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Royal D. Suttkus

Maurice F. Mettee

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ROYAL D. SUTTKUS[1] AND MAURICE F. METTEE[2*]

[1]Tulane University, Museum of Natural History,
Belle Chasse, LA 70037;
[2]Geological Survey of Alabama,
P.O. Box 869999, Tuscaloosa, AL 35486-6999

**Corresponding author:* smettee@gsa.state.al.us.

ABSTRACT

We compared minnow populations in the lower Sabine River from before and after the construction of the Toledo Bend Dam (TBD). Total cyprinid abundance and species richness decreased downstream of TBD while minnow populations remained fairly constant or increased upstream of Toledo Bend Reservoir. The red shiner (*Cyprinella lutrensis*), the dominant minnow species collected in the lower Sabine River in 1969-1970, was not collected in the 80 river km section of the Sabine River below TBD in 1979-1980 and 1982. It did occur in collections taken in the next 80 km downstream section of river in 1969-1970 and 1979-1980, but it also disappeared in this lower region by 1982 During the same period, the blacktail shiner (*C. venusta*) became the dominant cyprinid in both of these downstream regions. Two factors likely contributed to the changes in the cyprinid populations in this section of the lower Sabine River. Discharges from TBD lowered the water temperature of the lower Sabine River to below the optimum spawning temperature of most minnow species except *C. venusta*. Also, high energy discharges during hydroelectric generation disrupted marginal stream habitats that, prior to dam operation, provided important habitat for all Sabine River minnows.

INTRODUCTION

Dam construction has long been associated with subsequent declines in local populations of fishes (Helfman, 2007). Unfortunately, the full impact of dam construction on fish assemblages has been difficult to assess because pre-construction data are generally unavailable. The Sabine River originates northeast of Dallas, Texas and flows to the southeast toward Logansport, Louisiana, where it becomes the common boundary between Louisiana and Texas (Fig. 1). From Logansport, it takes a more southerly course for about 463 km and flows into Sabine Lake which empties into the Gulf of Mexico. Toledo Bend Dam (TBD) was constructed to create a water supply, a source of hydroelectric generation, and a recreational reservoir for the states of Louisiana and Texas. Dam construction started in April 1964 and the reservoir began filling in October 1966. When full reservoir capacity was achieved in 1968, Toledo Bend Reservoir inundated approximately 160 km of riverine habitat in the lower Sabine River, though over 371 river km upstream of the reservoir remained unobstructed.

Historically, the red shiner (*Cyprinella lutrensis*) and the blacktail shiner (*C. venusta*) were two of the most important bait fishes collected and sold from the Sabine River system . The bait fish industry of the lower Sabine River was important to both Louisiana and Texas. Approximately 40 million minnows were harvested annually in this section prior to the construction of TBD (USCOE, 1971). Our goals here were to document changes that occurred in the relative abundance of several minnow species (Cyprinidae), especially *C. lutrensis* and *C. venusta*, in the downstream section of the Sabine River after TBD was completed, and to offer possible explanations for the causes of these population changes.

MATERIALS AND METHODS

Twelve pre-impoundment fish samples were collected in 1963-1966 from the now inundated section of the Sabine River from Logansport to Toledo Bend (Fig. 1). Post-impoundment fish collections were taken from three different regions of the river. First, quarterly collections were made at seven sites between Burkeville and Bon Wier (downstream of TBD) in 1969-1970 and 1979-1980 (Fig. 1). In 1982, only one sample was collected at each of these sites. Second, 10 sites were each sampled once from Bon Wier to Deweyville in July 1969, July 1970, and July 1982. Finally, fishes were collected from four sites upstream of Toledo Bend Reservoir in September 1982 between Winona and Carthage (Fig. 1). Two of these sites and two new sites were also sampled in October 1982. Most fish collections were made with a nylon minnow seine (3.05 m x 1.83 m). All available habitats were sampled at each site during each effort. Fishes were sorted, identified, and catalogued into the Tulane Museum of Natural History.

