community structure in rivers with natural and modified daily flow regimes. University of Massachusetts; Master's Thesis, 152 pp.

Balon, Eugene. 1975. The reproductive guilds of fishes: a proposal and definition. Journal of the Fisheries Research Board of Canada, 32: 821-864.

Balon, Eugene. 1981. Additions and amendments to the classifications of reproductive styles in fishes. Environmental Biology of Fishes, 6(3): 377-389.

Balon, Eugene. 1984. Patterns in the Evolution of Reproductive Styles in Fishes. G. W. Potts and R.J. Wootton eds. Fish Reproduction Strategies and Tactics. Academic Press, London.

Bayley, P, B. 1995. Understanding large river floodplain ecosystems. Bioscience. 153-158.

Brown, A.V., and M.L. Armstrong. 1985. Propensity to drift downstream among various species of fish. Journal of Freshwater Ecology, 3(1): 3-17.

Brown, D. J. and T.G. Coon. 1994. Abundance and assemblage structure of fish larvae in the lower Missouri River and its tributaries. Transactions of the American Fisheries Society 123:718-732.

Bye, Victor J. 1984. The role of environmental factors in the timing of reproductive cycles. Potts, G.W. and R. J. Wootton eds. Fish Reproduction: Strategies and Tactics. Academic, London.

Calhoun, A.J. 1953. Distribution of striped bass fry in relation to water diversions. California Fish and Game 39(3): 279-300

Conover, D.O. 1992. Seasonality and the scheduling of life history at different latitudes. Journal of Fish Biology, 41(Supplement B): 161-178.

Copp G. H., and M. Penaz. 1988. Ecology of fish spawning and nursery zones in the flood plain, using a new sampling approach. Hydrobiologia 169: 209-224.

Corbett, B. and P.M. Poles. 1983. Spawning and early-life ecological phases of the White Sucker in Jack Lake, Ontario. Transactions of the American Fisheries Society 112:308-213.

Currie, K. D. and Spacie A. 1984. Differential use of stream habitat by spawning catostomids. American Midland Naturalist, 111: 267-269.

Cushing, D.H. 1990. Plankton Production and Year-Class Strength in Fish Populations: an update of the match/mismatch hypothesis. In Advances in Marine Biology. Baxter, J.H.S., and A.J. Southward eds. Academic. Vol. 26 pp 249-293.

Davies, Bryan R. and K. F. Walker eds. 1986. The ecology of river systems. Dr. W. Junk Publishers, Dordrecht the Netherlands. 793pp

Davies, P. R., Isao Hanyu, Kiyoshi Furukawa and Minoru Nomura. 1986. Effect of temperature and photoperiod on sexual maturation and spawning of the common carp III. Induction of spawning by manipulation of photoperiod and temperature. Aquaculture 52: 137-144.

Day, R. W. and G. P. Quinn. 1989. Comparisons of treatments after an analysis of variance in ecology. Ecological monographs 59(4): 433-463.

De Graaf, G. J. 1999. Larval fish movement in the River Lohajang Tangail, Bangledesh. Fisheries Management and Ecology, 6: 109-120.

De Vlaming, Victor L. 1972. Environmental control of reproductive cycles: a brief review. Journal of Fish Biology 4: 131-140.

Eckbald, J. W.,C.S. Volden and L.S. Weilgart. 1984. Alochthonous drift from backwaters to the main channel of the Mississippi River. American Midland Naturalist, 111: 16-22.

Floyd, K. B., W. H. Courtenay, and R.D. Hoyt. 1984. A new larval fish light trap: the quatrefoil trap. Progressive Fish Culturalist 46: 216-219.

Floyd, Keith B., R. D. Hoyt, and Shirley Timbrook. 1984. Chronology of appearance and habitat partitioning by stream larval fishes. Transactions of the American Fisheries Society, 113: 217-223.

Fuiman, Lee A., J.V. Conner, B.F. Lathrop, G.L. Buynak, D.E. Snyder, and J.J. Loos. 1983. State of the art of identification for cyprinid larvae of eastern North America. Transactions of the American Fisheries Society, 112: 319-332.

Gale, William F. and H.W. Mohr. 1978. Larval fish drift in a large river with a comparison of sampling methods. Transactions of the American Fisheries Society, 107(1): 46-55.

Gallagher, Robert P., and John Conner. 1983. Comparisons of two ichthyoplankton sampling gears with notes on microdistribution of fish larvae in a large river. Transactions of The American Fisheries Society. 112: 280-285.

Gore J. A. and F. D. Shields. 1995. Can large rivers be restored. Bioscience, 45(3) : 142-152.

