STATUS OF WILD RAZORBACK SUCKER IN THE GREEN RIVER BASIN, UTAH AND COLORADO, DETERMINED FROM BASINWIDE MONITORING AND OTHER SAMPLING PROGRAMS

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EXECUTIVE SUMMARY

Adults and larvae of razorback sucker were sampled in the Green River Basin, Utah and Colorado, from 1996 to 1999 to assess their status and monitor population trends. Data from other studies and years were added to enhance the strength of the relatively sparse data set. The wild adult population in the middle Green River, Utah, from 1985 to 1992 was small at about 300 to 600 adults but recruitment was thought sufficient to replace annual mortality. Sampling since 1992 indicated that wild razorback suckers remained in a large portion of the Green River, including the lower Yampa River and the middle and lower Green River. Negligible change in total length (TL) of razorback suckers in the middle Green River, based on recaptures of PIT-tagged fish since 1990, mirrors the findings of other investigators for this and other populations of this species. Abundance estimates conducted with data collected since 1992 suggested a substantial decline in the number of wild adult razorback suckers in the middle Green River when compared to earlier estimates. On average, the most recent and reliable estimates from 1998 and 1999 data suggested that only about 100 (95% CI, 80 to 180) wild fish remained. Survival rate estimates calculated from 1990 to 1999 data were similar to the earlier period and suggested that recruitment failure was the reason for population decline. Larvae were captured in each year from 1996 to 1999 in the lower and middle Green River and sporadically in the lower Yampa River. Concurrent with declines in adult abundance, captures of larvae have also declined throughout the Green River Basin since about 1994. Wild razorback suckers may soon disappear from the Green River system entirely. Reasons for decline and suggestions for future monitoring of stocked razorback suckers are discussed.

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INTRODUCTION

Endangered razorback sucker *Xyrauchen texanus* was once widespread and abundant throughout the Colorado River Basin but is now rare (Minckley 1983, Bestgen 1990, Minckley et al. 1991). Concentrations occur in lakes Mohave and Mead, Arizona and Nevada, and in the middle Green River, Utah but elsewhere occur only as scattered individuals (Minckley 1983, Tyus 1987, Bestgen 1990, Minckley et al. 1991, Modde et al. 1996, Holden et al. 2001). Wild fish in Lake Mohave have declined in abundance to about 4,000 individuals in 2001 (Minckley et al. 1991, Marsh 1994, G. Mueller pers. comm.). Abundance of adult Green River razorback suckers was estimated at about 300 to 950 during the 1980 to 1992 period (Lanigan and Tyus 1989, Modde et al. 1996), but the present status of that population is unknown. Wild populations of razorback suckers are dominated by large, old individuals, and recruitment rates everywhere are thought low or non-existent (Minckley 1983, Minckley et al. 1991, Tyus 1987, Modde et al. 1996).

Decline of razorback suckers has been attributed to alterations of physical habitat and negative effects of introduced fishes. Mainstem dams alter flow patterns, water temperature, and sediment loads and also serve as barriers to upstream fish movement (Carlson and Muth 1989). In the upper Colorado River Basin, flow reduction due to storage of spring runoff, and effects of channelization and levee placement, reduce frequency and duration of flood plain inundation. A decrease in warm, food-rich flood plain areas, which are likely important as rearing and resting habitat for early and life adult stages of spring-spawning razorback suckers, may limit recruitment (Modde et al. 1996). Predation on early life stages of razorback suckers, combined with slow growth, is also thought a primary factor limiting recruitment (Minckley et al. 1991).

Basinwide monitoring program sampling (Basinwide) began in 1996 with a goal to track status and trends in abundance of razorback suckers in the Green River Basin of the upper Colorado River Basin (Muth 1995; Muth et al. 1997). A basinwide monitoring program was deemed necessary to determine if restoration efforts were benefitting razorback suckers in the Green River. This initial effort was focused only in the Green River but sampling techniques and protocols may be applicable for monitoring razorback suckers throughout the upper Colorado River basin. Sampling protocols used in this study for adults and early life stages were a refinement of earlier work from 1992 to 1996, the rationale for which was discussed in Muth (1995). Unfortunately, Basinwide monitoring program sampling produced relatively sparse data, which made evaluation of status of razorback suckers in the Green River difficult. Sparse data also limited our ability to develop and evaluate a monitoring program for razorback suckers, which was a primary goal of this study. To bolster limited Basinwide program data, we incorporated all available information from other sampling programs conducted during 1996 to 1999. This allowed us to make stronger inferences about the status of wild razorback suckers in the Green River, which is the primary focus of this report.

STUDY AREA

The main study area was the Green River from the confluence of the Yampa River downstream to the confluence with the Colorado River. A small number of fish were also sampled in the lower portion of the Yampa, Duchesne, and San Rafael rivers during the course of this program and in other studies. Channel morphology varied among canyon and valley reaches of the Green River. In most canyon reaches, channel gradient was high, substrate was coarse, and the flood plain was confined. In valley reaches, channel gradient was lower, substrate was mostly sand, and the flood plain was relatively broad. Although more widespread historically, most razorback suckers now occur in relatively low-gradient reaches of the Green River from upstream of Jensen downstream to near the White River confluence (Fig. 1).

METHODS

Fish sampling, adults.–Basinwide sampling for adult razorback suckers was conducted in the lower Yampa, and the middle and lower Green rivers, both at sites that previously yielded razorback sucker adults (summarized in Muth 1995) and at other locations. In 1996, 1998, and 1999 sampling in the Yampa River was near the suspected spawning bar in the lower kilometer of the river in Echo Park (McAda and Wydoski 1980). Three reaches of the middle Green River received most of the 1996 to 1999 Basinwide sampling effort. Sampling in the most upstream reach was near Escalante Ranch (Escalante reach, river km (RK) 486 to 515; now called Thunder Ranch) and was focused near or on the suspected spawning areas at RK 494.3 and 501.5 and near the mouths of Cliff Creek and Brush Creek and the Helley Pump. Sampling in the second middle Green River reach (RK to 446 to 486) near Jensen (Jensen reach) occurred near Jensen Bridge, Kane Hollow, Red Wash, Spring Hollow, and Walker Hollow, but most effort was expended near Ashley Creek, Sportsmans Drain, and Stewart Lake Drain. In the third reach of the middle Green River reach near Ouray (Ouray reach, RK 399 to 446), sampling occurred mostly near the inlet or outlet of Old Charlie Wash and the mouth of the Duchesne River. Adult Basinwide sampling in the lower Green River was limited to the San Rafael River confluence in 1997, but was more extensive in 1998 and 1999. Most effort in the Green River valley reach (RK 151 to 193) occurred in or near the mouth of the San Rafael River, a suspected spawning area.

Downstream of the San Rafael River in the Labyrinth Canyon reach of the Green River, most sampling was near Anderson Bottom and Millard Canyon. Effort at individual sites or reaches varied among seasons and years due to differences in flow level and availability of suitable sampling areas so effort by sites was not reported.

Adult sampling was with fyke and trammel nets in low-velocity channel-margin eddies, large backwaters or pools, and flooded tributary mouths. These gears were thought less harmful than electrofishing capture of ripe adults over the spawning areas as was previously done (Muth 1995, Modde et al. 1996). Sampling began in late April to early May and usually extended through mid- to late June, thus encompassing most of the reproductive period for razorback suckers (Tyus and Karp 1990, Muth et al. 1998). Fyke nets were set for 1 to 3 days each; trammel nets were set for 1 to 3 hours each.

Additional data obtained outside of the Basinwide sampling program were used in analyses of the status of razorback suckers in the middle Green River. Those data were from the Interagency Standardized Monitoring Program (McAda et al. 1993 to 1997), the Levee Removal Program (Birchell et al. 2001 draft), other flood plain sampling (Modde 1997), and from 1998 and 1999 efforts aimed specifically at capturing adult razorback suckers for brood stock for the Ouray National Fish Hatchery. Boat electrofishing and passive gear such as trammel and hoop nets were used in those efforts. Broodstock collection involved springtime electrofishing of spawning bars near Escalante Ranch, the primary sampling location for data analyzed by Modde et al. (1996). Sampling at the spawning bar had not been conducted from 1994 to 1997 due to potential injury to reproducing adults. These additional data were collected in the same reach encompassed by Basinwide sampling, so we assumed that the same population was at risk of capture for all sampling.

All adult fish captured were weighed and measured, and scanned for the presence of a passive integrated transponder (PIT) tag or examined for presence of a carlin dangler tag. Beginning in 1990, fish captured that were tagged with carlin tags were re-tagged with PIT tags and the former tag type was removed (pers. comm. C. McAda). Data were reported to the centralized database manager for archiving.

Fish sampling, larvae.–Light traps were used as the primary sampling gear during Baisnwide monitoring because sampling during 1992 to 1995 (Muth 1995) demonstrated that light traps were a more effective means of sampling early life stages of razorback suckers from low-velocity areas than other gears. During 1996 to 1999, light-trap sampling for early life stages of razorback suckers occurred in the same reaches as adult sampling, but effort was distributed differently. Light-trap sampling localities for the middle and lower Green River reaches are listed in Appendix I and II, respectively. Only a few samples were collected in the lower Yampa River in 1996 and 1998, but none were collected in 1997 or 1999. Sampling in the middle Green River occurred in all three main reaches but was concentrated near the Escalante Ranch spawning area (e.g., Cliff Creek) in most years, and secondarily near downstream Old Charlie Wash and Ouray National Wildlife Refuge (e.g., Greasewood Corral). In general, sampling became more focused on areas where suitable low-velocity habitat was available each year and throughout the season regardless of flow level. In the lower Green River, sampling for larvae was concentrated in Labyrinth Canyon near Millard Canyon, Anderson Bottom, Holeman Canyon, and Stillwater Canyon, and near the mouth of the San Rafael River. Light-trap sampling was also conducted in the Green River Valley. These were many of the same places that were sampled in previous work from 1993 to 1995 (Muth 1995). Flooded tributary mouths and washes, large backwaters, and other low-velocity channel-margin areas were primary sampling areas. Similar to adult sampling, light-trap sampling effort at individual sites or reaches varied among seasons and years due to differences in flow level and availability of suitable sampling areas so effort by sites was not reported.

In each sampling area, 1 to 10 light traps were set at dusk and were emptied prior to dawn each sampling day. Light traps were described by Muth et al (1998). In the middle Green River, light-traps were usually set twice per week after catostomid larvae were first detected and sampling continued for until few or no additional larvae were captured, usually by mid- to late June. Additional samples were collected in the middle Green River in 1999 to capture larvae for brood stock development. Razorback sucker larvae were identified alive, based on their small size relative to other catostomids, and transported to Ouray National Fish Hatchery. Sampling in the lower Green River was less regular and dictated more by timing of associated sampling trips in this more inaccessible area. Lower Green River sampling in 1993 and 1994 was viewed as exploratory (Muth et al. 1998). Samples other than those for brood stock were preserved in ethanol for later identification in the laboratory.

Data analysis, adults.–We first present data and summary statistics for adult razorback suckers collected under Basinwide sampling from 1996 to 1999. We then present all available adult razorback sucker capture data from the Green River Basin during those and previous years. Fish were counted as captured only once per year for purposes of data analysis, even though a few individuals were captured twice in the same season. Since 1991, adult fish were tagged with PIT tags, data obtained prior to then were from carlin-tagged fish. This difference was potentially important because loss rates of carlin tags may be quite high, whereas PIT-tag loss was assumed to be zero. Differences in tag-loss rates may affect interpretation of apparent survival-rate estimates in the two periods and may also affect number of recaptures available to calculate abundance estimates. We expended considerable effort attempting to ensure that all tagging records were included and to ensure that capture histories of fish tagged with both carlin and PIT tags were merged. The few additional records that were matched with this effort are potentially important because longer capture histories may affect survival-rate estimates. Most additional data were obtained from the centralized database maintained by the U. S. Fish and Wildlife Service, Grand Junction, Colorado or from Modde et al. (1996). There were also several “re-discovered” recaptures from the years 1990 to 1992 (mostly fish for which carlin- and PIT-tag capture histories were not matched together), the last years for which abundance estimates were produced by Modde et al. (1996). These are important because the entire data set is sparse and overlooking just one or two individuals will bias abundance estimates based only on a few recaptures.

We were interested mostly in captures of wild fish so we could ascertain the status of that portion of the population. Hatchery-reared fish released into the Green River from 1996 to 1999 were also captured in Basinwide and other sampling programs. We made a concerted effort to segregate wild from hatchery-reared and released fish but it was often difficult because we were uncertain if all released fish had been recorded in a database and reported. We also had difficulty tracking the status of wild fish taken to the hatchery for brood stock and when, if ever, they had been returned to the river. For example, one individual was captured in the vicinity of the spawning area in 1989, 1992 and again in 1993 when it was removed from the river and held in captivity. There were no other records of this animal, including a date of repatriation from the hatchery, until it was recaptured again in 1998 and 1999. Finally, there was uncertainty regarding numbers, release locations, sizes, and tag status of hatchery-reared razorback suckers released into the Green River and associated flood plain habitat. A better system for tracking re-

release of wild fish and release of hatchery fish would enhance the ability of the Recovery Program to understand the contribution of different groups of hatchery fish to the Green River population.

Length-frequency data.– Length-frequency histograms of fish captured since 1980 were plotted to determine if size of fish changed over time. Similar to Modde et al. (1996), we combined 2 to 4 years of data into single histograms in order to increase sample size, but we only used fish size at first capture. Because we were particularly interested in detecting changes in length frequencies after fish stocking began in 1996, we plotted 1996 and 1997 data together and 1998 and 1999 data together. We also plotted mean length of razorback suckers captured over all sampling years to determine if changes in length were occurring. Changes in lengths of recaptured fish were also plotted as a function of time between first and last recapture intervals.

Abundance estimates.–Similar to Modde et al. (1996), we estimated abundance of razorback suckers in the Green River. Because the data-collection period spanned 20 years (1980-1999) and because mortality and recruitment were likely occurring, this population was most correctly classified as an open population. However, data collected in this study were too sparse to obtain abundance estimates for open populations using the usual Cormack-Jolly-Seber (CJS) methods (Pollock et al. 1990). Therefore, we used capture data from pairs of sequential years to estimate an index of abundance of razorback suckers using a Lincoln-Petersen estimator in program CAPTURE (White et al. 1982). We used captures and recaptures in years i and $i + 1$ and recaptures in year $i + 1$ to compute estimates for the year $i + 1$ as follows:

$$\hat{N}_{i+1} = \frac{n_i \cdot n_{i+1}}{m_{i,\, i+1}} ,$$

where $m_{i,\, i+1}$ is the number of fish captured in year *i* and *i* + 1, and n_i and n_{i+1} is the number of fish captured in each sampling year. We estimated abundance of adult razorback suckers for all pairs of years beginning in 1980 rather than using previously computed estimates from 1980 to 1992 because of corrections to capture histories that were discovered since the Modde et al. (1996) analyses. We tested for trends in abundance over time for periods 1980-1992, 1990 to 1999, and the entire period (1980 to 1999) by regressing abundance estimates (as *ln*) as a function of time. No correction was made for years when no estimates were available. We assumed these are the best available data, recognizing that mistakes in recording, non-detection of PIT tags, and other factors may affect the capture histories used in these analyses. Future efforts should ensure that accurate data recording and tag detection is a priority.