Water temperature data were obtained from annual U.S. Geological Survey water reports for the State of Texas (USGS, 1972; 1973; 1974; 1975; 1976; 1977; 1978; 1979; 1980; 1981; 1983) to assess the effects of TBD discharges on minnow spawning success and egg survival. We examined water temperature data taken during July and August from 1967 to 1982 at four sites: one upstream of Toledo Bend Reservoir (Tatum) and three downstream (Burkeville, Bon Weir, and Ruliff). For *C. lutrensis*, the most abundant cyprinid species in the lower Sabine River prior to impoundment, the lowest estimated temperature for hatching and larval survival is 29°C (Islam, 1972). We compared Sabine River water temperatures at these four sites with this reported minimum temperature.

RESULTS

Pre-impoundment collections - Logansport to Toledo Bend (1963 to 1966)

Twelve pre-impoundment fish collections from the main stem of the Sabine River (Logansport to Toledo Bend) produced 16 cyprinid species and 17,665 specimens (Table 1). The most numerous species was *C. lutrensis* which comprised 40% of all minnows collected. Other common cyprinid species collected were ghost shiners (*Notropis buchanani*) and bullhead minnows (*Pimephales vigilax*) comprising 19.7 % and 16.4% of all minnows collected, respectively. The remaining 23% of minnows collected included *C. venusta*, shoal chubs (*Macrhybopsis hyostoma*,), Sabine shiners (*Notropis sabinae*), pallid shiners (*Hybopsis amnis*), emerald shiners (*Notropis atherinoides*), Mississippi silvery minnows (*Hybognathus nuchalis*), mimic shiners (*Notropis volucellus*), and weed shiners (*Notropis texanus*).

Post-impoundment collections - Burkeville to Bon Wier (1969-1982)

Cyprinid species richness and relative abundance declined over time in the Burkeville to Bon Wier region with 15 species and 42,063 specimens collected in 1969-1970, 12 species and 9,602 specimens collected in 1979-1980, and 9 species and 3,220 specimens collected in 1982 (Table 1). In 1969-1970, *C. lutrensis* comprised 40% of all minnows collected, followed by *C. venusta* (29.1%), *P. vigilax* (16.9%), and *N. sabinae* (8.7%). Species comprising the remaining 5.1% of minnows included *H. nuchalis*, *M. hyostoma*, *N. atherinoides*, *H. amnis*, *N. buchanani*, *N. texanus*, and *N. volucellus*. Golden shiners (*Notemigonus crysoleucas*), ribbon shiners (*Notropis fumeus*), pugnose minnows *(Opsopoeodus emiliae*), and suckermouth minnows (*Phenacobius mirabilis*) were also collected in this region but in lower numbers. Only 39 specimens were collected in 1969-1970 and 38 specimens were collected in 1979-1980.

Five minnow species collected between Burkeville and Bon Wier in 1969-1970 (*C. lutrensis*, *N. buchanani*, *H. amnis*, *M. hyostoma*, and *N. atherinoides*) were not collected in 1979-1980 (Table 2). The relative abundances of *P. vigilax*, *N. sabinae*, and *H. nuchalis* declined over this period as well (Table 2). By contrast, the relative abundance of three species (*C. venusta*, *N. texanus*, and *N. volucellus*) increased between these two periods (Table 2). The largest change in relative abundance occurred in *C. venusta* whose abundance increased from 29.1% of all minnows collected in 1969-1970 to 83.3% in 1979-1980 (Table 2). Similarly, 145 *N. texanus* were collected in 1969-1970 versus 316 in 1979-1980 (Table 2).

In 1982, *C. lutrensis*, *N. atherinoides*, and *N. buchanani* remained absent from Burkeville to Bon Wier collections (Table 1). Three other species (*H. nuchalis*, *N. texanus*, *and P. vigilax*) continued to decline in abundance while *N. texanus* and *N. volucellus* increased slightly. Again, the dominant species in this river region was *C. venusta*, accounting for 83.4% of all minnows collected (Table 2).