Halyk, Lawrence C., and Eugene K. Balon. Structure and ecological production of the fish taxocene of a small floodplain system. Canadian Journal of Zoology, 61: 2446-2464.

Hamel, Patrice, Pierre Magnan, Pierre East, Michele Lapointe, and Phylippe Laurendeau. 1997. Comparison of different models to predict the in situ embryonic developmental rate of fish. with special reference to the white sucker *(Catostomus commersoni)*. Canadian Journal of Fisheries and Aquatic Sciences 54: 190-197.

Hamel, Patrice, Pierre Magnan, Michele Lapointe and Pierre East. 1997. Timing of spawning and assessment of a degree-day model to predict the in situ embryonic developmental rate of white sucker *(Catostomus commersoni)*. Canadian Journal Fisheries and Aquatic Sciences, 54: 2040-2048.

Harkness, R.E., W.R. Berkas, S.W. Norbeck, and S. M. Robinson. 2000. Water Resources Data, North Dakota Water Year 1999. U.S. Geological Survey, Water Resources Division, Bismarck, North Dakota.

Harkness, R. E., W.R. Berkas, S.W. Norbeck, and S. M. Robinson. 2001. Water Resources Data, North Dakota Water Year 2000. U.S Geological Survey. Water Resources Division, Bismarck, North Dakota.

Harvey, Bret C. 1991. Interaction of abiotic and biotic factors influences of larval fish survival in an Oklahoma stream. Canadian Journal of Fisheries and Aquatic Sciences, 48: 1476-1480.

Harvey, Bret C. 1987. Susceptibility of young-of-the-year fishes to downstream displacement by flooding. Transactions of the American Fisheries Society 116: 851-855.

Hegrenes, Scott. 1992. Age, Growth and Reproduction of Channel Catfish in the Red River of the North. Thesis, The Unversity of North Dakota

Henley, W. F., M.A. Paterson, R.J. Neves, and A. D. Lemly. 2000. Effects of sedimentation and turbidity on lotic food webs: A concise review for natural resource managers. Reviews in Fisheries Science, 8(2): 125-139.

Hogarth, D.D.; Cowan, V.J.; Halls, A.S.; Aeron-Thomas, M.; McGregor, J.A.; Garaway, C.A.; Payne, A.I.; Welcomme, R.L. 1999. Management guidelines for Asian floodplain river fisheries. Part 2. Summary of DFID research. FAO Fisheries Technical paper. No. 384/2. Rome, FAO. 1999. 117 pp.

Holland-Bartels, Leslie, Susan K. Littlejohn and Mark Huston. 1990. A Guide to Larval Fishes of the Upper Mississippi River. U.S. Fish and Wildlife Service National Fisheries Research Center PO Box 818 Lacrosse Wisconsin 54602-0818 107 pp.

Holland, Leslie E. 1986. Distribution of early life history stages of fish in selected pools of the upper Mississippi river. Hydrobiologia 136, 121-130.

Hontella, Alice, and Norman E. Stacey. 1990. Cyprinidae. Munro, A. D., A. P. Scott and T.J. Lam eds. chapter 4 in Reproductive Seasonality in Teleosts and Environmental Influences. CRC Press Boca Raton, 254 pp.

Houde, E. D. 1969. Sustained swimming ability of larvae of walleye *(Stizostedion vitreum vitreum)* and yellow perch *(Perca flavescens)*. Journal of Fisheries Research Board of Canada, 26: 1647-1659.

Humphries, Paul and P. S. Lake. 2000. Fish larvae and the management of regulated rivers. Regulated Rivers: Research and Management, 16: 421-432.

Johnson B. L., W. B. Richardson and T. J. Naimo. 1995. Past Present and future concepts of large river ecology. Bioscience, 45: 134-141.

Johnson, R.P. 1963. Studies on the life history and ecology of the bigmouth buffalo, *Ictiobus cyprinellus* (Valenciennes). Journal of the Fisheries Research Board of Canada, 20(6): 1397-1429.

Johnston, Thomas A, et al. 1995. Larval Fish Drift in the Valley River, Manitoba: Influence of Abiotic and Biotic Factors, and the Relationships with Future Year-Class Strengths. Canadian Journal of Fisheries and Aquatic Sciences 52: 2423-2431.

June, F. C. 1977. Reproductive patterns in seventeen species of warmwater fishes in a Missouri River reservoir. Environmental Biology of Fishes, vol. 2, no. 3: 285-296.