Survival estimates.–Jolly-Seber type models (recapture only and Barker's survival and population rate of change models) in program MARK (White and Burnham 1999) were used to estimate survival rates of wild adult razorback suckers. The goal of these analyses was to estimate probability of capture (*p*) and apparent survival rate (N) of fish in the population available for capture. We assumed that all individuals in the middle Green River population were available for capture so that apparent survival rate N, assuming tag loss of zero and site fidelity = 1, can be considered an estimate of true survival *S*. The assumption of site fidelity was not specifically evaluated, but can be considered so for the purposes of this analysis because movement of fish in the middle Green River was thought restricted to the area encompassed by our sampling (Tyus and Karp 1990). We used Barkers model to estimate lambda (8), the population rate of change, which is a joint function of survival, recruitment, and fidelity of the animal to the study area. A 8 value less than one indicates a declining population, 8 > 1 indicates an increasing population, and 8 = 1 indicates a stable population. Global models that fit parameters (*p*, N), 8) for all years were tested against models with a reduced parameter set. Akaike's Information Criterion (AIC) was used as a guide in model selection; model fit was also assessed with tests in program RELEASE (Burnham et al. 1987). We were careful to guard against overfitting models with the sparse data available in this study and focused on those that gave reasonable estimates of parameters that were critical to understanding the status of razorback suckers in the middle Green River.

Data analysis, larvae.–We present capture data for all species and also catch per unit effort (CPUE) for three native catostomids, razorback sucker, flannelmouth sucker *Catostomus latipinnis,* and bluehead sucker *Catostomus discobolus*. We also used data from 1993-1996 presented by Muth et al. (1998) to obtain a longer data series so that we could evaluate potential trends in capture rates. The CPUE analyses were number of fish captured per hour of light trapping; average sampling time was about 8.5 hours. Total annual sampling effort was based on samples collected only after the first sucker larvae was captured each year.

Capture dates of razorback sucker larvae were used to reconstruct timing and duration of hatching embryos and reproduction by adults in relation to flow and water temperature regimes. This approach follows Muth et al. (1998) except they used otolith increments to estimate hatching dates and growth rates of larvae. We back-calculated hatching dates for individual larvae by subtracting length of larvae at capture from average length at hatching (8.0 mm TL). We divided the difference by 0.3 mm, which was the average daily growth rate of wild larvae observed by Muth et al. (1998). The result was an estimate of the number of days since hatching, which was subtracted from the capture date. Time of embryo fertilization (spawning) was estimated by subtracting temperature-dependent times of incubation from hatching dates; incubation times were estimated from Bozek et al. (1990). Dates of incubation, hatching, and capture compared to flow and temperature regimes gathered from U.S. Geological Survey gauges or other sources (pers. comm., G. Smith, U.S. Fish and Wildlife Service, Denver, CO). Temperature data were average daily or instantaneous readings. Winter and early spring temperatures (through mid-April) for the middle Green River gauge at Jensen, Utah were not available in 1998 and 1999 but were estimated from the average of daily readings collected from 1980 to 1997. Lower Green River data were from the gauge at Green River, Utah.

RESULTS

Razorback sucker distribution.–Since 1992, wild adult razorback suckers were captured throughout most segments of the Green River Basin, including the lower and middle Green River, at the confluence of the San Rafael River, in the lower Yampa River, and in the Green River in Lodore Canyon. We used distributional data collected only since 1992 because other investigators had reported data collected prior to then (Modde et al. 1996). During 1996 to 1999 Basinwide and other sampling, most effort and captures (97%, N = 118 unique fish) were concentrated in the middle Green River from upstream of the White River to just below Split Mountain Canyon (Fig. 2). Most fish captured in the middle Green River were from the Escalante reach (46 %), whereas fewer were captured in the Ouray (32 %) and Jensen (22 %) reaches. Most razorback suckers (70 %) captured in the middle Green River from 1996 to 1999 were from just three locations, the Escalante Ranch spawning sites (RK 500.4), Ashley Creek (RK 481), and near Old Charlie Wash (RK 401.4 to 401.6). Most adult razorback suckers were captured in May (56 %) or June (37 %). Adult razorback suckers were very rare in other portions of the Green River Basin. Only two adults were taken in each of the lower Yampa (RK 0.0 to

0.3) and the lower Green rivers (RK 156 and 236.7). The stocked razorback suckers captured in 1996 to 1999 (N = 25) were mostly from the same areas in the middle Green River (N = 21) and were concentrated in the Escalante Ranch spawning bar reach; four were also captured in the lower Green River.

Early life stages of razorback sucker have been captured at more locations than adults since 1992, but encompassed essentially the same range (Fig. 3). The distribution of sampling sites was relatively broad in the study area during Basinwide sampling (appendices I and II), but fish were captured at relatively few sites. Larvae have been collected as far upstream as the mouth of the Yampa River downstream to the lower Green River in Labyrinth Canyon. Most razorback sucker larvae were captured in the middle Green River from the Escalante and Ouray reaches, and in the lower Green River near the San Rafael River and in Labyrinth Canyon. Few fish were captured in the Jensen reach or in the Green River near Green River, Utah. We also note that a razorback sucker larva was captured in the lower Yampa River on 2 July 2000 during drift net sampling for larvae of Colorado pikeminnow *Ptychocheilus lucius*. That fish was only 9 mm TL and suggested continued spawning in that system at a relatively late time in the year.

Basinwide sampling, adults, 1996 to 1999.– A total of 83 adult fish were captured in Basinwide sampling from 1996 to 1999 (Table 1). Of those, a minimum of 25 individuals were of hatchery origin, assuming no loss of PIT tags. Of the remaining 58 presumptive wild fish captured, only five of those were recaptures of fish that were tagged or recaptured and released in the period 1996 to 1999. The low number of captures and recaptures prevented any type of abundance estimation using only fish captured in Basinwide sampling. Basinwide sampling suggested that stocked fish were surviving and in 1999, outnumbered wild fish captured. Of 33 total fish captured in 1999, 19 (58 %) were hatchery-reared fish.

The length-frequency distribution of stocked razorback suckers captured in Basinwide and other sampling programs from 1996 to 1999 suggested the presence of fish from 280 to 460 mm TL (Fig. 4). Recaptures of hatchery fish released since 1995 suggested that few or none of the relatively small razorback suckers stocked in 1995 survived but some larger fish stocked in 1996, 1998, and 1999 survived and grew (Table 2). The average change in length for fish stocked in 1996 and recaptured in 1997 and 1998 was 99 and 130 mm TL, respectively. Razorback suckers stocked in 1998 and recaptured in 1999 grew an average of 66 mm TL. Even fish stocked and recaptured in 1999 exhibited an average positive change in length of 19 mm TL. Inferences about individual growth rates are impossible to make because only a mean length was taken for batches of hatchery fish released from 1996 to 1999. Several hatchery fish captured were in spawning condition and four of those were found with wild fish on or near the Green River spawning bars near Escalante Ranch.

Middle Green River sampling, adults, 1980 to 1999.–A total of 593 individual razorback suckers were captured from 1980 to 1999 (Table 3). A total of 184 recaptures were recorded, for a total of 777 capture events. Length frequency distributions of wild fish captured since 1980 reflected the preponderance of large fish in samples, and fish 440 mm TL or less were absent in most years (Fig. 5). Selective sampling for larger fish during Basinwide sampling was discounted because the sampling gear captured stocked fish that were 300 to 440 mm TL (Fig. 4). Sampling in Basinwide and other programs was also conducted in a variety of main stem and flood plain areas, so it seems unlikely, especially in the middle Green River, that concentrations of fish went undetected. The mean size and size range of fish also changed little over time, with the exception of 1994 and 1995 (Fig. 6). Most of the small fish captured in 1994 and 1995 were from a managed wetland, Old Charlie Wash, that was drained in autumn (Modde 1996). Only two other individuals less than 400 mm TL were detected in sampling in the 1990's that could be reasonably classified as wild fish. Regression of average annual length of fish captured as a function of time resulted in a negative slope coefficient (-2.96, SE = 1.55, P = 0.07), which was heavily influenced by the few small fish captured in 1994 and 1995. In the absence of those few small fish in 1994 and 1995, average length of fish in the middle Green River was similar over time.

The negligible changes in length of recaptured PIT-tagged fish from 1990 to 1999 suggested that razorback suckers in the Green River grew slowly over time (Fig. 7). Changes in length between recapture intervals was generally less than 20 mm TL for most fish, regardless of the length of the recapture interval. Notably, two individuals which were at large 10 and 11 years, increased an average of 2 and 0.45 mm TL per year, respectively. Many fish apparently decreased in TL, which suggested measurement error.

Abundance estimates.–Abundance estimates of adult razorback suckers calculated for pairs of sequential years from 1985 to 1992 averaged 456 animals (Table 3, Fig. 8 in part). Regression analysis did not detect a substantial change in average annual abundance over the same period (Table 4), although the coefficient was negative. We excluded the 1982 estimate which was based on only a single recapture to provide the most conservative trend analysis. Inclusion of that abundance estimate would have leveraged the slope of the regression coefficient substantially downward.

Abundance estimates of adult razorback suckers calculated for pairs of years from 1993 to 1999 were reduced from earlier levels and averaged about 210 animals. From 1994 to 1997, captures and recaptures were particularly sparse so estimates in 1995 (1994 and 1995 year pair) and 1997 (1996 and 1997 year pair) were unavailable and estimates for 1994 and 1996 were unreliable because there was only a single recapture event. However, the more reliable 1993, 1998 and 1999 estimates averaged only 163 animals and provided persuasive evidence of a downward trend in abundance. Those estimates were more convincing because of the higher number of fish captured and recaptured and resultant relatively small values for coefficients of variation (CV) and confidence intervals.

Regression analyses of abundance estimates (*ln*) as a function of time that were available between 1990 to 1999, conducted both with and without sparse data years 1994 and 1996, detected significant declines in abundance from about 500 animals in 1990 to about 100 animals in 1998 and 1999. Data from 1990 to 1992 were included in each of the early and later analyses because that was when PIT tags replaced carlin tags. This was important because tag type may play a role in tag retention, number of recaptures observed, and subsequent abundance estimates. It also seemed reasonable to include that data in each analysis, because that was the time during which population status may have been changing. Regression analysis including years 1985 to 1999 also suggested a significant decline in population abundance.

Survival estimates.–Survival estimates were generated with the recaptures only model in program MARK for time periods 1980 to 1992 and 1990 to 1999. Model goodness-of-fit to the data was assessed with program RELEASE in MARK and was deemed adequate (a non-significant chi-square test, P = 0.93). Model selection by AIC suggested the overwhelming model choice for each time period was constant N with time-varying p. Apparent survival, N, was 0.728 (SE = 0.0287) for the time period 1980 to 1992, and was 0.762 (SE = 0.0475) for 1990 to 1999. The larger SE for N from 1990 to 1999 reflected the fewer years of sampling and the lower number of individuals recaptured.

We used Pradel's survival and population rate of change model in program MARK for the full 1980 to 1999 data set to estimate 8, the population rate of change. The most reasonable candidate model had constant 8 and N and time-varying *p*. Survival rate was estimated at 0.69 (SE 0.021) and 8 = 0.91 (SE = 0.014). This suggested an average overall population decline from the joint effects of emigration, immigration, recruitment, and mortality of about 9% per year during the period 1980 to 1999. A 9% decline per year would be the interpretation of a lambda value of 0.91 because a value of 1.0 (1.0 - 0.91 = 0.09, or 9%) indicates no change in the population rate of change. Another candidate model with time varying 8 was not interpreted because estimates from the early 1980's were unreasonably small or large (>200,000).

Other adult fish sampling, 1996-1999.– Relatively few wild adult fish were captured in other areas of the Green River basin. Only two were captured in the lower Yampa River and two were captured in the lower Green River during Basinwide sampling. Four stocked fish were captured in the lower Green River during that time.

Larvae, middle Green River.–During Basinwide sampling in 1996 to 1999, larvae were sampled with light traps in both the middle and lower Green River reaches. In the middle Green River, a total of 20,844 fish in 15 taxa were captured in light-trap samples from 1996 to 1999 (Table 5). Of those, 10,048 (48.2 %) were native catostomids (included all unidentified fish), and 247 (1.2 %) were razorback sucker larvae. We consider only native catostomids in these analyses because abundance of the only other catostomid captured, introduced white sucker *Catostomus commersoni*, was low in all years. In 1999, the 12 larvae captured were sent to Ouray National Fish Hatchery for possible rearing and use as brood stock. All other specimens were discarded so information for other taxa was not available. Capture rates of catostomid larvae did not appear related to sampling effort for 1996 to 1998 when data were available for all taxa.

In 1992 to 1999, a total of 60,977 fish were captured using all sampling gear types. Of those, 31,999 (52.5 %) were sucker larvae, and 1,808 (3.0 %) were razorback suckers. From 1993 to 1998 when light traps were used consistently and full samples were retained, the number of catostomid larvae captured varied from 106 in 1997 to 13,386 in 1994. Capture rates of catostomid larvae did not appear related to sampling effort for 1993 to 1998 (r = - 0.15). The CPUE for all native suckers and for razorback sucker larvae was highest in 1994 by a considerable margin (Table 6). The CPUE for razorback sucker was relatively low in 1995 and 1997 to 1999. The proportion of razorback sucker larvae to all catostomid larvae was relatively high in 1993 and 1994 but also declined after that (Fig. 7).

Razorback sucker larvae were relatively rare in samples collected from 1996 to 1999. Number of razorback sucker larvae captured varied by more than an order of magnitude (12 to 174), in spite of the relatively even numbers of samples collected (126 to 247) and a relatively constant (1,115 to 2,158) number of sampling hours among years. Sampling effort and number of razorback sucker larvae captured were not positively correlated (r = - 0.10) as the highest level of sampling effort conducted in 1999 captured only 12 larvae. Larvae were relatively small in 1997 and 1998; average size in those years was 11.6 and 12.5 mm TL, respectively (Table 7). No lengths were taken on larvae captured in 1999 because those fish were sent to the Ouray National Fish Hatchery.