Post-impoundment collections - Bon Wier to Deweyville (1969-1982)

Cyprinid species richness and relative abundance also declined in the Bon Wier to Deweyville region, but the process occurred over a longer time period. Fourteen species and 6,497 specimens were collected in this region in 1969, 15 species and 7,944 specimens were collected in 1970, and only 10 species and 3,615 specimens were collected in 1982 (Table 1). The slight increase in total species and specimens collected from 1969 to 1970 possibly occurred after minnows in the Burkeville to Bon Wier section moved downstream to escape the initial effects of cool water discharge from TBD. Consistent collection results from both of these downstream regions in 1982 likely resulted when the full effects of cool water discharge were realized throughout minnow populations that inhabited the lower 160 river km of the Sabine River.

Post-impoundment collections - Winona to Carthage (1982)

The magnitude of the faunal change brought about by the impounding of the lower Sabine River is also evident in a comparison of data collected upstream of Toledo Bend Reservoir (Winona to Carthage) in 1982 with data collected downstream of TBD during the same time period. Sixteen species and 65,184 specimens were collected upstream of Toledo Bend Reservoir in eight collections (Table 1). Fifty-four percent of all minnows collected were *C. lutrensis*, 31.6% were *P. vigilax*, 4.5% were *N. sabinae*, and 4.0% were *M. hyostoma*. Compared to post-impoundment downstream regions where *C. venusta* became dominant, *C. venusta* comprised only 2.5% of all minnows collected between Winona and Carthage. In contrast, only nine species and 3,220 minnows were taken in nine collections made between Burkeville and Bon Wier and 10 species and 3,615 minnows were taken in 10 collections made between Bon Wier and Deweyville.

Post-impoundment water temperatures: Tatum, Burkeville, Bon Weir, and Ruliff (1969 -1982)

Post-impoundment water temperatures collected upstream of Toledo Bend Reservoir (as measured at Tatum) in July and August usually exceeded the 29°C minimum temperature reported for successful *C. lutrensis* hatching and larval survival (Islam, 1972) while post-impoundment temperatures collected below TBD at Burkeville, Bon Weir, and Ruliff were consistently lower than 29°C (Fig. 2).

DISCUSSION

The abundance and diversity of most cyprinid species inhabiting the lower Sabine River substantially declined following the construction of TBD. The most marked change is the apparent extirpation of *C. lutrensis* downstream of the impoundment. Prior to construction, *C. lutrensis* had been the most common minnow in this region. We recognize that without actual experimentation it is somewhat difficult to ascertain those intrinsic factors actually involved in changes in the relative abundance of minnow populations in the lower Sabine River. Our long-term data and observations, though, allow us to offer likely explanations for these changes. In the lower Sabine River, the artificial lowering of river temperatures downstream of the impoundment along with other factors such as increased turbidity and habitat alteration all likely contributed to the reduction of *C. lutrensis* reproduction and survival. While we have focused here on changes to the two dominant species (*C. lutrensis* and *C. venusta*), it is also apparent that the post-impoundment disruptions have reduced overall cyprinid diversity and abundance, including the extirpation of *N. atherinoides* and *N. buchanani* from the Burkeville to Bon Wier region. While these two species differ in some aspects from *C. lutrensis* in regard to habitat requirements (e.g., neither are crevice spawners), we suspect that the post-impoundment conditions in the region were not conducive for their survival due to other factors.

Water temperature is a major factor determining *C. lutrensis* habitat selection and it can also influence *C. lutrensis* meristics (Matthews, 1977; 1987). Under experimental conditions, the optimal temperature range for hatching *C. lutrensis* eggs was 29° to 31°C and the highest growth rate (3.3 mm/week) occurred at 29°C (Islam, 1972). Frequency histograms for *C. lutrensis* collected in Oklahoma and Texas suggested prolonged high reproductive conditions in populations from both areas, but seine mesh-size young were never collected until the middle of July (Farringer et al., 1979). Collections of small *C. lutrensis* throughout August and September suggested spawning occurred from about mid-June to the end of August and possibly into September (Farringer et al., 1979). During this study, average water temperature was 30°C in July and August with slightly lower temperatures in September (Farringer et al., 1979). In another Oklahoma study, 47.6% of adult *C. lutrensis* were collected in August when water temperatures ranged from 33° to 37°C (Matthews and Hill, 1979).

