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Porter & Massong - Habitat affecting distribution of the Rio Grande silvery minnow (421-432)

Habitat fragmentation and modifications affecting distribution of the Rio Grande silvery minnow

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Abstract

The life history of the Rio Grande silvery minnow begins as semi-buoyant pelagic eggs that drift in the current for several days. The combination of diversion and flood control dams have modified channel morphology and divided the river into distinct reaches. These factors have contributed to the decline of the silvery minnow in the last 5-10% of its former range. This research uses ArcMap (Environmental Systems Research Institute - ESRI) to analyse the interactions of diversion and mainstem dams on river channel geomorphology, silvery minnow populations and habitat to provide insights for designing restoration projects. The objective of this study is development of a spatial model using population indicators for silvery minnows to evaluate ecological parameters that may affect recovery of this endangered minnow species. Spatial analyses examine habitat fragmentation by diversion dams, water quality as a population limiting factor, and preliminary habitat features for silvery minnow egg and larvae nursery areas as potential variables in a spatial habitat model.

Key words

aquatic habitat, environmental management, fish ecology, geomorphology, habitat fragmentation, Hybognathus amarus, nursery habitat, populations, water quality.

1. Introduction

The endangered Rio Grande silvery minnow, *Hybognathus amarus* (Girard, 1856), is an endemic minnow species found in the Rio Grande and previously in the Pecos River, USA (Bestgen and Platania, 1991). This species was listed by the US Fish and Wildlife Service as endangered in 1994 (US Department of the Interior, 1994). The silvery minnow has been extirpated from much of its former range for various reasons (Bestgen and Platania, 1991). Silvery minnow population size continues to decline within its current range from Cochiti Dam to Elephant Butte Reservoir (Middle Rio Grande). The cause of this population decline has been attributed, in part, to habitat fragmentation (Bestgen and Platania, 1991; Dudley *et al*., 2003), urban water pollution (Buhl, 2002), and the lack of suitable nursery habitat for the eggs and larvae (Porter and Massong, 2003, 2004).

The silvery minnow is sexually mature at 1 yr post hatching, producing pelagic semi-buoyant eggs that are carried downstream by river currents (Platania and Altenbach, 1998). The eggs hatch within 24-48 h with the larvae reaching a mobile stage in 2-3 d post hatching. This is the only remaining species of native cyprinids that produces semi-buoyant eggs in the Middle Rio Grande. The four other species of this reproductive guild were extirpated from the Middle Rio Grande between 1939 and 1964 (Platania, 1991).

In the 1930s several irrigation diversion dams were built or renovated, including Cochiti, Angostura, Isleta, and San Acacia. The Isleta and San Acacia dams were designed with vertically raised radial gates to sluice accumulated sediment from behind the dams. Cochiti diversion dam was replaced with a mainstem flood control and sediment retention dam in 1973. These diversion dams are considered to be barriers to upstream movement of silvery minnows, fragmenting their current range into smaller reaches (Dudley *et al*., 2003).

Three factors (*habitat fragmentation, water pollution, and nursery habita*t) have been suggested as possible limiting factors on silvery minnow populations. This project uses GIS to examine several hypotheses associated with these factors and the continued decline of the silvery minnow in its current range. The habitat fragmentation hypothesis suggests that sample silvery minnow populations are correlated with reach length. Under the water pollution hypothesis, silvery minnow populations will be lower at sample stations in affected areas downstream of wastewater treatment outfalls. The nursery habitat hypothesis is based on the availability of nursery areas and dispersal distance to sample stations. Two reaches along the Rio Grande are highlighted, as they have attributes that allow for the examination of the three hypotheses: the Bernalillo / Albuquerque reach and the Socorro reach.

The Bernalillo/Albuquerque reach constitutes the Rio Grande from approximately the New Mexico State Highway 550 crossing to the Interstate 25 Highway crossing (31 river miles, 49 km). Channelization efforts were extensive in this section of the Rio Grande due to the proximity of the city of Albuquerque. Continuous levees were built in the 1950-1970 period with extensive Kellner jetty jack lines for protection (Lagasse, 1980). The channel itself was straightened and narrowed to fit within the levees during this timeframe. The cities of Bernalillo, Rio Rancho, and Albuquerque each have wastewater outfalls in the reach releasing treated effluent on a continuous basis. This effluent is hypothesized to contain toxins having detrimental effects on silvery minnow populations (Buhl, 2002).