Timing of captures of razorback sucker larvae were relatively late in the middle Green River from 1997 to 1999, ranging from 2 June to 1 July (Fig. 8). Back-calculation of spawning dates based on captures of larvae suggested that spawning occurred from early May to early June in 1997 and 1998. Most spawning occurred during peak flow levels and when water temperatures were rising. Flow levels during spawning were variable within and among years and water temperatures were generally in the 10 to 17°C range. Environmental conditions during spawning were similar to those during other sampling years since 1993 (Table 8). In general, razorback suckers spawned in the middle Green River from mid-April to mid-May when water temperatures were 10 to 16°C and when accumulated degree days ranged from about 400 to 900. Spawning generally began 5 to 36 days prior to day of highest spring runoff flow and nearly always before water temperatures reached 14°C. In 1997 and 1998, most larvae were captured when spring runoff flows were declining. Only in 1999 did timing of high flows correspond with occurrence of most razorback sucker larvae in samples, a year in which few larvae were collected.

Larvae, lower Green River.–In the lower Green River from 1996 to 1999, a total of 41,829 fish in 13 taxa were captured in light-trap samples (Table 9). Of those, 6,824 (16.3 %) were native catostomids (included all unidentified sucker larvae), and 304 (4.4 %) were razorback sucker larvae. The number of native catostomid larvae captured varied from 146 in 1997 to 2,666 in 1998. Sampling effort and number of catostomids captured was positively correlated (r = 0.93) with sampling effort for 1996 to 1999.

In 1993 to 1999, a total of 72,864 fish were captured using all sampling gear types. Of those, 8,343 (11.5 %) were sucker larvae, and 530 (0.7 %) were razorback suckers. Light-trap sampling data showed high variation in catostomid abundance as the number of catostomid larvae captured varied from 122 in 1993 to 2,666 in 1998. Capture rates of catostomid larvae were positively correlated with sampling effort (r = 0.80) from 1994 to 1999. The CPUE for all native suckers varied considerably by year and was mostly a function of changes in abundance of flannelmouth suckers. The CPUE for razorback sucker was highest in 1993 when the only samples were collected from 17 and 19 June, second highest in 1994, and declined to relatively low levels after that. Similar to the middle Green River, the proportion of razorback sucker larvae to all catostomid larvae in lower Green River samples was relatively high in the sparse sampling year 1993 and in 1994 but declined after that (Fig. 7).

Razorback sucker larvae were relatively rare in samples collected from 1996 to 1999. Number of razorback sucker larvae captured varied from 3 to 214, in spite of the relatively even numbers of samples collected (263 to 295) and a relatively constant (2,480 to 3,644) number of sampling hours among those four years. Sampling effort and number of razorback suckers captured were positively, but only weakly (r = 0.44) related to sampling effort.

Most razorback sucker larvae captured in the lower Green River area from 1997 to 1999 (67 of 90, 74%) were from the vicinity of the mouth of the San Rafael River (in lower San Rafael River and Green River, RK 156.1 - 152.0). Ten of the remaining larvae were from upstream of the San Rafael near Anvil Bottom (RK 161.6) and the other thirteen were captured downstream from the Anderson Bottom and Millard Canyon areas. Larvae collected in the lower Green River from 1997 to 1999 were slightly larger than those collected in the middle Green River, and in 1998, several relatively large larvae were found in samples collected in the mouth of the San Rafael River (Table 7). For example, on May 4 and 5, a 16 mm TL larva was captured on each day, which produced estimated spawning dates of 21 and 22 March, respectively. Water temperature in the San Rafael was 19 to 20°C, compared to 15°C in the Green River. Larvae up to 19 mm TL were captured that year.

Timing of captures of razorback sucker larvae in the lower Green River from 1997 to 1999 were relatively early, generally ranging from early May to early June, although a single specimen was captured on 1 July in 1999 (Fig. 9). Back-calculation of spawning dates based on captures of larvae suggested that spawning occurred from late March to early June, which is substantially earlier and over longer period than in the middle Green River. Most spawning occurred when flow levels were relatively low or increasing and when water temperatures were relatively low but rising. Flow levels during spawning were variable within and among years and water temperatures in the Green River were also variable and ranged from 7 to 21°C in 1998. Those environmental conditions were similar to those during other sampling years since 1993 (Table 8), except that water temperatures were generally cooler and days prior to peak discharge were higher. Differences could be an artifact of the manner in which spawning times were calculated or may represent real differences in conditions in those years. In general, razorback suckers spawned in the lower Green River from early-April to early-May when water temperatures were 10 to 16°C and when accumulated degree days ranged from about 350 to 1100. Spawning generally began 28 to 78 days prior to the highest flow day during spring runoff and nearly always before water temperature reached 14°C. In contrast to the middle Green River, larvae in the lower Green River were captured prior to or during high flow periods.

DISCUSSION

Previous investigators classified the population of razorback suckers in the middle Green River as precariously small but stable between 1985 to 1992 and estimated population abundance at about 300 to 600 animals (Modde et al. 1996). Modde et al. (1996) also estimated annual survival rate, N, at about 0.71 (SE = 0.0246) and concluded that some recruitment must be occurring to sustain the population at that level. Our more recent analysis suggested that razorback suckers in the middle Green River had declined since 1992 with only about 100 wild razorback suckers remaining in 1999. We discuss several lines of evidence that support the hypothesis of a declining population. We also make recommendations for monitoring remaining wild fish as well as hatchery fish that have been stocked in the Green River to rebuild the population.

Razorback sucker distribution.– Sampling since 1992 indicated that razorback suckers remain in a large portion of the Green River, but that most individuals still occur in the middle Green River from near Jensen, Utah, downstream to Ouray National Wildlife Refuge. Reproduction was documented in summer 2000 in the Yampa River in Echo Park, so a small population of adults must still exist in that vicinity. Given the similar capture rates of larvae in the lower Green River relative to the middle Green River, presence of a few ripe adults, rare occurrence of larvae in samples collected in Green River Valley, and capture of larvae prior to their appearance in the middle Green River, a reproducing population of adults must also occur in that area. Reproduction by razorback suckers has been suspected in or near the San Rafael River (Muth et al. 1998, Chart et al. 1999), but definitive evidence in the form of a relatively large number of ripe fish has proven elusive to this point.

The status of outlier populations, particularly those in tributaries, should be conclusively documented immediately so that habitat protection can be implemented. If wild fish play a role in attracting stocked fish to areas where successful spawning has occurred, understanding where successful reproduction by outlier populations is occurring may influence success of hatchery fish in those areas as well.

Basinwide sampling, adults, 1996 to 1999.–Basinwide sampling for razorback suckers in the Green River contributed to a data set that allowed analysis of the status of razorback suckers in the Green River, Utah and Colorado. In particular, Basinwide sampling was sufficient to detect adults and larvae in many locations that were scattered throughout the Green River Basin. Basinwide sampling also contributed information on the distribution and status of razorback suckers stocked into the Green River since 1995. However, data collected under the Basinwide sampling was too sparse to allow for more rigorous population level analysis and estimation of vital population statistics such as adult population size, and recruitment and survival rates. Such analyses were possible only when Basinwide sampling data were combined with data collected in spring 1998 and 1999 when fish for brood stock development were captured.

Middle Green River adult population analyses, 1980-1999.–Negligible change in TL of razorback suckers in the middle Green River, based on recaptures of PIT-tagged fish since 1990, mirrors the findings of other investigators for this and other populations of this species (Minckley 1983, Tyus 1987, Modde et al. 1996). With the exception of 1994 and 1995, the bulk of the middle Green razorback sucker population since the early 1980's was composed of individuals 460 to 560 mm TL and most of those were 480 to 520 mm TL. Given the slow growth of these fish, the likelihood of a fish growing out of a mode represented by a 20 mm-wide size increment on a length-frequency histogram is very small. Modde et al. (1996) suggested that recruitment was occurring during there study when length frequency histograms were stable and few relatively small fish were noted from 1980 to 1992. Recruitment was either low or non-existent after 1992 when the razorback sucker population declined in spite of the presence of small fish in the 1993 to 1995 length-frequency histogram. This suggested that length frequency histograms be interpreted cautiously when making inferences about recruitment or mortality rates and in conjunction with other data, as was done by Modde et al. (1996).

Abundance estimates calculated with data collected since 1992 suggested a substantial decline in the number of razorback suckers in the middle Green River when compared to earlier estimates. On average, the most recent and reliable estimates from 1998 and 1999 data suggested that only 116 (SE = 29) wild fish remained. Abundance estimates from 1985 to 1992 averaged 524 fish (Modde et al. 1996). Even recalculating those estimates with a revised data base that included more recapture records suggested that the population averaged about 456 fish from 1985 to 1992 (SE = 185). Those earlier estimates were mostly based on sampling fish only at the spawning bar upstream of Jensen, which may have under-estimated population abundance in the entire middle Green River reach. Captures made from 1996 to 1999 were from sampling that was more evenly distributed, and thus, it is likely that recent estimates more closely reflect the population in the entire middle Green River. We also considered that size-selective sampling may have biased low the number of small-bodied razorback suckers available for capture and influenced conclusions about declining population size and lack of recruitment. We dismissed that notion because recently stocked razorback suckers that were relatively small were captured in Basinwide and other sampling in the Green River. Thus, we feel as though conclusions regarding substantially reduced population size were warranted. Given the low recapture rates and the small apparent population size, we urge that more reliance be placed on interpreting and reporting a range of possible abundance values (e.g. confidence intervals) rather than annual point estimates.

We attempted survival-rate estimation from several different models. The Cormack-Jolly-Seber model, which also permits abundance estimation, did not converge because data were too sparse. The recaptures only model and Pradel's survival and population rate of change model yielded useful estimates of survival for this population. Estimates of N were relatively consistent for all time periods (N = 0.72, 1980 to 1992; N = 0.76, 1990 to 1999) and were consistent with the early estimate from Modde et al. (N = 0.71, SE = 0.0246). Small differences in 1980 to 1992 estimates from Modde et al. (1996) and this study were likely due to recent changes in capture histories of some individuals that were used in each analysis.

The N parameter in the Pradel model was also consistent with other estimates of survival of razorback suckers in the middle Green River. Pradel's 8, which estimates annual population rate of change from all sources including emigration, immigration, mortality, and recruitment, also suggested that the razorback sucker population was declining over time. However, the 8 parameter appears sensitive to large differences in sample sizes that occurred in the early 1980's and data is likely too sparse for reliable parameter estimation. Thus, we do not place much confidence in 8 estimates and instead rely on estimates of survival and population abundance to make inferences about the status of wild razorback suckers in the middle Green River.

If one assumes that 500 razorback suckers remained in 1992, average annual survival rate between the six yearly intervals until 1999 was 0.76 (our 1990 to 1999 estimate), and no recruitment or tag loss occurred over the period from 1992 to 1999, about 73 fish should remain (Fig. 10). This estimate is consistent with the average estimated abundance of 116 for the 1998-1999 period. This again suggests that little or no recruitment occurred from 1992 to 1999.

Larvae, middle and lower Green River.– Reproduction by razorback suckers was documented from 1996 to 1999 in both the middle and lower Green River reaches based on captures of early life stages of razorback suckers in each reach. That data extends the record documenting annual reproduction in the middle Green to 10 years (since 1992, Muth et al. 1998) if 2000 and 2001 are considered (unpublished data, K. Bestgen, Larval Fish Laboratory, Colorado State University). Reproduction occurred in seven consecutive years in the lower Green River since sampling began in 1993; no sampling has been conducted there since 1999. Documenting consistent annual reproduction might be considered something of a surprise given the apparent rarity of wild adult razorback suckers. This is particularly true in the lower Green River, given the number of razorback sucker larvae captured is relatively high and no large spawning aggregations have ever been detected with certainty in that area (Muth et al. 1998, Chart et al. 1999). We feel reasonably certain that larvae captured in the lower Green River were produced there rather than in the middle Green River based on the presence of larvae in that area prior to their appearance in the middle Green River.

The probability of documenting reproduction in the middle Green River is perhaps more certain given that a known spawning aggregation exists, but the number of wild spawning adults was certainly low and appeared to be declining. Most razorback suckers stocked in the middle Green River from 1996 to 1999 are, or soon will be, of reproductive size and age, and captures of those fish in ripe condition on or near the spawning bar suggested that those fish may be already contributing to annual reproduction.

Annual sampling with light traps appeared to be an effective sampling technique to document reproduction by rare razorback suckers in the Green River. We do not know if the number of larvae captured in light traps was a reliable indicator of their abundance. As discussed by Muth et al. (1998), annual or even inter-annual differences in environmental conditions may bias abundance indices such as CPUE that are estimated from light-trap sampling. For example, a high flow year that creates an abundance of flood plain habitat would widely disperse even a large number of larvae, whereas a lower flow year would concentrate even a few larvae into a small amount of sampling habitat. Thus, inferences about abundance data from light-trap sampling need to be made cautiously, especially with regard to relationships with environmental variables such as stream flows.

One possible inference from light-trap data for both the middle and lower Green River reaches is that the number of larvae captured since the early to mid-1990's appears to be declining, in terms of absolute numbers and CPUE data. An obvious reason for reduced reproduction is the decline of the presumed largest population of wild fish in the middle Green River. Other reasons for reduced reproduction are not apparent. Initially, we thought light-trap data from a site or sites that has a known history of captures and from sites present in all years regardless of flow level, may provide some index of reach-wide reproductive success over time. Unfortunately, capture data were too sparse in many years to allow for such an analysis.

Use of light-trap data to reliably estimate annual reproductive success of razorback suckers in the Green River may be possible, but additional information is needed. For example, no information exists to describe the probability larvae will be detected in a suitable habitat if light-trap sampling is conducted. Minimally, the relationship between fish density, backwater size, sampling effort, and detection probabilities should be quantified. At a reach scale, an aggregate of samples gathered to estimate a CPUE index may give an adequate picture of reproductive success only if capture probabilities are equal or known across sites and years. One way to estimate this would be to mark and recapture larvae over the sampling season that were released upstream of capture areas. The eventual and perhaps imminent loss of remaining wild fish and their reproductive output seemingly makes it easy to detect reproductive success by stocked fish. Light-trap sampling may give some reliable measure of reproductive success of stocked fish, especially if numbers of larvae captured increase by an order of magnitude (e.g., thousands instead of < than 100 captured per year).

The relationships between timing and duration of reproduction and stream flow and water temperatures that we found for 1997 to 1999 were similar to those found by Muth et al. (1998) from 1992 to 1996. Our analyses with relatively sparse data suggested that razorback sucker spawning in the middle Green River occurred from early May to early June when flow levels were increasing or at their peak and when water temperatures were in the 10 to 17°C range. Spawning was earlier in the lower Green River, from late March to early June, and over a longer period, than in the middle Green River perhaps because the river warms earlier at that lower elevation. Flow levels during razorback sucker spawning in the lower Green River were relatively low compared to the middle Green River because of earlier reproduction, but occurred at a similar 6 to 15°C temperature range. This suggested rising water temperature or absolute temperature level may be a more important environmental cue for spawning than flow level.