Water temperatures were consistently lower downstream of the impoundment after TBD began discharging (Fig. 2). In most cases, the July and August temperatures were lower than the 29° to 31°C reported for optimum spawning and egg survival of *C. lutrensis* (Islam, 1972). By comparison, July and August water temperatures at Tatum, upstream of Toledo Bend Reservoir, remained constant after impoundment and *C. lutrensis* remained the numerically dominant cyprinid in this region (Table 1). At Burkeville in 1969-1970, *C. lutrensis* represented 40% of all cyprinids but none were collected either in 1979-1980 or 1982. Similarly, at Ruliff where July and August temperature averages were slightly higher than Burkeville (Fig. 2), we suspect they were still too low to support *C. lutrensis* spawning. In 1970, 25.7% of all cyprinids collected at Ruliff, just downstream of the Bon Wier to Deweyville section, were *C. lutrensis*, but the species had disappeared in this area by 1982. The relative abundance of *C. venusta* increased substantially at both sites during the same period, from 29.1% in 1969-1970 to 83.4% in 1982 at Burkeville, and populations increased from 22.5% to 53.9% at Ruliff. We suspect that the broader habitat tolerance of *C. venusta* allowed for its rapid replacement of declining populations of *C. lutrensis*.

Although *C. lutrensis* is noted for its turbidity tolerance, especially where it has been introduced beyond its native range (Ross, 2000; Boschung and Mayden, 2004), we suspect that increased turbidity downstream of the impoundment may have also contributed to *C. lutrensis* population declines. In Oklahoma, adult *C. lutrensis* were typically collected in habitats where turbidity ranged from 4 to 27 JTU (~ NTU) in August (Matthews and Hill, 1979). By comparison, our turbidity measurements, taken from the Sabine River between Bon Wier and Deweyville during July 1969 ranged from 88 to 325 JTU. Measurements taken in the same region in July 1970 ranged from 35 to 50 JTU. These elevated turbidities may have impacted *C. lutrensis* spawning either by contributing to the instability of shallow substrates or by disrupting chemical cues used to attract conspecifics during spawning events (Asbury et al., 1981).

Other post-impoundment changes that possibly affected *C. lutrensis* populations include an input of excess woody debris, loss of low-energy marginal feeding habitats, and changes in water chemistry. Large quantities of partially burned limbs, bark, and small logs were flushed downriver when TBD began operating. Much of the potential reservoir area was never cleared of timber and many piles of uprooted trees were never burned before impoundment. This debris cluttered the formerly clean, white, sandbars downriver for many miles and altered shoreline habitat. In the Colorado River of central Texas, *C. lutrensis* feed primarily in shallow water along the shore (Harwood, 1972). These areas are biologically, physically, and chemically critical for successful reproduction of *C. lutrensis* in the Sabine River. The loss of optimum conditions for a prolonged period, more than the typical life span of the species, may have played a role in the extirpation of *C. lutrensis* in the lower Sabine River. Changes in water chemistry may have also affected downstream minnow survival. The lower zone of the reservoir stratified chemically and thermally, and dissolved oxygen was depleted each summer. This stratification allowed iron, manganese, and hydrogen sulfide concentrations to increase to nuisance levels. Stratification usually continued until the fall of the year (Shampine, 1971). We did not measure the three above mentioned parameters during our Sabine River fish surveys, so we are unable to comment on their affect, if any, on water quality below TBD.