Junk, W.J., P.B. Bayley, R.E. Sparks. 1989. The Flood Pulse Concept in River-Floodplain Systems, p. 110-127. *In* D. P. Dodge(ed.) Proceedings of the International Large River Symposium. Canadian Special Publication in Fisheries Aquatic Sciences, 106.

Koel, M.T. 1997. Distribution of Fishes in the Red River of the North Basin on Environmental Gradients. PhD dissertation. North Dakota State University, Fargo.

Koenst, Walter M., and L. L. Smith Jr. 1976. Thermal requirements of the early life history stages of walleye, *Stizostedion vitreum vitreum,* and sauger *Stizostedion canadense*. Journal of the Fisheries Research Board of Canada, 33:1130-1138.

Kwak, Thomas J. 1988. Lateral movement and use of floodplain habitat by fishes of the Kankakee River, Illinois. Am. Nat. 120: 240-249.

Lam, T.J. 1983. Environmental influences on gonadal activity in fish. Pages 65-116 in W.S Hoar and D.J. Randal editors. Fish Physiology, vol 3Academic, New York.

Markle, D.F. 1984. Phosphate buffered formalin for long-term preservation of formalin fixed ichthyoplankton. Copeia, 1984(2): 525-528.

Menaks, Maija. 2000. Juvenile and larval fishes of the Red River of the North. University of Minnesota, master's thesis. 85pp

Mion, Joseph B., Roy Stein, and Elizabeth A. Marschall. 1998. River discharge drives the survival of larval walleye. Ecological Applications, 8(1): 88-103.

Morgan, Steven G. and John H. Christy. 1994. Plasticity, constraint, and optimality in reproductive timing. Ecology 75(8): 2185-2203.

Moyle, P. B. 1984. America's Carp. Natural History, 93: 42-52.

Mraz, Donald, and E. L. Cooper. 1957. Reproduction of carp, largemouth bass, bluegills and black crappies in small rearing ponds. Journal of Wildlife Management, 21(2): 127-133.

Munro, Angus D., Alexander P. Scott and T.J. Lam. 1990. Reproductive Seasonality in Teleosts: Environmental Influences, CRC Press Inc. Boca Raton Florida: 254 pp.

Muth, Robert T and James Schmulbach. 1984. Downstream transport of fish larvae in a shallow prairie river. Transactions of the American Fisheries Society, 113:224-230.

Naesje, Tor F., Bror Jonsson, and Odd T. Sandlund. 1986. Drift of cisco and whitefish in a Norwegian River. Transactions of the American Fisheries Society, 115: 89-93.

Nesler, Thomas P., Robert Muth, and Anthony F. Wasowicz. 1988. Evidence for Baseline Flow Spikes as Spawning Cues for the Colorado Squawfish in the Yampa River, Colorado. American Fisheries Society Symposium, 5: 68-79.

Parker, Brian and William Franzin. 1991. Reproductive biology of the quillback, *Carpiodes cyprinus* in a small prairie river. Canadian Journal of Zoology, 69: 2133-2139.

Pavlov, D.S., A.M. Pakhorukov, G.N. Kuragina, V.K. Nezdolity, N. P. Nekrasova, D.A. Brodsiy, and A.L. Ersler. 1978. Some features of the downstream migrations of juvenile fishes in the Volga and Kuban Rivers. Journal of Ichthyology, 17: 363-374.

Pennak, Robert. 1971. Towards a classification of lotic habitats. Hydrobiologia, 38(2): 321-334.

Pitlo, John Jr. 1989. Walleye spawning habitat in pool 13 of the upper Mississippi River. American Journal of Fisheries Management, 9: 303-308.

Potts, G.W., and R.J. Wootton. 1984. Fish Reproduction: Strategies and Tactics. Academic, London 410 pp.

Rider, S.J., and F.J. Margraf. 1997. Dynamics of ichthyoplankton in the Kanawha, West Virginia. Journal of Freshwater Ecology, 12(2): 239-251.

Robinson, Anthony T., Robert W. Clarkson, and Robert E. Forrest. 1998. Dispersal of larval fishes in a regulated river tributary. Transactions of the American Fisheries Society, 127: 772-786.

Ross, Stephen T. and John A. Baker. 1983. The response of fishes to periodic spring floods in a southeastern stream. American Midland Naturalist, 109: 1-14.

Sammons, Steve and Phillip W. Bettoli. 1998. Larval sampling as a fisheries management tool: early detection of year class strength. Journal of Fisheries Management, 18: 137-143.

Secor, David H., J.M. Dean, and J. Hansbarger. 1992. Modification of the quatrefoil light trap for use in hatchery ponds. The Progressive Fish-Culturalist, 54: 202-205.