Changes in historical stream flow and temperature patterns may affect not only spawning periodicity but also recovery potential of endangered razorback sucker. Recommendations for operation of Flaming Gorge Dam in the upper Green River system included increasing the frequency and duration of spring flows to inundate flood plains (Muth et al. 2000). Flood plain inundation may create relatively food-rich and warm areas for larvae of spring-spawning razorback suckers, which may enhance their recruitment success. A key element of that flow management scenario is to time releases to provide habitat when larvae are present (e.g., post-emergence). Based on limited capture data, larvae were present in the lower Green River prior to or during most of the high flow periods from 1997 to 1999. Relatively early spawning in that area would allow larvae to incubate and emerge about the time that flows were peaking. In contrast, capture dates of the few larvae available from the middle Green River in 1997 and 1998 coincided only with the latter part of spring peak flows, or with declining flow levels. This was the case for several years from 1992 to 1996 as well (Muth et al. 1998). Larvae coincided with high flows for a longer period in 1999 when Green River discharge was maintained by relatively high and extended releases from Flaming Gorge Dam. Sampling to determine presence of larvae and duration of the spawning season would allow managers to fine tune timing and duration of releases from Flaming Gorge Dam.

The mouth of the San Rafael River and the Green River just downstream appeared to be a concentration area for razorback sucker larvae from 1997 to 1999. Relatively large numbers of larvae were also captured there from 1993 to 1996 (Muth et al. 1998). The presence of those larvae and their relatively large size, suggested that the San Rafael River may be an important rearing area for razorback suckers.

The consistent presence of relatively large numbers of larvae in the San Rafael inflow area also suggested that a spawning site for razorback suckers may be nearby. Adult razorback suckers may be attracted to the relatively warm water temperatures of the San Rafael River in early spring when the larger Green River remains cold. Spawning in the San Rafael River as well as the Green River may explain the relatively early presence of larvae and the apparently extended spawning season in the lower Green River. The importance of the San Rafael River and its inflow area to razorback sucker reproductive ecology should be further investigated.

Reasons for population declines.– Differences in tag loss rates from adult razorback suckers from 1985 to 1992 and from 1992 to 1999 had the potential to affect estimates of abundance and survival for this small population of fish. Modde et al. (1996) did not know tag loss rate during their study. We initially thought we may be able to estimate carlin tag loss rate from recaptures of fish tagged first with carlin tags and later with PIT tags. Unfortunately, carlin tags were removed from fish that were subsequently PIT tagged and it is unlikely that reliable estimates could have been achieved given low recapture rates. Use of PIT tags has likely reduced tag loss rates and tag failure is unlikely. Nevertheless, a PIT-tagged fish scanned with faulty equipment or one that is not scanned at all, errors in tag recording, or failure to report a tag, essentially results in "tag loss" and subsequent biased estimates of population parameters. The main point is that accurate tag detection rates are crucial to unbiased abundance estimation, especially when number of recaptures and population size is very low.

Whether tag loss and recapture rates biased abundance estimates high from 1985 to 1992 is unknown. We also do not know why populations were stable from 1980 to 1992 and declined after that. A decrease in survival rate does not appear to be responsible. In fact, N appears to have increased slightly in the later period, which suggested negligible recruitment must be responsible for population declines. Other than the few individuals captured by Modde (1996, 1997) in the managed wetland, recruits to the population were not apparent because few small fish were captured.

Small fish have been notably absent in collections historically (Minckley 1983, Bestgen 1990, Modde et al. 1996) and it was only in the 1990's that presence of a few juvenile fish was noted (Gutermuth et al. 1994, Modde et al. 1996). The recent documented presence of young fish in the system may simply be a function of more sampling effort and different sampling techniques compared to earlier periods. In spite of the documented presence of young fish, a substantial decline in the number of adult fish occurred during that time.

Reduced captures of larvae in light traps in the mid- to late-1990's may suggest insufficient reproduction for recruitment to occur. This could be due to low numbers of adults, poor embryo viability, poor condition of larvae, or environmental conditions that are not conducive to recruitment. Reproduction by razorback suckers was first documented conclusively in 1992 and relatively large numbers of larvae were produced in the middle and lower Green river in 1993 and 1994. Since that time, fewer larvae have been captured, both in terms of CPUE and proportion of razorback larvae to all catostomids. This suggested an overall decline in abundance of early life stages of razorback suckers rather than a decline in conditions associated with production of catostomid larvae in general. One must be careful interpreting such data because sampling variation is high. Nevertheless, reduced reproduction and declines in abundance of adults in the Green River system seem to be correlated.

Specific management efforts and natural events in the later 1990's provided flows necessary for flood plain inundation thought necessary for recruitment of small razorback suckers (Tyus and Karp 1991, Modde et al. 1996, Muth et al. 2000). For example, flows were relatively high and sustained in 1995, 1997, and 1999, and yet few larger juveniles, other than those documented by Modde (1996), were noted. Lack of a positive response by razorback suckers was likely due to too few adults in the system, reproduction that was inadequate or poorly timed with flows and flood plain availability such that recruitment could not occur, or predation on early life stages by non-native fishes. A positive response from razorback suckers to active flow and flood plain management may be possible only after adequate numbers of reproducing adults are in the system.

It may also be offspring viability is low in this population thought to be composed mostly of old fish (Tyus 1987). Some have speculated populations of wild razorback suckers in the lower Colorado River may be senescent and undergoing a rapid population decline in the face of recruitment failure (Minckley 1983, Minckley et al. 1991). Many individuals in the relatively large but declining Lake Mohave population are thought to be 40 to 50 years of age and pre-date reservoir construction (McCarthy and Minckley 1987, Minckley et al. 1991). A similar situation may be occurring in the Green River as the abundance of aging fish continues to decline (Tyus 1987).

Regardless of the reason for population declines in the Green River, what appears to have been documented with reasonable certainty is the decline and near extirpation of the only remaining wild population of riverine razorback suckers in existence. If 0.72 is a reasonable estimate of annual survival, only about half of the wild fish alive in 1999 (about 108 animals) remain in 2001. It is fortunate efforts were made in 1998 and 1999 to secure fish from the remaining wild population for brood stock. That additional sampling effort, over and above Basinwide sampling, captured sufficient animals for reasonably accurate abundance estimates and also provided fish for hatchery production.

The near extirpation of wild razorback sucker populations throughout the upper Colorado River Basin places additional urgency and importance on securing the status of the remaining relatively large population in Lake Mohave. Even though the upper Colorado River basin Recovery Program has secured its own broodstock, that population is especially important because it has relatively high genetic diversity (Dowling et al. 1996).

Future monitoring.–Reduced distribution and abundance of razorback suckers in the Green River system requires management actions to improve status of this species. A first step to bolster populations of adult razorback suckers in the Green River has begun in the form of stocking hatchery propagated fish. Some of those fish have survived for one to several years and females may soon be of sufficient size to reproduce. Determining wether these stocked fish are self-sustaining in the Green River and other areas should be the focus of future monitoring. Other management activities designed to recover endangered fishes in the Green River include implementing flow and temperature regime recommendations for operation of Flaming Gorge

Dam (Muth et al. 2000), control of non-native fishes, and acquisition and restoration of flood plain areas. An efficient monitoring program should be able to track the response of the Green River razorback sucker population to those and other management actions implemented in the future.

Tracking status of razorback suckers in the Green River should proceed along at least three fronts. First, abundance and survival rates of stocked hatchery fish and remaining wild adult fish needs to be explicitly documented. Because most stocked and the few remaining wild fish occur in the middle Green River, this would be a logical area to focus intensive efforts. This could be accomplished by annual sampling in spring time when razorback suckers are susceptible to capture near spawning areas and could occur in conjunction with sampling to estimate abundance of other rare fishes such as Colorado pikeminnow. Minimally, sampling should occur with sufficient intensity such that annual estimates of abundance, similar to those presented in this report, could be calculated.

A level of effort that includes one or two electrofishing passes with two boats through the middle Green River should yield a reasonable level of information about the distribution of razorback suckers in the reach and add to a data set of recaptures for stocked fish. Sampling for Colorado pikeminnow in the same reach suggests that a single pass with two boats yields capture probabilities of about 10% (unpublished data) so that level of effort seems warranted. Such information could be collected during sampling for pikeminnow abundance estimates. Additional emphasis should be given to sampling on or near the spawning area at times that are appropriate for capture of relatively large numbers of razorback suckers. Such sampling would document the reproductive state of stocked hatchery fish and add additional fish to the recapture data set. Fyke and trammel net sampling similar to that which occurred under the Basinwide sampling program should also be conducted, especially if only a single electrofishing sampling pass was completed. Addition of that gear type ensures that different habitats are sampled and offers some insurance against gear bias for different-sized fish. This level of data collection, when combined with appropriate pre-stocking data collection, should be sufficient to permit estimation of abundance and length dependent survival rates of stocked fish. Partitioning of the data within a season may allow for two-sample abundance estimation within a year, if enough fish captures are made. Two or three years of data collection should be sufficient to understand if that level sampling yields suitable estimates. Such would also allow for fine-tuning of hatchery propagation programs to produce fish that are stocked at an optimal size. Annual sampling effort should be expanded in the future to provide more precise abundance estimates needed for tracking progress toward meeting recovery goals.

A level of sampling necessary to monitor recovery of razorback suckers in the lower Green River or the lower Yampa River is unknown at this time. Until such populations expand in size or concentration areas such as spawning bars and post-spawning recovery areas are discovered, monitoring of adult populations in those areas will remain difficult. Existing data such as that being collected under Colorado pikeminnow abundance estimation efforts should be scrutinized so that concentration areas of fish might be discovered. Additional sampling should focus on areas where razorback suckers have been previously captured such as the inflow area of the San Rafael River. This may help focus sampling to monitor populations of adults in those reaches.

A second area of emphasis to track recovery of razorback suckers in the Green River involves sampling for early life stages. Light-trap sampling such as has occurred during the Basinwide program should be continued in the middle Green River and reinitiated in the lower Green River. Additional sampling at other sites should be conducted to determine if reliable concentration areas for larvae can be identified. This information is critical to determine if stocked fish are successfully reproducing at a level sufficient for recruitment to occur. Successful recruitment also requires that other potentially important recruitment-limiting factors such as predation on early life stages are overcome. Such sampling would also aid in determining if flow and temperature recommendations proposed for Flaming Gorge Dam are benefitting razorback suckers. More in depth analysis of captured specimens may also aid in flow and temperature recommendation evaluations, and ultimately recovery of the species. Minimally, otolith analysis of specimens could provide better information on timing of spawning of adults and emergence of larvae in relation to flow regimes that influence habitat availability. Growth-rate and gut content information may also help determine bottlenecks to survival of larvae, approaches for which have already been investigated (Muth et al. 1998, Bundy and Bestgen 2001).

The third area of emphasis to track recovery of razorback suckers in the Green River involves estimating recruitment of new fish to the adult population. Recruitment rates can be directly estimated from capture-recapture data if sufficient numbers of individuals are sampled over a long time period. A key to obtaining the needed information may be to learn more about the life history of juveniles so that sampling can be conducted more efficiently. Obtaining reliable information about recruitment rates also requires tracking the history of all fish stocked into the system, including larvae. Only then can estimates of recruitment from a self-sustaining population be made. This will require increased coordination and enhanced database management.

Effective monitoring is a necessary step in documenting the status of razorback suckers but does not by itself ensure recovery of the species. In most situations, populations of adult razorback suckers consist of large and old fish (Minckley 1983, McCarthy and Minckley 1987, Tyus 1987). Reproduction has been commonly documented but few juveniles have ever been found (Taba et al. 1965, Minckley 1983, Bestgen 1990, Minckley et al. 1991, Gutermuth et al. 1994, Modde 1996, Muth et al. 1998). In lower Colorado River Basin reservoirs, lack of recruitment has been linked mostly to predation on early life stages of razorback suckers. Evidence for this comes from successful rearing of razorback suckers in predator-free habitat, although nutritional deficiencies and timing of reproduction in relation to food availability may also play a role (Marsh and Langhorst 1988, Papoulias and Minckley 1990, Horn 1996). Limited recruitment of razorback suckers in the Green River of the upper Colorado River Basin may be related to reduced availability of warm, productive flood plain habitat in spring, a mismatch in timing of availability of larvae and flood plains, and presence of introduced species that reduce survival of early life stages of razorback suckers. Modde et al. (1996) presented evidence that recruitment of razorback suckers was linked to high flow years in the 1980's. It seems clear that cause and effect relationships for recruitment failure in razorback suckers are complex and likely involve multiple, interacting factors. Survival and reproduction by stocked hatchery razorback suckers is a necessary first step in the recovery process. Ultimately, recovery will occur only when factors that caused razorback suckers to decline are identified and remedied.

CONCLUSIONS

! The population of wild razorback suckers in the Green River system, which was considered small but relatively stable from about 1980 to 1992, has declined and may be extirpated in the near future. This conclusion is based on reductions in annual abundance estimates of adult fish in the middle Green River since the early 1990's, and river-wide reductions in captures of larvae after about 1994.

! Larvae were captured in both the middle and lower Green River from 1993 to 1999, indicating some level of reproduction in spite of low abundance of adults.

! Because survival rates of adult razorback suckers have remained essentially constant over time, recruitment failure at the early juvenile or larval life stage may be the reason for population declines.

! The exact mechanisms for recruitment failure were not further elucidated by results of this study. Discovery and amelioration of factors limiting recruitment success are critical to recovery of razorback sucker.

! The presence of larvae in the lower Green River, capture of a few ripe adults, and capture of larvae prior to their appearance in the middle Green River, suggested that a reproducing population of adults must also occur in that area. In particular, the San Rafael River and its Green River inflow area may be the foci of an important nursery or spawning area. The number of adults remaining in the lower Green River is presumed very low based on the few captures that have been made.

! Data collected for adult fish under adult Basinwide sampling were too sparse to allow for rigorous population-level analyses. More rigorous analyses were possible only when Basinwide sampling data were supplemented with data collected in spring 1998 and 1999 when fish for brood stock development were captured.

! Light-trap sampling in low-velocity channel-margin areas is an effective means to detect reproduction by even a relatively small population of razorback suckers. Data gathered may be useful to evaluate effects of implementation of Flaming Gorge flow and temperature recommendations and to evaluate whether stocked hatchery fish are reproducing.

! Information on growth rates of stocked and recaptured razorback suckers is limited by lack of individual size data at time of release.

! Quality assurance and quality control of data and integration of various databases is needed.

RECOMMENDATIONS

! The small and declining population of wild razorback suckers remaining in the Green River mandates continued stocking of hatchery fish.

! Stocked populations should be used to gain conclusive information regarding mechanisms of recruitment failure of razorback suckers so that threats can be removed and recovery can proceed. Areas of focus may include effects of non-native fishes in critical nursery areas, and timing of flow releases and availability of critical habitat in relation to reproduction.