Our long-term sampling and observations suggest that the main channel of the Sabine River was the obvious center of *C. lutrensis* populations in the upper and lower sections of the Sabine River prior to the completion of TBD. Tributary populations of *C. lutrensis* did not repopulate the main channel after impoundment. Though we have no evidence, we suspect that tributary populations were too small and were incapable of producing sufficient numbers of individuals to outcompete rapidly expanding *C. venusta* populations. This suspicion is supported in our collection results from two Sabine River tributaries. Fifty-three samples collected at five sites along Anacoco Bayou (Fig. 1), an eastern tributary to the Sabine River, from August 1969 through January 1980 produced ten times more *C. venusta* (22,514 specimens) than *C. lutrensis* (2,249 specimens). Eleven samples collected from Big Cow Creek, a western tributary to the Sabine River at km 76, from July 1970 through November 1973 contained eight times more *C. venusta* (1,875 specimens) than *C. lutrensis* (238 specimens). The collection of *C. lutrensis* x *C. venusta* hybrids was not unexpected since both species spawn at almost the same temperatures and in the same habitats in Sabine River tributaries. We collected 12 *C. lutrensis* x *C. venusta* hybrids in 53 samples collected in Anacoco Bayou and one hybrid in 11 samples collected in Cow Creek. We never observed any evidence of hybrid swarms in any tributaries or the main stem of the Sabine River

Two other examples of post-impoundment *C. lutrensis* extirpations exhibit similar characteristics to conditions found in the lower Sabine River. In 1970, the senior author and associates began a sampling program that would eventually document the extirpation of a previously recognized introduced population of *C. lutrensis* in the Grand Canyon area of the lower Colorado River. The first records of introduced *C. lutrensis* in the lower Colorado River occurred in 1953 (Hubbs, 1954) and five locality records were documented, presumably prior to 1970 (Minckley, 1973). Powell Reservoir, the impoundment created by Glen Canyon Dam, obtained full pool level in 1968 and thereafter began discharging cool water from the bottom of the reservoir. Water discharged from Mead Reservoir (located more than 360 km downstream of Glen Canyon Dam) during the summer months was about 10°C cooler than normal river water in the area. After impoundment, five *C. lutrensis* were collected at km 194.5 in the Colorado River on 16 August 16 1971 and a single specimen was collected at km 340 (Suttkus et al., 1976; Suttkus and Clemmer, 1979). No additional *C. lutrensis* were collected even though one or two collecting trips were completed in this 360 km-long section of river every year from 1971 through 1981. Other populations of *C. lutrensis* were collected in Mead Reservoir at the mouth of Spencer Creek (km 246) and elsewhere along the shores of the reservoir where summer water temperatures were not appreciably modified by upstream releases from Glen Canyon Dam (Suttkus et al., 1976; Suttkus and Clemmer, 1979).

The creation of Lake Texoma also led to *C. lutrensis* extirpations, particularly in those tributaries that fed into the lake. In this case, though, temperature change did not play a role. The elimination process likely began during severe droughts and continued when stream recolonization was inhibited by Lake Texoma, which fragmented the original river-creek system (Matthews and Matthews, 2007). In addition, extensive high-water flooding events modified the lower reaches of these tributaries. These modifications formed deep pools near the stream mouths which favored piscivorous species (e.g., centrarchids) and provided poor habitat for *C. lutrensis*. These population changes were not detected until decades after the impoundment was completed. These delayed observations suggest that biologists should be alert to long-term changes in direct tributaries following reservoir construction (Matthews and Mathews, 2007).

Our long-term data on cyprinid declines in the lower Sabine River provide more evidence of impoundment-related negative effects on local fish populations. When essential fish habitats are altered for periods longer than the typical life span of local fishes, population recovery becomes problematic. Prolonged disturbances increase the possibility of invasion by other species. These invaders may, in turn, become numerically dominant and preclude later recolonization by the original species. Our hope is that with proper management and restoration efforts, the cyprinid fauna of the lower Sabine River can be eventually restored to its pre-impoundment abundance and diversity.