Sabo, M.T. and W. E. Kelso. 1991. Relationships between morphometry of excavated floodplain ponds along the Mississippi River and their use as fish nurseries. Transactions of the American Fisheries Society 120:552-561.

Schlosser, Isaac J. 1985. Flow regime, juvenile abundance, and the assemblage structure of stream fishes. Ecology, 66(5): 1484-1490.

Scheidegger, K.J. and M.B. Bain. 1995. Larval fish distribution and microhabitat use in free-flowing and regulated rivers. Copeia, no. 125-135.

Scott, M.T. and L.A. Nielson. 1989. Young fish distribution in backwaters and main-channel borders of the Kanawha River, West Virginia. Journal of Fish Biology, 35 (Supplement A): 21-27.

Scott, W. B. and E.J. Crossman. 1973. Freshwater Fishes of Canada. Bulletin 183: Fisheries Research Board of Canada. 966pp.

Sheaffer William A. and John Nickum. 1986. Backwater areas as nursery habitats for fishes in pool 13 of the upper Mississippi river. Hydrobiologia, 136: 131-140.

Smith, J. B. and W. A. Hubert. 1989. Use of a tributary by fishes in a great plains river system. Prairie Nat. 21: 27-38.

Snyder, D. E. 1976. Terminologies for the intervals of larval fish development. in Great Lakes Fish Eggs and Larvae Identification: Proceedings of a workshop, ed. J. Borman, 41-60. U.S. Fish and Wildlife Service FWS/OBS-76/23. 220 pp.

Sommer, Ted, Bill Harrell, Matt Nobriga, Randall Brown, Peter Moyle, Wim Kimmerer, and Larry Schemel. 2001. California's Yolo bypass: evidence that flood control can be compatible with fisheries, wetlands, wildlife, and agriculture. Fisheries, 26(8): 6-16.

Sokal, Robert R. and F. J. Rohlf. 1995. Biometry 5th edition. W. H. Freeman and Co. New York, 887 pp.

Stacey, N. E. 1984. Control of the timing of ovulation by exogenous and endogenous factors. G. W. Potts and R. J. Wootton eds. Fish Reproduction Strategies and Tactics. Academic, London.

Stacey, N. E. 1979. Spontaneous and gonadotropin-induced ovulation in the goldfish, *Carasius auratus* L: effects of internal factors. Journal of Fish Biology: 15, 349-361.

Starnes, Lynn B., Peter A. Hackney, and Thomas A. McDonough. 1983. Larval fish transport: a case study of White Bass. Transactions of the American Fisheries Society 112: 390-397.

Stoner, J.D., D.L. Lorenz, G. J. Wiche, and R. M. Goldstein. 1993. Red River of the North Basin, Minnesota, North Dakota and South Dakota. Water Resource Bulletin, 29(4): 575-615.

Swedberg, Donald V. and Charles H. Walburg. 1970. Spawning and early life history of the freshwater drum in Lewis and Clark Lake, Missouri river 3: 560-570.

Swee, U Boon, and Hugh McCrimmon. 1966. Reproductive biology of the carp, *Cyprinus carpio* L., in Lake St. Lawrence, Ontario. Transactions of the American Fisheries Society, 95: 372-380.

Turner, T.F., J.C. Trexler, G.L., Miller, and K.E. Miller. 1994. Temporal and spatial dynamics of larval fish and juvenile fish abundance in a temperate floodplain river. Copeia 1994(1): 174-183.

Vannote, Robin L., G. Wayne Minshall, Kenneth W. Cummins, James Sedell, and Colbert E. Cushing. 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences, 37: 130-137.

Verma, Prabha. 1970. Normal stages in the development of Cyprinus carpio var. communis L. Acta Biol. Acad. Sci. Hung., 21(2): 207-218.

Walker, Meddie C. and Philip T. Frank. 1952. The propagation of buffalo. Progressive Fish Culturalist. 14(3): 129-130.

Welcomme, Robin L. 1979. Fisheries Ecology of Floodplain Rivers. Longman; New York 317pp.

Wolf, A.E., D.W. Willis, and G. J. Power. 1996. Larval fish community in the Missouri river below garrison dam, North Dakota. Journal of Freshwater Ecology, 11(1): 11-19.

Wootton R. J. 1984. Reproductive strategies. Potts an Wootton eds. Fish Reproduction: Strategies and Tactics. Academic, London 410 pp.

Yeager, L.E. 1936. An observation on spawning buffalo in Mississippi. Copea, 1936(4): 238-239.