! Population status, nursery habitat, and spawning areas of razorback suckers in the lower Green River should be identified and further protection extended to those areas if necessary and possible. The San Rafael River inflow area should be one area of emphasis.

! Develop a rigorous monitoring scheme for adult, juvenile, and larval life stages of razorback sucker in the middle and lower Green River. Sampling should be integrated with existing programs to facilitate multiple uses of the data. Explicit estimates of reproduction, rates of survival and recruitment, and abundance should be gathered to track the long-term status of populations.

! Evaluate efficacy of light-trap sampling in low-velocity channel-margin habitat to detect larvae and to estimate annual reproductive success of razorback suckers. Minimally, the relationship between fish density, backwater size, sampling effort, and detection probabilities should be quantified. Another approach to evaluate light traps as a monitoring gear would be to release batches of marked larvae into the Green River during the sampling season. Subsequent sampling with light traps could document dispersal rates, identify important nursery habitats, and offer insights into efficacy of light-trap sampling to assess annual reproductive output of razorback suckers. Data gathered may be useful to evaluate effects of implementation of Flaming Gorge flow and temperature recommendations and to evaluate whether stocked hatchery fish are reproducing.

! If possible, measure individual PIT-tagged fish to be stocked. This will allow investigation of possible size-dependent effects on survival and may guide future fish culture and stocking practices.

! Implement more rigorous quality assurance and quality control of data gathered in monitoring and stocking programs. Integration of the databases will facilitate efficient data analysis and maximize information gained.

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Table 1.–Basinwide monitoring program captures of wild adult razorback suckers from 1996 to 1999 in the Green River basin, Utah and Colorado. Captures were by hoop and trammel nets set in low-velocity habitat in spring; only a single capture event per year is represented even though a few fish were captured more than once within a year. Fish of hatchery origin were determined from cross-referencing databases; recaptures from previous year and recaptures of fish tagged or released from 1996 to 1999 were of interest for abundance estimation.

Year	Total fish captured	Frequency of hatchery fish of the total	Recaptures from previous year	Recaptures from 1996 to 1999
1996	12	0	NA	NA
1997	28	5	0	0
1998	10	1	0	2
1999	33	19	1	3
total	83	25		

Table 2.–Mean total lengths (TL) of razorback suckers stocked in the Green River and recaptured in 1995 to 1999. Only mean TL was available for groups of stocked fish so calculation of changes in length for individual recaptured fish was not possible.

Year stocked (mean TL mm)	Mean TL and number of fish recaptured				
	1995	1996	1997	1998	1999
1995 (127)	—	—	—	—	—
1996 (237)	—	—	336 (N = 6)	367 (N = 1)	—
1998 (355)	—	—	—	—	421 (N = 31)
1999 (379)	—	—	—	—	398 (N = 6)

Table 3.–Lincoln-Petersen abundance estimates from program CAPTURE, and associated capture data for razorback sucker from the middle Green River, 1980 to 1999. Abundance estimates are for pairs of years, with the first sampling occasion in the year previous to the year reported. The number of fish recaptured are the number tagged in the previous year and recaptured in the year the estimate was made. Some estimates from Modde et al. (1996) from 1980 to 1992 were recalculated because capture histories of a few individuals were changed to reflect new information. The 1982, 1994, and 1996 estimates are particularly unreliable because of sparse recaptures but are presented to illustrate the wide confidence intervals that result from such estimates.

Year	Fish captured	Fish recaptured	Abundance estimates	SE (N-hat$_i$)	cv$_i$	Confidence limits (95%)
1980	17	0	NA	–	–	–
1981	65	0	NA	–	–	–
1982	35	1	2,131	2,124	95.5	515-10,958
1983	3	0	NA	–	–	–
1984	81	0	NA	–	–	–
1985	18	5	282	99	35.1	166-589
1986	80	2	696	442	63.4	262-2274
1987	56	6	735	268	36.5	395-1517
1988	51	11	255	60	23.3	175-419
1989	77	8	483	145	30.1	291-892
1990	38	5	574	226	39.4	298-1257
1991	39	5	289	109	37.7	158-621
1992	44	5	335	128	38.2	181-724
1993	30	5	257	95	37.1	143-549
1994	8	1	221	185	83.8	73-984
1995	21	0	NA	–	–	–
1996	17	1	338	303	89.6	96-1585
1997	33	0	NA	–	–	–
1998	27	7	124	34	27.4	82-225
1999	37	9	108	24	22.4	78-179
Total	777	71				
Average 1985-1992			456	185	38.0	
1993, 1998, 1999			163	51	28.0	

Table 4.–Intercept (β_o) and slope (β_1) coefficients and associated statistics of regression models of abundance estimates (*ln*) for adult razorback suckers as a function of time. A significant and negative model slope parameter may indicate a decline in adult razorback sucker abundance over the time period indicated. The 1990 to 1999 models are presented with and without (reduced) the 1994 and 1996 estimates, the 1985 to 1999 model includes 1994 and 1996 estimates.

Model years	*df*	β_o (SE)	β_1 (SE)	Model *P*-value	r^2
1985 to 1992	7	6.26 (0.41)	- 0.0392 (0.070)	0.590	0.050
1990 to 1999	7	7.52 (0.51)	- 0.191 (0.047)	0.007	0.730
1990 to 1999 (reduced)	5	326.78 (45.11)	- 0.161 (0.023)	0.002	0.927
1985 to 1999	12	200.61 (52.36)	- 0.098 (0.026)	0.003	0.557

Table 5.-- Number of fish (mostly larvae or early juveniles), by species and sampling gear per year, collected during sampling for larval razorback suckers, *Xyrauchen texanus* , in the middle Green River, Utah and Colorado.

Gear:	1992 Drift net	1992 Seine	1993 Drift net	1993 Seine	1993 LT	1994 LT	1995 LT	1996 LT	1997 LT	1998 LT	1999 LT	Total
Native taxa												
Cyprinidae												
Gila sp.	2	7	0	0	1	0	0	0	2	0		12
Ptychocheilus lucius	0	0	0	0	1	0	1	0	0	0		2
Rhinichthys osculus	119	85	15	0	4	0	58	23	2	3		309
Catostomidae												
Catostomus discobolus	1516	583	69	58	100	6455	2088	3277	39	256		14441
C. latipinnis	579	612	140	760	938	5252	634	5142	64	1005		15126
Xyrauchen texanus	3	17	9	55	228	1217	32	174	3	58	12	1808
Unidentified suckers	7	1	12	79	32	462	13	14	0	4		624
Cottidae												
Cottus bairdi	0	3	0	0	0	0	0	2	2	0		7
Nonative taxa												
Cyprinidae												
Cyprinella lutrensis	5	167	12	65	5859	0	1655	281	366	558		8968
Cyprinus carpio	1	3	2	0	1360	0	3	230	104	8		1711
Notropis stramineus	3	25	60	12	1584	0	0	129	258	116		2187

Table 5.-- Continued

Gear:	1992 Drift net	1992 Seine	1993 Drift net	1993 Seine	1993 LT	1994 LT	1995 LT	1996 LT	1997 LT	1998 LT	1999 LT	Total
Nonative taxa (cont.)												
Pimephales promelas	0	38	29	1	1239	0	0	3678	1465	2372		8822
Richardsonius balteatus	0	0	0	0	3	0	0	12	131	23		169
Unidentified minnows	7	0	0	221	94	430	4955	623	65	230		6625
Catostomidae												
Catostomus commersoni	2	1	2	1	4	0	3	5	3	2		23
Esocidae												
Esox lucius	0	0	0	1	0	0	0	0	0	0		1
Gasterosteidae												
Culaea inconstans	0	0	0	0	0	0	0	8	2	0		10
Centrarchidae												
Lepomis cyanellus	0	0	0	0	17	0	22	1	86	6		132
Total number of fish	2244	1542	350	1253	11464	13816	9464	13599	2592	4641	12	60977
Number of Collections	52	30	90	52	203	195	287	168	190	126	247	
Hours of sampling; total	51.7		82.5		1835.1	1524.1	2051.9	1496	1681.2	1114.6	2157.5	
(collection mean)	(1.0)		(0.9)		(9.0)	(7.8)	(7.2)	(8.9)	(8.8)	(8.8)	(8.7)	

Table 6.-- Mean catch per unit effort (CPUE) for larval catostomids captured during light trapping in the middle and lower Green River, Colorado and Utah, 1993-1999. CPUE is number of fish per hour of light trapping (effort averaged 8.5 hours per collection) . Effort was based on collections made on and following the date of first capture of sucker larvae in each year (number of collections). The SE and number of samples are presented parenthetically for 1997-1999 data.

Reach	Species	1993	1994	1995	1996	1997	1998	1999
Middle Green River	Bluehead sucker	0.0545	4.2353	1.0176	2.1905	0.0358	0.2350	0
						(0.0149, 126)	(0.0730, 127)	
	Flannelmouth sucker	0.5111	3.4460	0.3090	3.4372	0.0580	0.9088	0
						(0.0143, 126)	(0.1769, 127)	
	Razorback sucker	0.1242	0.7985	0.0156	0.1557	0.0027	0.0523	0.0077
						(0.0016, 126)	(0.0144, 127)	(0.0023, 180)
Lower Green River	Bluehead sucker	0.0000	0.3203	0.0226	0.0437	0.0004	0.0580	0.0176
						(0.0004, 264)	(0.0202, 391)	(0.0056, 300)
	Flannelmouth sucker	0.0129	0.5981	0.1037	0.6495	0.0556	0.0656	0.5188
						(0.0259, 264)	(0.1070, 391)	(0.1241, 300)
	Razorback sucker	0.7747	0.2154	0.0024	0.0667	0.0012	0.0155	0.0109
						(0.0007,264)	(0.0041, 391)	(0.0053, 300)

Table 7.-- Mean total length (TL) of razorback sucker larvae collected in the middle or lower Green River, Utah, 1997-1999.

Middle Green	n	mean TL	SD	Range
1997	3	11.6	0.404	11.2-12
1998	57	12.5	1.308	10.7-16.3
1999		n/a		
Lower Green				
1997	3	12.9	0.702	12.2-13.6
1998	57	13.2	2.279	10.8-19.7
1999	30	12.4	1.549	10.5-15.5

Table 8.-- Selected mainstem water temperature and discharge parameters associated with the earliest estimated date of spawing by razorback suckers in the middle or lower Green River, Utah, from 1993-1999. Degree days is the sum of instantaneous daily water temperatures between 1 January and the earliest date of spawning. Days > 10°C or > 14°C are the number of days between 1 Janurary and the earliest date of spawning that recorded instantaneous daily water temperatures equaled or exceeded each respective threshold. Days before peak discharge is the number of days between the earliest date of spawning and the highest recorded mean daily river discharge for that spring. Date of spawning for 1993-1996 based on otolith analysis, spawning dates for 1997-1999 was backcalculated using average daily growth of 0.3 mm/day and a hatch size of 8.0 mm TL. Lower Green River 1993 data based on sampling conducted only from 17-19, June. Sample size is five fish or less for lower Green River in 1995 and 1997, and for middle Green River 1997. Data for 1993-1996 were from Muth et al. (1998).

River section and Year	Earliest date of spawning	Water temperature (°C) on earliest spawning date	Degree days	Days > 10°C	Days> 14°C	Days before peak discharge
Middle Green						
1993	5-May	16	377	18	3	23
1994	19-Apr	10	570	16	0	31
1995	11-May	11.5	849	36	0	36
1996	9-May	13	722	18	0	11
1997	31-May	13.8	931	38	0	5
1998	11-May	11.1	697	26	0	13
1999	n/a					
Lower Green						
1993	22-May	19	1090	58	36	9
1994	24-Apr	16	798	47	14	28
1995	6-May	14	1016	61	25	44
1996	2-Apr	12	357	12	0	50
1997	11-Apr	7	353	12	0	60
1998	22-Mar	10	338	4	0	65
1999	7-Apr	11	545	22	0	78

Table 9.-- Number of fish (mostly larvae or early juveniles), by species and sampling gear per year, collected during sampling for larval razorback suckers, *Xyrauchen texanus* , in the lower Green River, Utah.

Gear:	1993 Seine	1993 LT	1994 Seine	1994 LT	1995 Seine	1995 LT	1996 Seine	1996 LT	1997 LT	1998 LT	1999 LT	Total
Native taxa												
Cyprinidae												
Gila sp.	0	0	1	19	0	0	3	47	0	3	1	74
Ptychocheilus lucius	1	0	36	0	82	11	42	12	0	1	1	186
Rhinichthys osculus	0	1	0	36	0	6	8	388	0	29	4	472
Catostomidae												
Catostomus discobolus	0	0	49	113	7	47	17	140	1	200	48	622
C. latipinnis	1	2	0	211	91	216	529	2083	142	2373	1465	7113
Xyrauchen texanus	2	120	15	76	0	5	8	214	3	57	30	530
Unidentified suckers	1	0	3	0	1	1	4	27	0	36	5	78
Nonative taxa												
Cyprinidae												
Cyprinella lutrensis	804	273	206	9118	1617	1658	4037	19769	2539	223	4547	44791
Cyprinus carpio	3	7	0	19	1	1	22	0	0	7	13	73
Notropis stramineus	1	3	0	78	220	126	376	265	329	131	626	2155
Pimephales promelas	2	32	0	708	73	1	332	133	5	639	55	1980

Table 9.-- Continued

Gear:	1993 Seine	1993 LT	1994 Seine	1994 LT	1995 Seine	1995 LT	1996 Seine	1996 LT	1997 LT	1998 LT	1999 LT	Total
Nonative taxa (cont.)												
Richardsonius balteatus	0	0	0	0	0	0	1	6	0	0	0	7
Unidentified minnows	0	82	0	8	42	9331	65	5083	0	92	44	14747
Catostomidae												
Catostomus commersoni	1	0	0	0	0	0	2	0	0	13	0	16
Ictaluridae												
Ameiurus melas	0	0	0	0	0	0	1	0	0	0	0	1
Ictalurus punctatus	0	0	0	0	11	0	7	0	0	0	0	18
Centrarchidae												
Lepomis cyanellus	0	0	0	0	0	0	1	0	0	0	0	1
Total number of fish	816	520	310	10386	2145	11403	5455	28167	3019	3804	6839	72864
Number of Collections	2	30	2	41	34	232	186	347	263	395	312	
Hours of sampling; total (collection mean)		154.9 (5.2)		352.8 (8.8)		2082 (9.0)		3206.9 (9.2)	2480 (9.4)	3644.3 (9.2)	2934.1 (9.4)	