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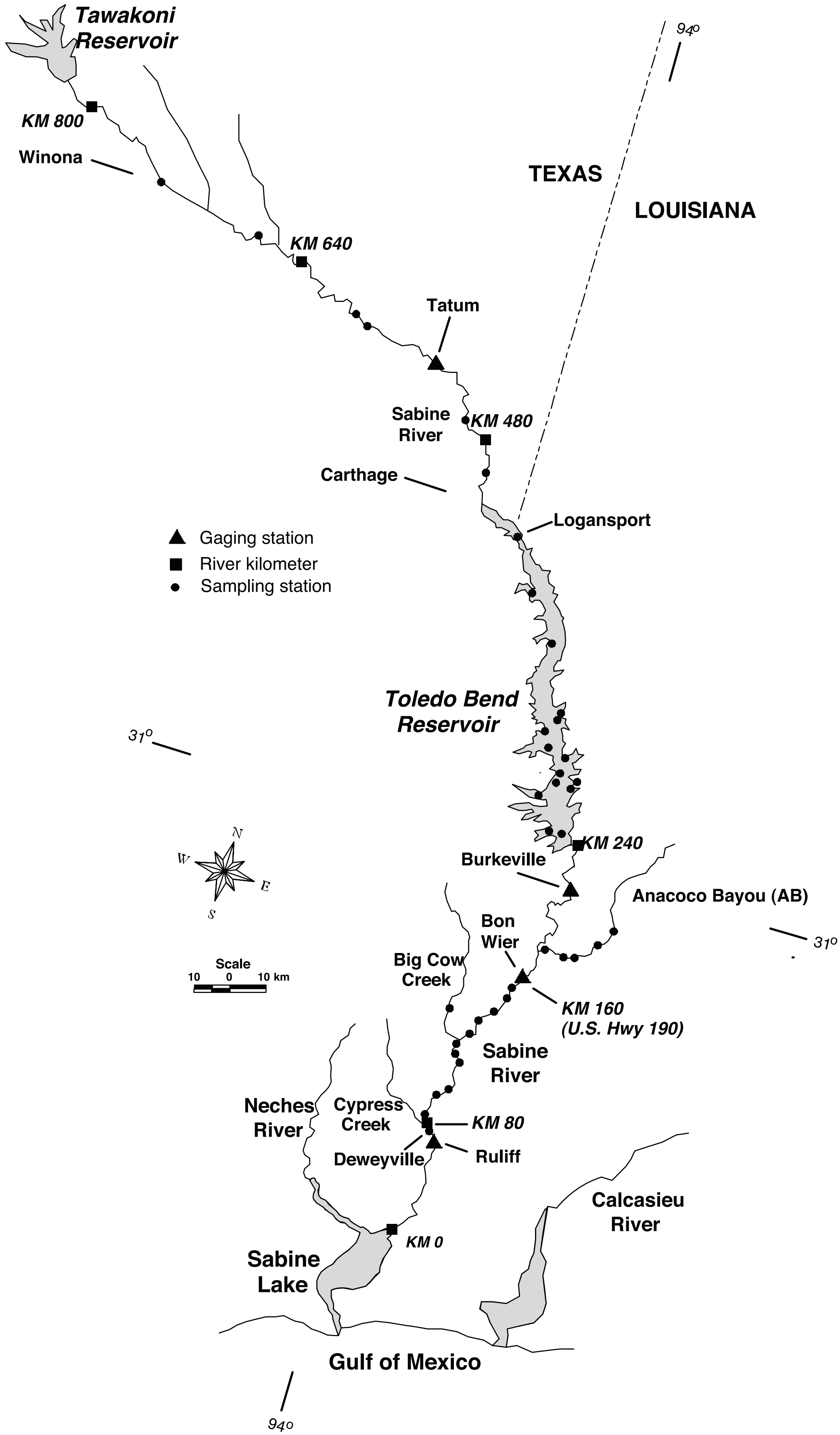

FIGURE 1. Map of the Sabine River in Louisiana and Texas showing sampling stations.