The Socorro reach encompasses 15 km of the Rio Grande from approximately River Mile 96 to the US Highway 380 crossing (RM 87). This reach is approximately 160 km (100 miles) downstream from the Bernalillo/Albuquerque reach. Based on aerial photo review, channelization activities occurred in the 1950s and 1960s with the building of the low flow conveyance channel; the current levee along the west bank and Kellner jetty jacks were also constructed at this time (Lagasse, 1980). Arroyo connectivity and other off-channel features, such as the floodplain, are assumed to be the key-habitat features associated with nursery habitat.

2. Materials and Methods

Fish community population monitoring surveys have been conducted from Angostura Dam to Elephant Butte Reservoir since 1993 (Dudley *et al*., 2003). Fish were collected by seining in representative habitats, with catch per unit effort (c.p.u.e.) calculated as the number of fish per 100 m^2. Five sites in the Albuquerque reach have been sampled regularly from 1996 through 2001.

Habitat fragmentation was evaluated by comparing c.p.u.e. with reach lengths. ArcMap 8.1 (Environmental Systems Research Institute – ESRI) was used to determine the lengths of river reaches between dams on the Rio Grande from Cochiti Dam downstream to Elephant Butte Reservoir. The c.p.u.e. From 2002 sampling records were compared with reach length.

Three cyprinid species were selected for evaluating potential effects of treated wastewater effluent on fish populations in the Albuquerque reach: *Cyprinella lutrensis, Hybognathus amarus,* and *Pimephales promelas*. The numbers for each fish species collected at each site for the 5 yr period were added together. Definite declines in fish populations downstream of treated wastewater inflow would indicate adverse impacts of the wastewater effluent.

Nursery habitat for larval riverine fish often consists of slackwater found in inlets, submerged arroyos and floodplain depressions (Sheaffer and Nickum, 1986; Coutant, 2004). Silvery minnow nursery habitat was initially determined by field sampling using a quadrat consisting of 2-mm nylon mesh stretched across a 0.5 x 0.5 m square PVC frame to collect minnow eggs. Subsequent research indicates that the presence of a large drift zone with no measurable velocity or flow direction is essential for egg and larval fish retention (Porter and Massong, 2003). These nursery habitats also collect organic material, providing a food base for larval fish.

Stream data for the Bernalillo and Socorro reaches consists of historic and recent aerial photographs (1935-2001), cross-section surveys interpreted from aerial photographs (1962, 1972 and 1992), field-collected cross-section data (2001) and bed material data (1980-2001). For the determination of physical channel features and bed elevations, the cross-section data were analysed in US Corps of Engineers' HEC-RAS 3.0 application at a flow of 141.6 m^3s^{-1}, approximately the channel-forming flow. Bed material mobility was determined using a comparison of basal shear stress to critical shear stress (Knighton, 1998).

3. Results and discussion

3.1 Habitat fragmentation

The current range of the silvery minnow in the Middle Rio Grande is divided into four reaches of varying lengths (Table 1). The former range of the silvery minnow in the Pecos River is included in Table 1 for comparison. Habitat fragmentation is considered a major cause for the decline of the silvery minnow (US Fish and Wildlife Service, 1999). Fish collections in the late 1970s indicate that silvery minnow abundance was equivalent to collections between 1926 and 1960 (Bestgen and Platania, 1991). Overall c.p.u.e. of silvery minnows has declined in the last 10 yr (Table 2 and Figure 1), though c.p.u.e. is higher in the longer, downstream reaches (Dudley *et al*., 2003). Because silvery minnows produce semi-buoyant drifting eggs (Platania and Altenbach, 1998), it is difficult to determine whether c.p.u.e. is higher in the most downstream reach due to a longer reach, accumulation of eggs and larvae from upstream reaches during spawning, or more nursery habitat. Periodic intermittency of the San Acacia and Isleta reaches has contributed to declining c.p.u.e. through mortality and constriction of habitat (Dudley *et al*., 2003).

Table 1. Characteristics of four reaches in the Rio Grande (Cochiti, Bernalillo, Isleta, and San Acacia) and one reach in the Pecos River. C.p.u.e. data from Dudley *et al.* (2003).