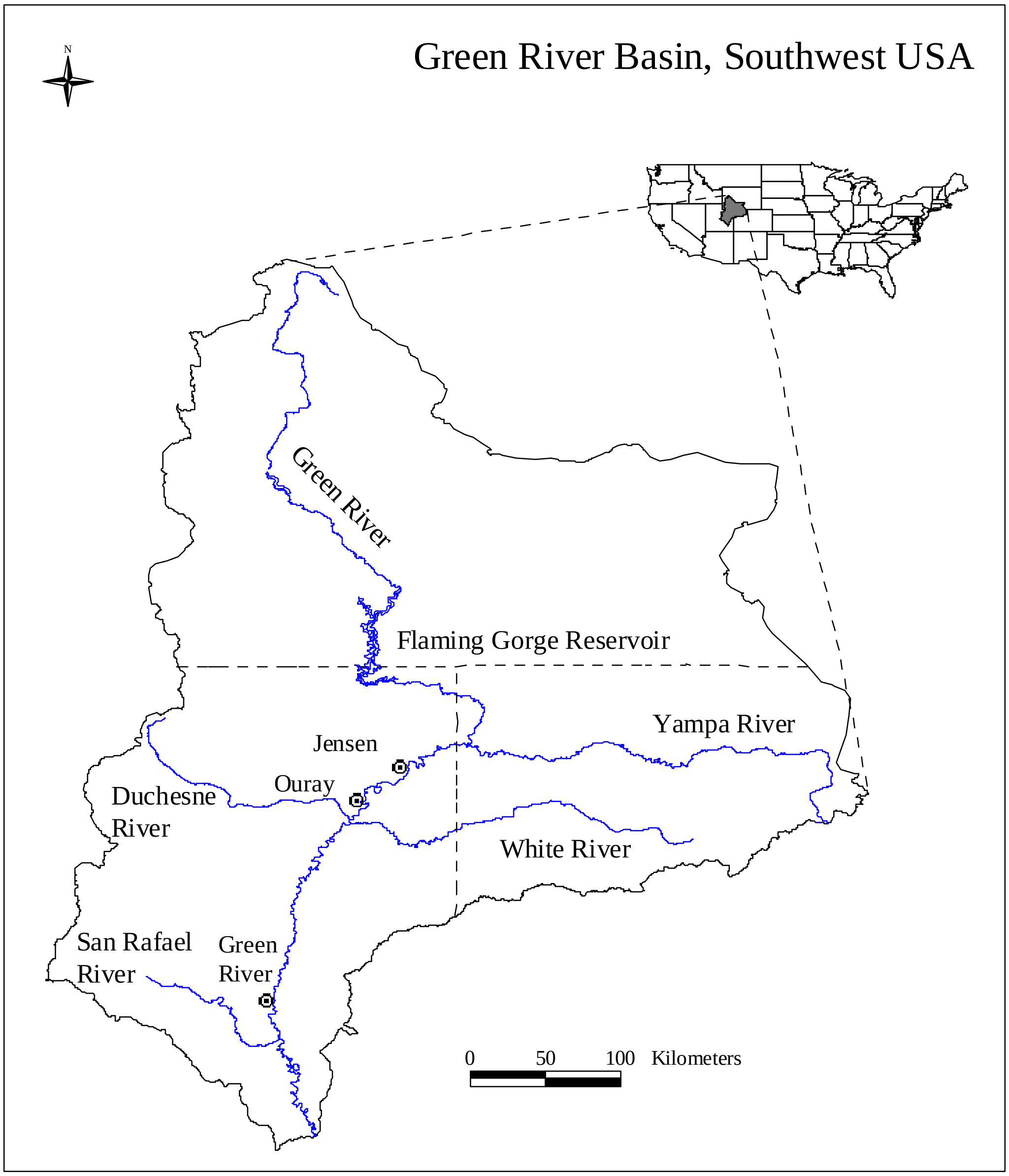


Figure 1. Green River sub-basin of the Colorado River Basin. Circled dots indicate towns.

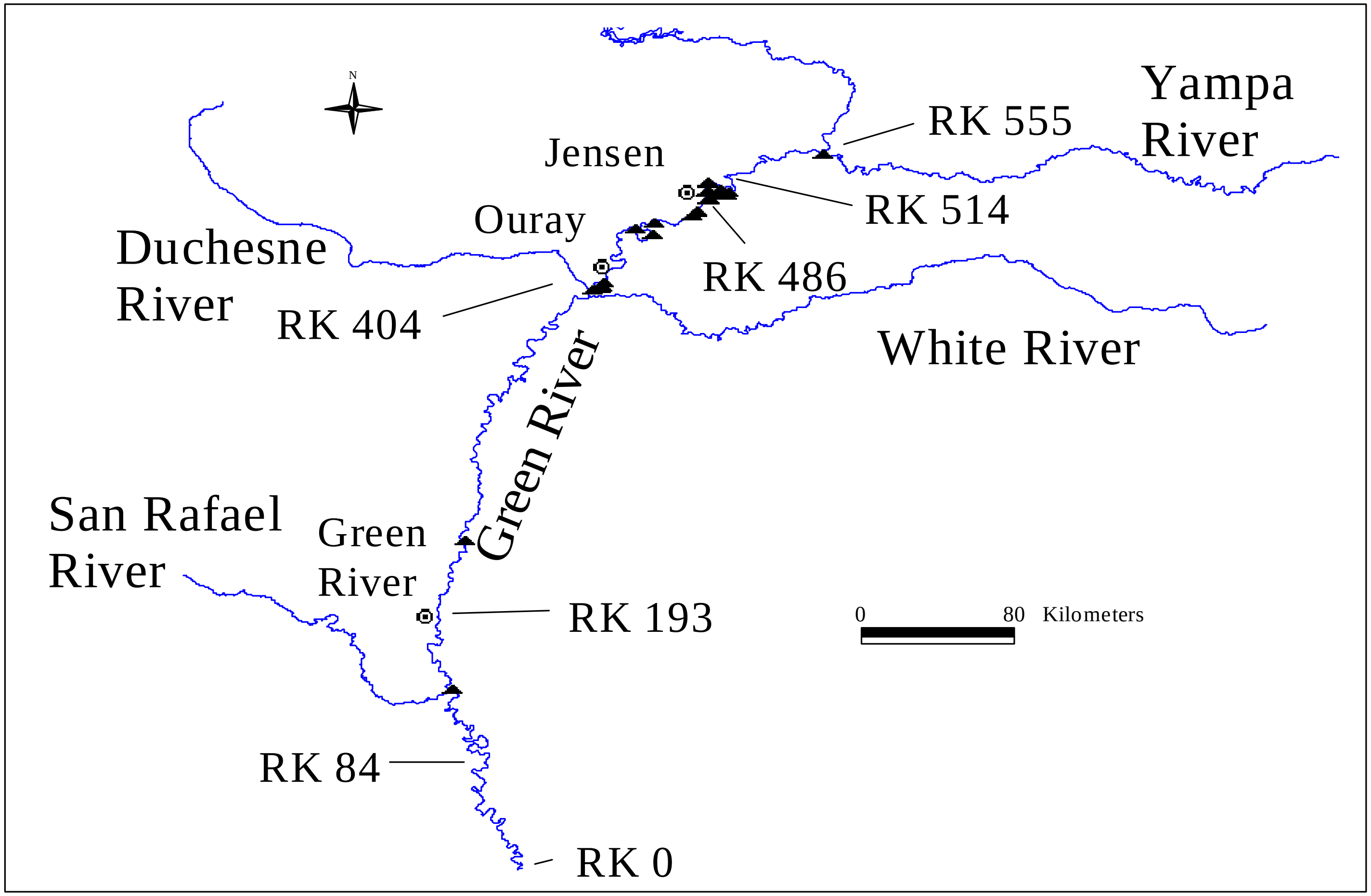


Figure 2. Locations (darkened triangles) of adult razorback suckers captured during Basinwide monitoring program sampling, 1996 to 1999. Circled dots indicate towns.

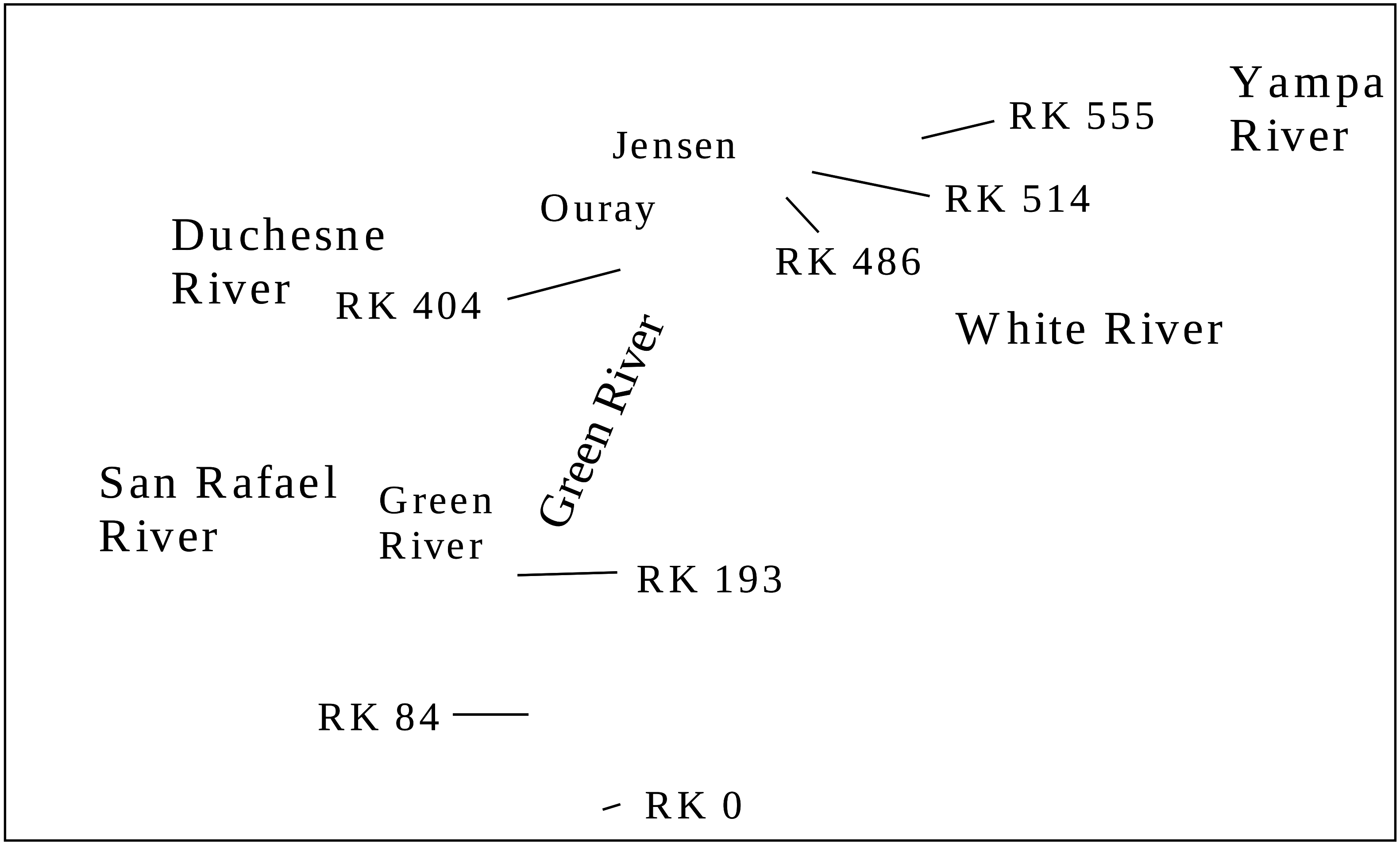


Figure 3. Locations (darkened triangles) of early life stages of razorback sucker captured during Basinwide monitoring program sampling, 1996 to 1999. Circled dots indicate towns.

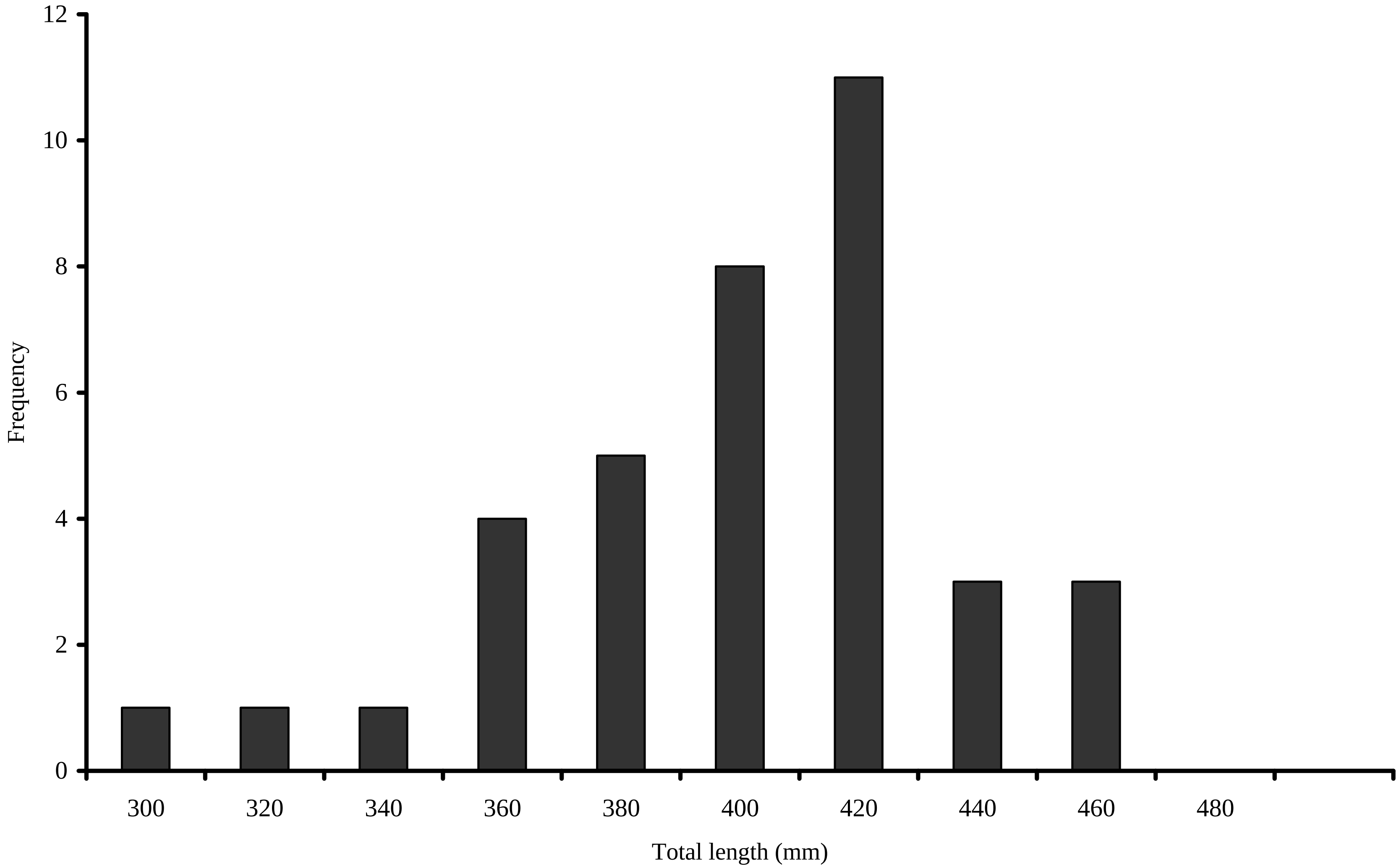


Figure 4.-- Length frequency distribution of stocked razorback suckers captured during Basinwide Monitoring Program and other sampling, 1996-1999.