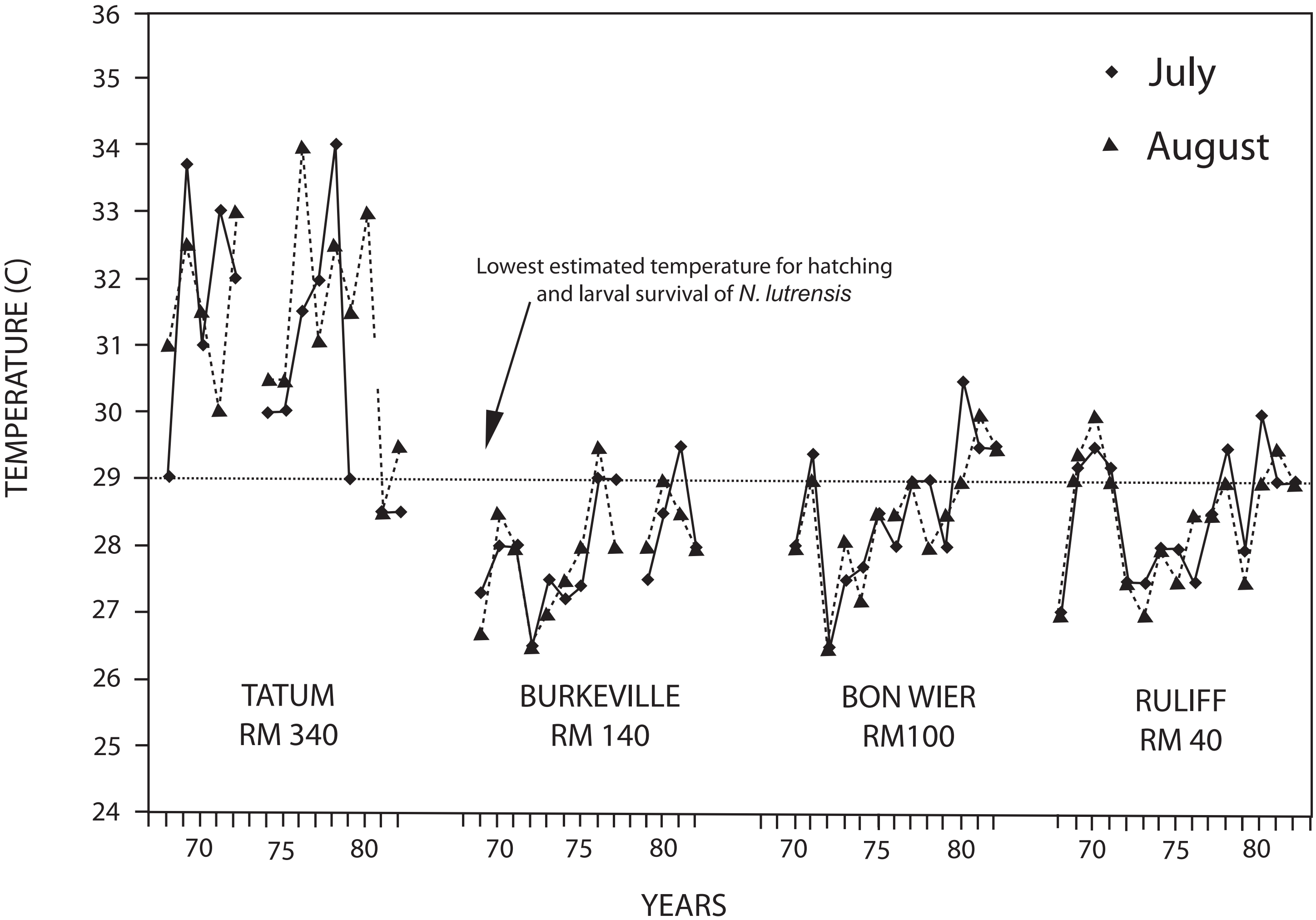

FIGURE 2. Average July and August water temperatures (°C) at four U.S. Geological Survey sampling stations (Tatum, Burkeville, Bon Weir, and Ruliff) on the Sabine River, Texas. Tatum is upstream of the Toledo Bend Reservoir while Burkeville, Bon Weir, and Ruliff are downstream of the impoundment. The horizontal line at 29°C represents the lowest estimated temperature for hatching and larval survival of *C. lutrensis*.