Reach	**Year**	**Upstream Boundary**	**Downstream boundary**	**Distance (km)**	**2002 c.p.u.e. (fish / m^2)**
			Rio Grande		
Cochiti	1938 1973	Cochiti Dam (Diversion) (Flood Control)	Angostura Dam	37	-
Bernalillo	1933	Angostura Dam (Diversion)	Isleta Dam	67	0.003 2
Isleta	1934	Isleta Dam (Diversion)	San Acacia Dam	86	0.009 7
San Acacia	1935	San Acacia Dam (Diversion)	Elephant Butte Reservoir	97	0.014 4
			Pecos River		
Ft. Sumner	1937	Ft. Sumner Dam	Brantley Reservoir	330	Extirpated

Table 2. Catch per unit effort (c.p.u.e.) fish / m^2, for Rio Grande silvery minnow in three reaches regularly sampled in the Rio Grande from 1993 through 2002.

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Bernalillo	0.066 7	0.057 7	0.080 5	0.032 4	0.061 3	0.031 9_a	0.002 4	0.025 3	0.014 4	0.003 2
Isleta	0.077 9	0.263 1	0.231 3	0.061 7	0.037 8	0.024 9_a	0.012 0	0.001 6	0.030 0	0.009 7
San Acacia	0.514 0	0.404 5	0.528 7	0.361 9	0.188 4	0.272 5_a	0.356 6	0.083 3	0.061 9	0.014 4

	Slope	R^2
Bernalillo	-0.007 8	0.721 6
Isleta	-0.021 9	0.492 0
San Acacia	-0.055 3	0.803 3

a. Values interpolated from 1997 and 1999 date for each reach. No fish sampling was permitted on the Rio Grande in 1998.

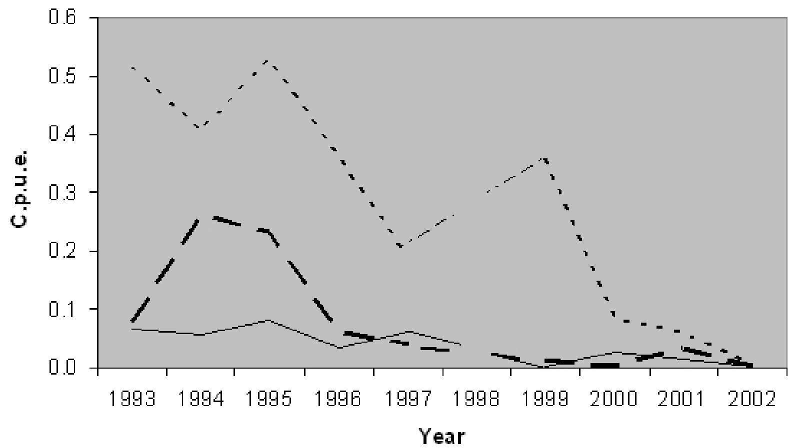


Figure 1. Catch per unit effort (c.p.u.e. = fish x m^2) for Rio Grande silvery minnow in three reaches regularly sampled in the Rio Grande from 1993 through 2002 (dotted curve, San Acacia reach; dashed curve, Isleta reach; solid curve, Bernalillo / Albuquerque reach). No fish collections were conducted in 1998.

The silvery minnow was extirpated from the Pecos River in the 1960s, 30 yr following closure of Ft. Sumner Dam (Cowley, 1979). The silvery minnow population in the Middle Rio Grande declined through the 1990s following the closure of Cochiti Dam in 1973 (Bestgen and Platania, 1991; Dudley *et al*., 2003). This recent decline of silvery minnow abundance since 1980 is difficult to link to habitat fragmentation by diversion dams alone because these dams have been operating since the late 1930s.

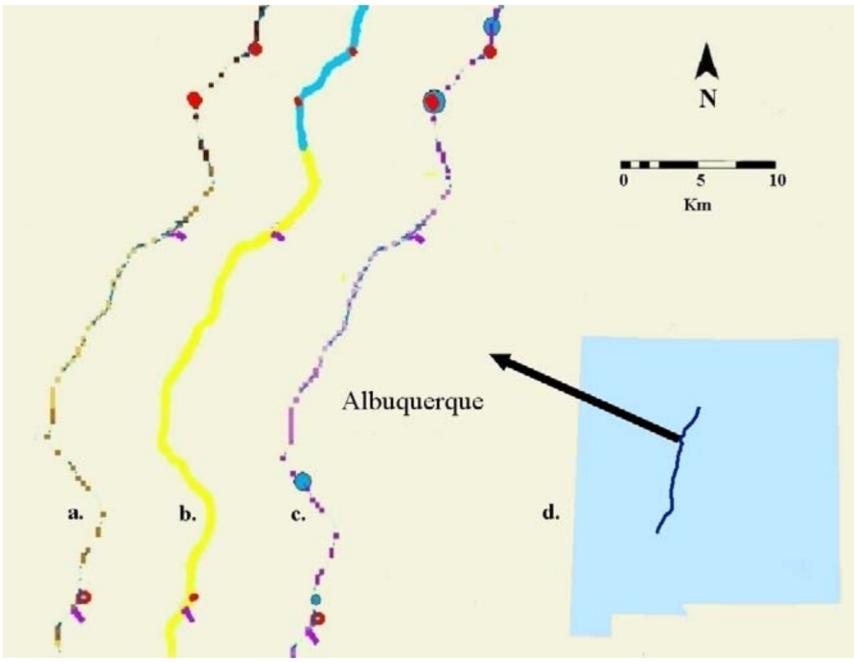
3.2 Changing habitat, geomorphology, and water quality in the Bernalillo/Albuquerque reach