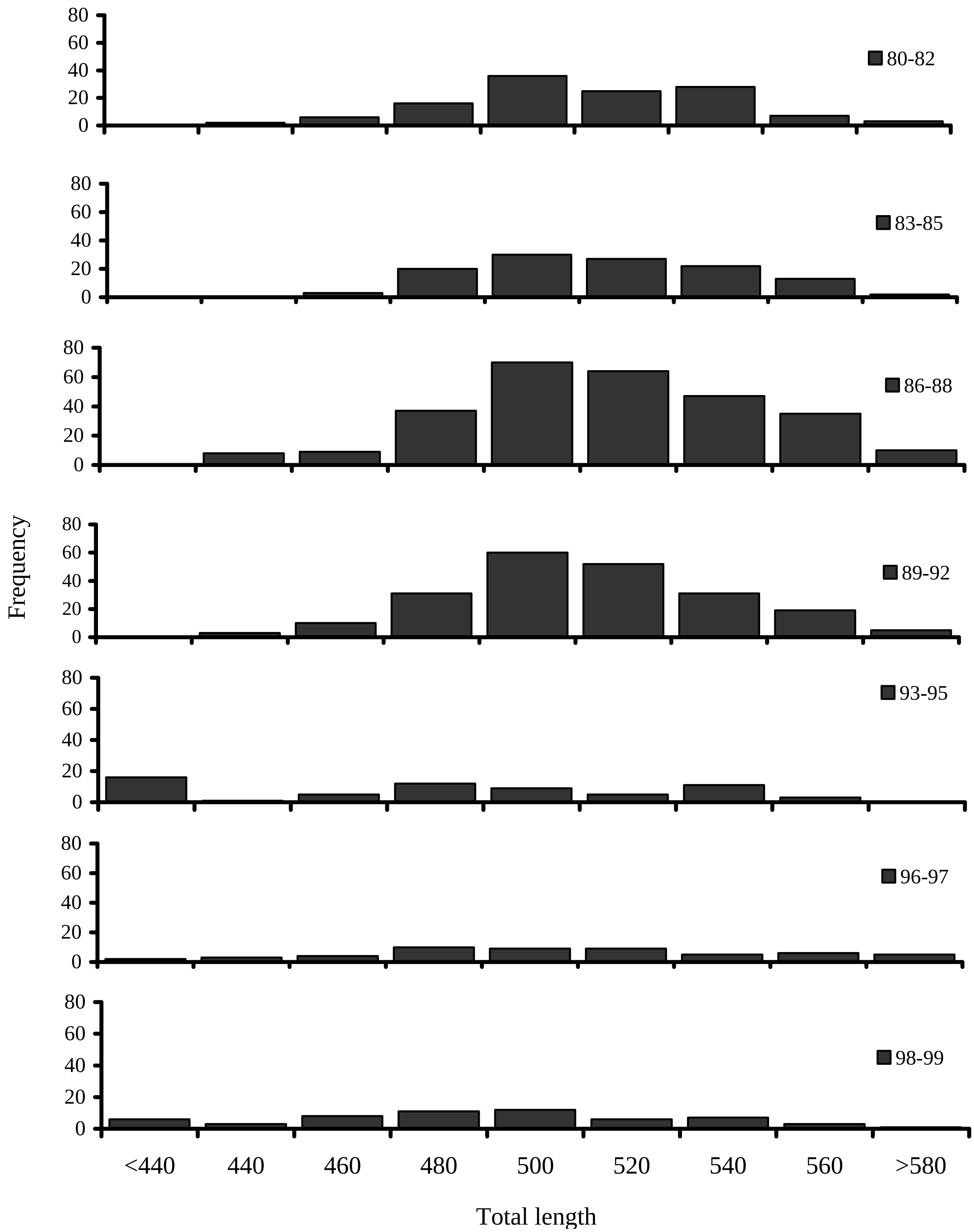


Figure 5. Length frequency distribution of adult razorback suckers captured in the middle Green River, 1980-1999.

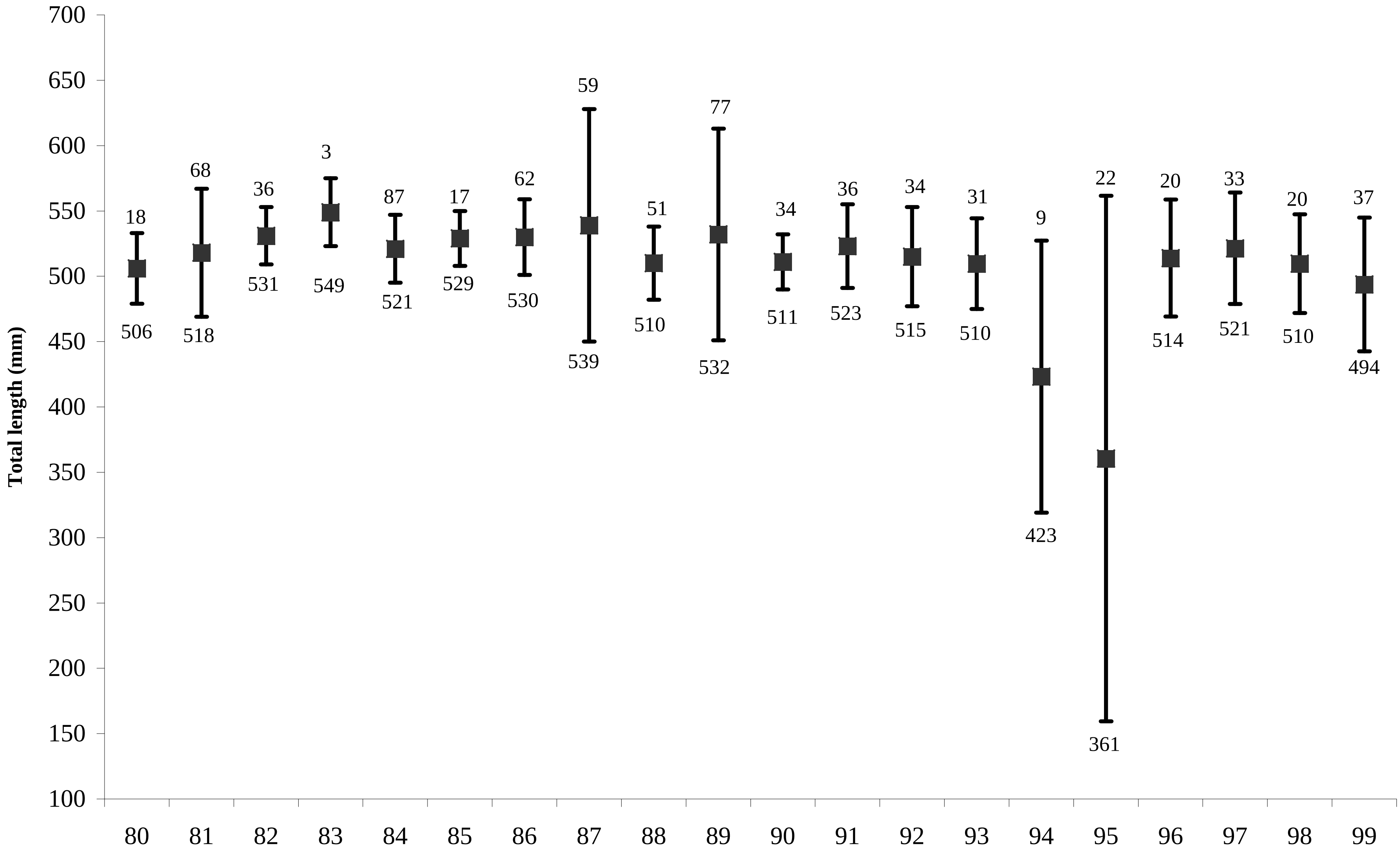


Figure 6. Mean TL (SD) of wild razorback suckers captured in the middle Green River, 1980-1999. Number of fish in the sample and their mean TL are presented above and below the SD bars for each year.

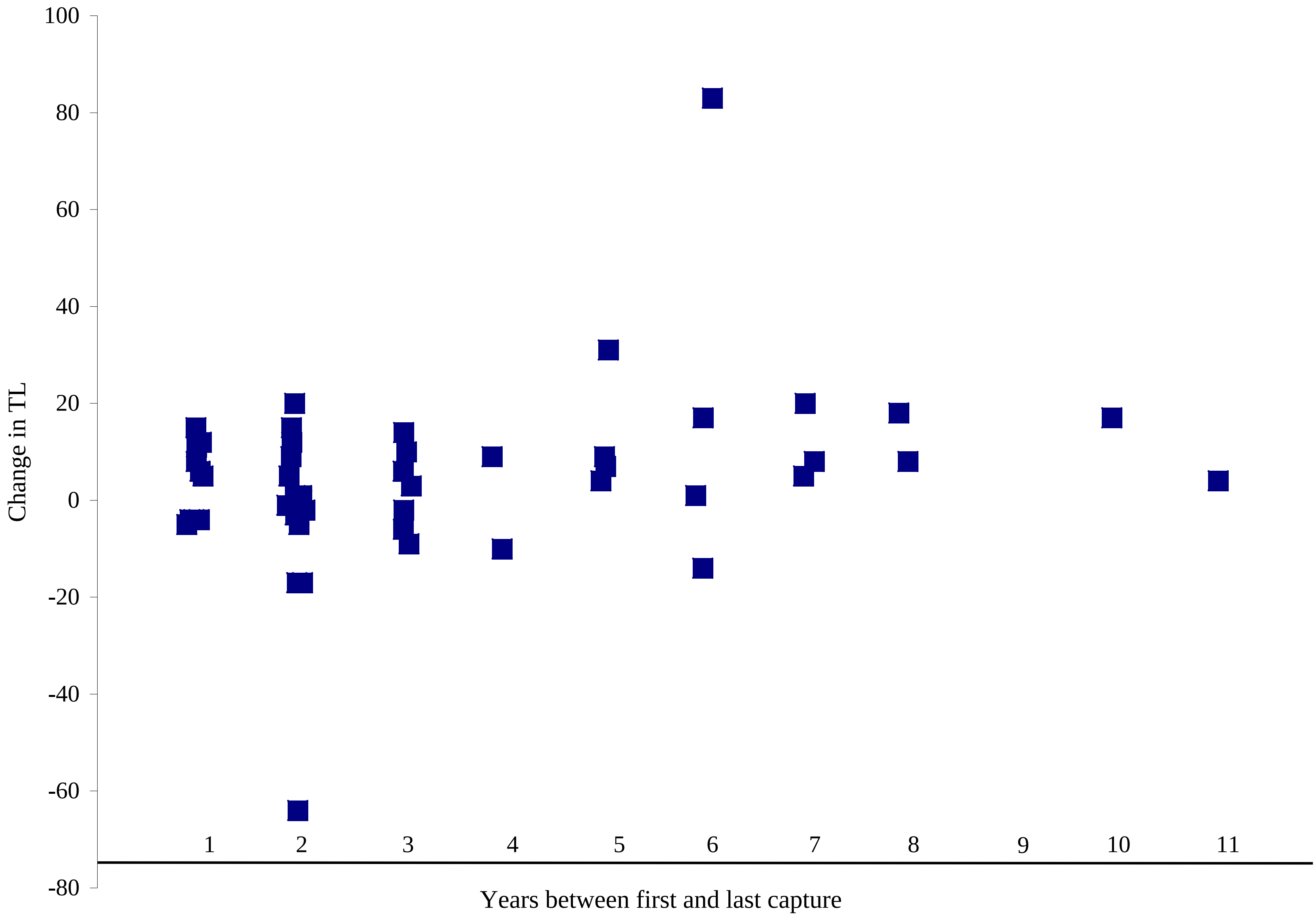


Figure 7. Changes in length of recaptured razorback suckers as a function of time since first capture, 1990-1999.

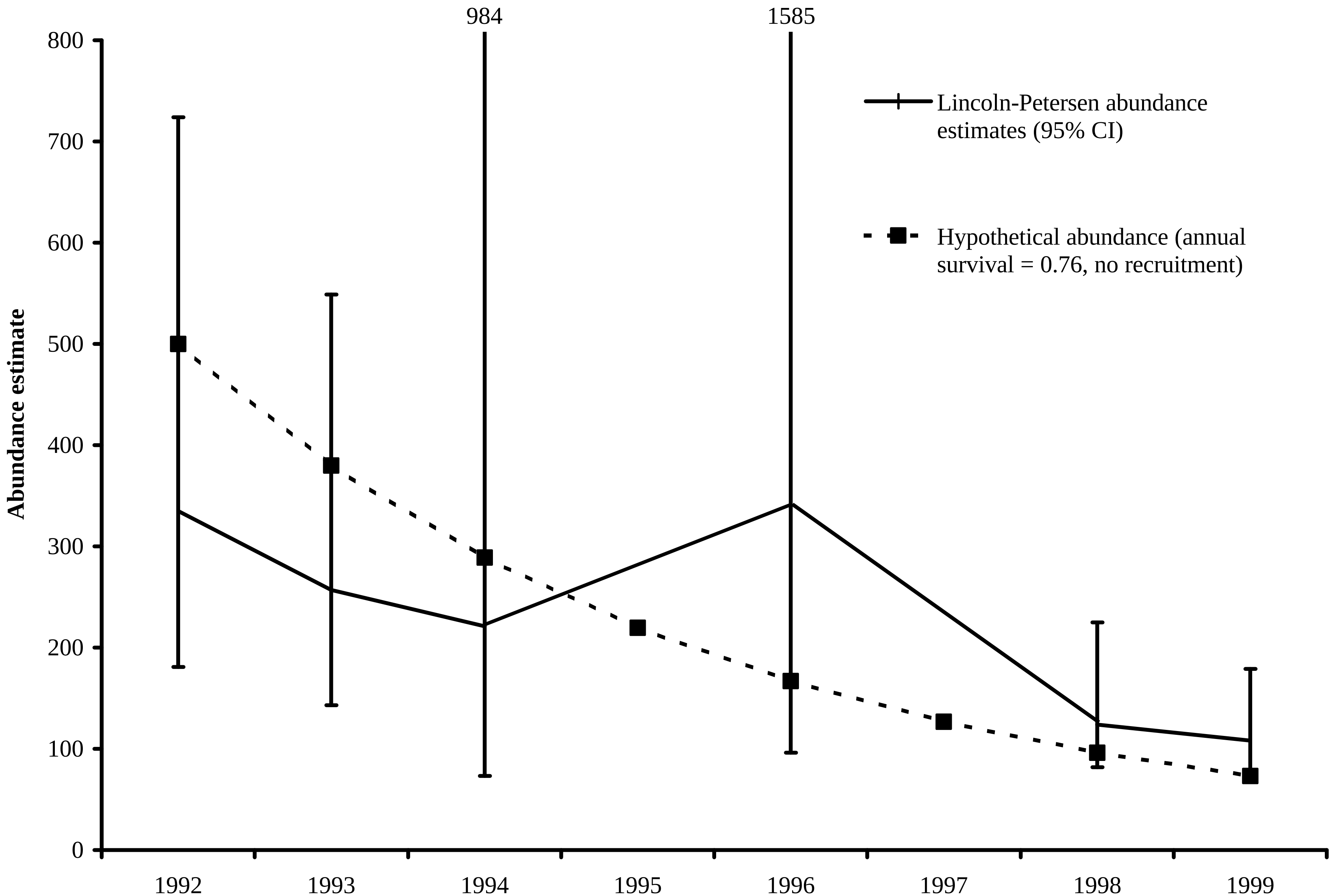


Figure 8. Lincoln-Petersen estimates of abundance of razorback suckers in the middle Green River, Utah, compared to hypothetical abundance estimates. Hypothetical abundance estimates assuming a population of 500 animals in 1992, annual survival of 0.76, and no recruitment are shown for comparison.