TABLE 1. Comparison of relative abundance of 11 minnow species collected from four regions of the Sabine River, Louisiana and Texas. Note that the 12 Logansport to Toledo Bend collections were taken prior to impoundment by the Toledo Bend Dam and that the eight Winona to Carthage collections were taken upstream of the impoundment.

River section (upstream to downstream)	RKm 240-400 Logansport to Toledo Bend	RKm 160-240 Burkeville to Bon Wier			RKm 80-160 Bon Wier to Deweyville			RKm 472-672 Winona to Carthage
Sample dates	1963-1966	1969-1970	1979-1980	July 1982	July 1969	July 1970	July 1982	Sept-Oct 1982
Total collections	12	28	28	7	10	10	10	8
Total specimens	18,969	42,889	10,910	3,582	7,264	8,944	4,139	68,620
Total species	51	50	53	31	45	44	30	46
Total minnows (%)	17,665 (93.1)	42,063 (98.1)	9,602 (88.0)	3,220 (89.9)	6,497 (89.4)	7,944 (88.8)	3,615 (87.3)	65,184 (95.0)
Total minnow species	16	15	12	9	14	15	10	16
Minnow species	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Cyprinella lutrensis	40.0	40.0	0.0	0.0	14.7	25.7	0.0	54.5
C. venusta	4.1	29.1	83.0	83.4	4.9	22.4	53.9	2.5
Hybognathus nuchalis	1.3	1.7	0.7	0.03	24.5	13.6	3.8	0.01
Hybopsis amnis	1.7	0.1	0.0	0.9	3.4	1.3	1.9	0.01
Macrhybopsis hyostoma	7.6	0.1	0.0	0.03	0.09	0.3	0.08	4.0
Notropis atherinoides	1.4	0.08	0.0	0.0	1.3	0.02	0.0	0.07
N. buchanani	19.7	1.0	0.0	0.0	0.1	0.3	0.0	1.1
N. sabinae	5.6	8.7	4.2	4.9	4.6	3.3	14.2	4.5
N. texanus	0.2	0.3	3.3	0.06	19.1	16.5	8.8	0.6
N. volucellus	1.3	1.8	2.9	5.6	13.4	5.7	7.8	0.55
Pimephales vigilax	16.4	16.9	5.5	4.9	13.2	9.0	8.0	31.6

TABLE 2. Relative abundance, percentage composition, and frequency of occurrence of 11 species of minnows (Cyprinidae) in four quarterly samples collected at seven stations on the Sabine River between Burkeville and Bon Wier, 1969-1970 and 1979-1980.

Species	1969-70	% of all minnows collected	Frequency of occurrence in 28 samples	1979-80	% of all minnows collected	Frequency of occurrence in 28 samples
Cyprinella lutrensis	16,829	40.1	28	0	0.0	0
Cyprinella venusta	12,231	29.1	28	7,968	83.3	28
Pimephales vigilax	7,105	16.9	28	532	5.6	23
Notropis sabinae	3,671	8.7	28	405	4.2	23
Notropis volucellus	766	1.8	23	278	2.9	21
Hybognathus nuchalis	715	1.7	24	65	0.6	11
Notropis buchanani	405	1.0	16	0	0.0	0
Notropis texanus	145	0.3	16	316	3.3	17
Hybopsis amnis	62	0.1	8	0	0.0	0
Macrhybopsis hyostoma	60	0.1	5	0	0.0	0
Notropis atherinoides	35	0.1	10	0	0.0	0
Total specimens	42,024			9,564		