Historically, the Bernalillo / Albuquerque reach of the Middle Rio Grande has been described as an aggrading, sand-bedded, braided channel (Lagasse, 1980). Although the active channel was narrowing prior to channelization, the post-channelization channel width (1962 to 1992) did not changed significantly (US Bureau of Reclamation, 1998; Massong, 2003a, 2003b). Prior to 1972 and the closing of Cochiti Dam, a slight aggradation pattern is discernible reach-wide in the survey data; however, between 1972 and 1992, reach-wide degradation began (up to 1 metre), a pattern that has persisted through the 1990's. The vegetation of medial bars in the 1980s / 1990s re-initiated the narrowing trend, but has also converted the planform more towards an island braided / anastomosing pattern rather than a bar/braided pattern (Massong, 2003a, 2003b). By the mid-1990s, a single-threaded, laterally migrating channel formed in the upstream section of the reach, which appeared to have been coincident with the conversion of the sand bed to gravel. Field observations and other data indicate that this transition to gravel and a single-threaded planform is progressing downstream (Massong, 2003a, 2003b).

With the emergence of a gravel bed, not only the size of sediment transported in this reach has obviously changed, but also the timing of the sediment transport is changing. A simple shear stress comparison indicates that 1) the larger gravel-sized sediment (d_{84}) found on the channel bed is not mobile at the 2-year recurring flow (141.6 – 198.2 m^3s^{-1}), 2) the median gravel-sized sediment size (d_{50}) is mobile for flows near the 2-year recurring flow, and 3) the channel bed that has not converted and is still sand-bedded, has mobile sediments at all flows assessed (56.6 – 283.2 m^3s^{-1}). These data indicate that the sediment in the gravel bed is rarely mobile, while the sand sizes, similar to historic bed conditions, are mobile at nearly all flows. This changing riverine system has created significantly different habitat conditions than found prior to Cochiti Dam operations (Schmidt *et al*., 2003). Silvery minnows are associated with shallow, sand-bedded, low-velocity habitats (Dudley and Platania, 1997).

In the 1980s, fish collections in the Bernalillo / Albuquerque reach had low abundance and a small silvery minnow population size (Bestgen and Platania, 1991). These low-density fish collections were attributed to poor water quality from several cities (Bernalillo, Rio Rancho, and Albuquerque) (Buhl, 2002). Fish communities adversely affected by point-source pollution have depressed fish community abundance and diversity downstream of the source, with abundance and diversity increasing with distance (Lewis *et al*., 1981). Recent collections have generally equivalent abundance upstream and downstream of outfalls (Dudley *et al*., 2003). However, the relative large distances between sample sites may not detect population declines due to pollution inflows from other sources, or localized effects.

Red shiners (*Cyprinella lutrensis*) had a distinct shift in c.p.u.e. in the middle of the Bernalillo / Albuquerque reach (Map 1a) associated with the transition to a sand substrate river bed downstream of Arroyo de las Barrancas (Map 1b). The higher c.p.u.e. samples are associated with the gravel substrate upstream of Arroyo de las Barrancas, and may result from preferred spawning and / or feeding habitat. Silvery minnows are nearly absent from collections at two sites (Map 1c) in the Bernalillo /Albuquerque reach (Dudley and Platania, 2001), with both sites upstream from local wastewater treatment inflows (Map 1b). The specific decline in silvery minnows at the two sampling sites is not known. Silvery minnows and fathead minnows have similar sensitivities to a number of toxins (Buhl, 2002), allowing fathead minnows to be used as surrogates for silvery minnows in fish community analysis to identify areas with potential water quality problems (Lewis *et al*., 1981). Mapping the abundance of fathead minnows (*Pimephales promelas*) over a similar 5 yr period indicates an even abundance throughout sites around Albuquerque. These patterns indicate a low likelihood that treated wastewater effluents adversely affecting silvery minnow populations in the Bernalillo / Albuquerque reach.



Map 1. (a) Estimated Cyprinella distribution in the Albuquerque area. Darker colour represents higher c.p.u.e. (b) Albuquerque area geomorphology with gravel (blue) and sand (yellow) substrate. Red denotes waste water treatment inflows to the river, and purple indicates storm inflows. (c) Estimated Hybognathus distribution in the Albuquerque area. Darker colour represents higher c.p.u.e. (d) Rio Grande silvery minnow range in New Mexico.

3.3 Identifying silvery minnow nursery habitat in the Socorro reach

Assuming a transport rate of about 3 km h^{-1} (1 m s^{-1} = 3.6 km h^{-1}), silvery minnow eggs and larvae could drift 288-360 km before the larvae are able to swim out of the current (Platania and Dudley, 2003). This estimate exceeds the current range of the silvery minnow, implying an unknown factor for their eggs or larvae to exit from the river current. The placement of quadrats at the mouth of Socorro North Diversion Channel established that some silvery minnow eggs settle out of the current at tributary confluences. Eggs were present on the quadrat located in the slackwater at the mouth of Socorro North Diversion Channel (Porter unpublished data). Quadrats placed in the current and 3 m up the arroyo did not have any eggs present after 1 h. This suggests that inundated arroyo inflow channels may serve as important locations for eggs and larvae to reside after exiting the main flow nursery habitat for silvery minnow.

Although rivers are always changing, the Socorro section of the river is still aggrading, sand-bedded, and braided channel similar to historic conditions. The Socorro reach has two large arroyos contributing to the Rio Grande: Arroyo de las Canas (~ RM 95) and Socorro North Diversion Channel (~RM 94). Arroyo de las Canas is currently contributing a moderate amount of gravel-sized sediment, which is transported only a short distance downstream (Hilldale, 2001), while Socorro North Diversion Channel mostly contributes sand-sized material. Generally, this area has always been the widest section of the Middle Rio Grande, but even this section was narrowing prior to the channelization activities of the 1950s. The cross-section data (1962-1999) indicate that the main channel has continued to generally narrow; however, the amount of overbank flooding, estimated at 141.6 m^3s^{-1}, has increased over the same period. Bed elevation data indicate some aggradation prior to 1972 (~0.5 m), some degradation between 1972 and 1992 (~0.5 m), and then no change in the 1990s (Massong *et al*., 2002). These data indicate a rather stable channel, in contrast to the Bernalillo / Albuquerque reach, in which incision, bed coarsening, and channel morphology have changed. Based on present conditions, this reach is not expected to evolve significantly in the near future. The channel width, which is one of the only variables changing, will likely continue to narrow. Other features such as channel elevation, bed material, and the braided channel form appear stable and are expected to remain stable (Massong *et al*., 2002).

The persistence of silvery minnows in the Bernalillo and Isleta reaches indicates some egg retention occurs within these areas. The higher, more reliable flow in these two reaches produces a range of available habitats. Water quality issues do not appear to significantly affect the minnow populations. Silvery minnows maintain higher densities in the reach with the least channel incision and the highest connectivity with arroyo tributaries, an observation consistent with the stable channel form found in the San Acacia reach (i.e. Socorro North Diversion Channel section). The slackwater in inundated arroyo channels along the main Rio Grande may provide essential nursery habitat for silvery minnow eggs and larvae throughout the range of the minnow, which provides the basis for higher population densities. This aspect of life history and habitat interactions should receive verification in the field.

Currently habitat fragmentation, water quality, and nursery habitat do not provide predictive variables for a spatial model. Habitat fragmentation needs additional definition to differentiate its effects from those predicted by the nursery habitat hypothesis. Recent fish community data appear to falsify chronic, widespread effects of treated wastewater effluents, while identifying locations for more detailed investigation. The distances between sample sites are too large to detect localized water quality effects from wastewater treatment facilities or other point sources. The role of nursery habitat for the silvery minnow requires quantification of the relationships between location, area, and recruitment at sample sites. These data would encompass the interactions between geomorphology and flow for inclusion in a spatial habitat model. The negative results from these analyses illustrate where data need to be refined to develop useful spatial habitat models for the silvery minnow.

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