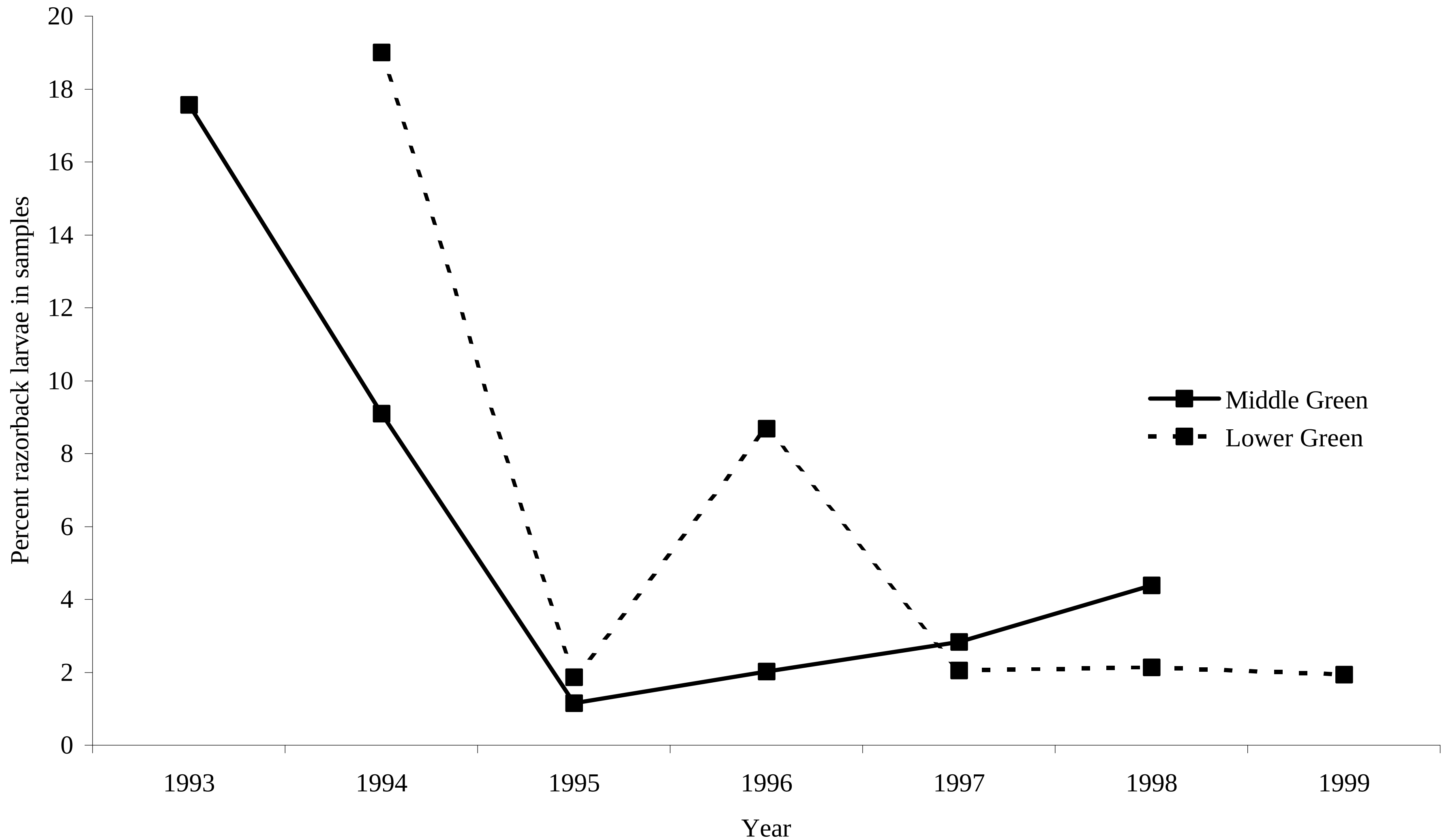
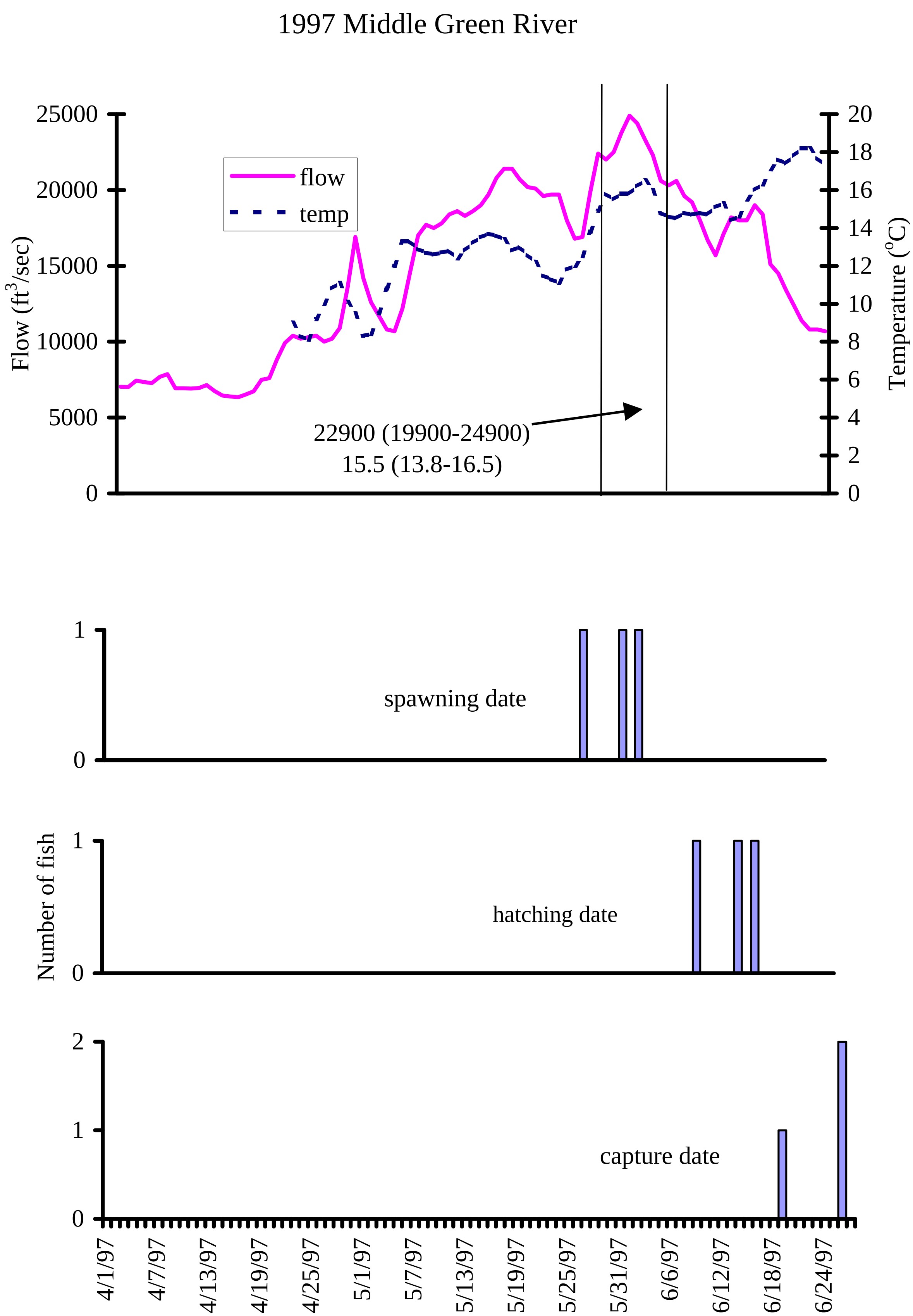
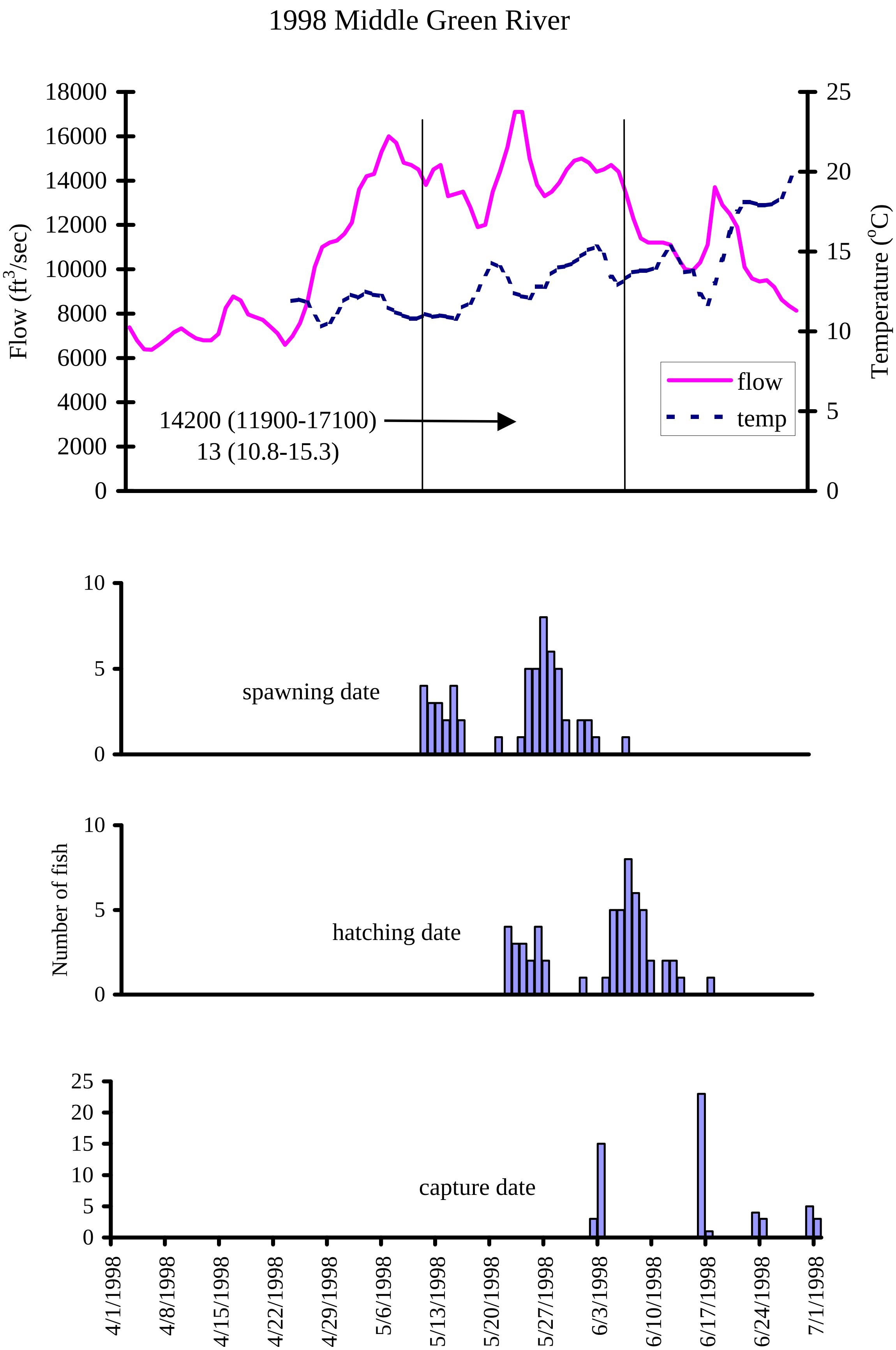


Figure 9.-- Percent of razorback sucker larvae to total native sucker larvae captured in light-trap samples in the middle and lower Green River reaches, 1993-1999.

Figure 10. Timing of capture, hatching, and spawning of razorback suckers relative to flow and water temperature regimes in the middle Green River, 1997 to 1999. Vertical lines in the upper panel demarcate flow and temperature regimes during spawning; values indicated for the window indicate mean (range) flow (solid) and temperature (dashed) conditions. Spawning period estimation was not possible for 1999 because length information was not available for those specimens which were sent to Ouray National Fish Hatchery.


1997 Middle Green River
25000
20000
15000
10000
5000
0
Flow (ft3/sec)
20
18
16
14
12
10
8
6
4
2
0
Temperature (oC)
flow
temp
22900 (19900-24900)
15.5 (13.8-16.5)
1
0
spawning date
1
0
Number of fish
hatching date
2
1
0
capture date
4/1/97
4/7/97
4/13/97
4/19/97
4/25/97
5/1/97
5/7/97
5/13/97
5/19/97
5/25/97
5/31/97
6/6/97
6/12/97
6/18/97
6/24/97


1998 Middle Green River
Flow (ft3/sec)
Temperature (oC)
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
25
20
15
10
5
0
flow
temp
14200 (11900-17100)
13 (10.8-15.3)
Number of fish
spawning date
hatching date
capture date
10
5
0
25
20
15
10
5
0
4/1/1998
4/8/1998
4/15/1998
4/22/1998
4/29/1998
5/6/1998
5/13/1998
5/20/1998
5/27/1998
6/3/1998
6/10/1998
6/17/1998
6/24/1998
7/1/1998

1999 Middle Green River

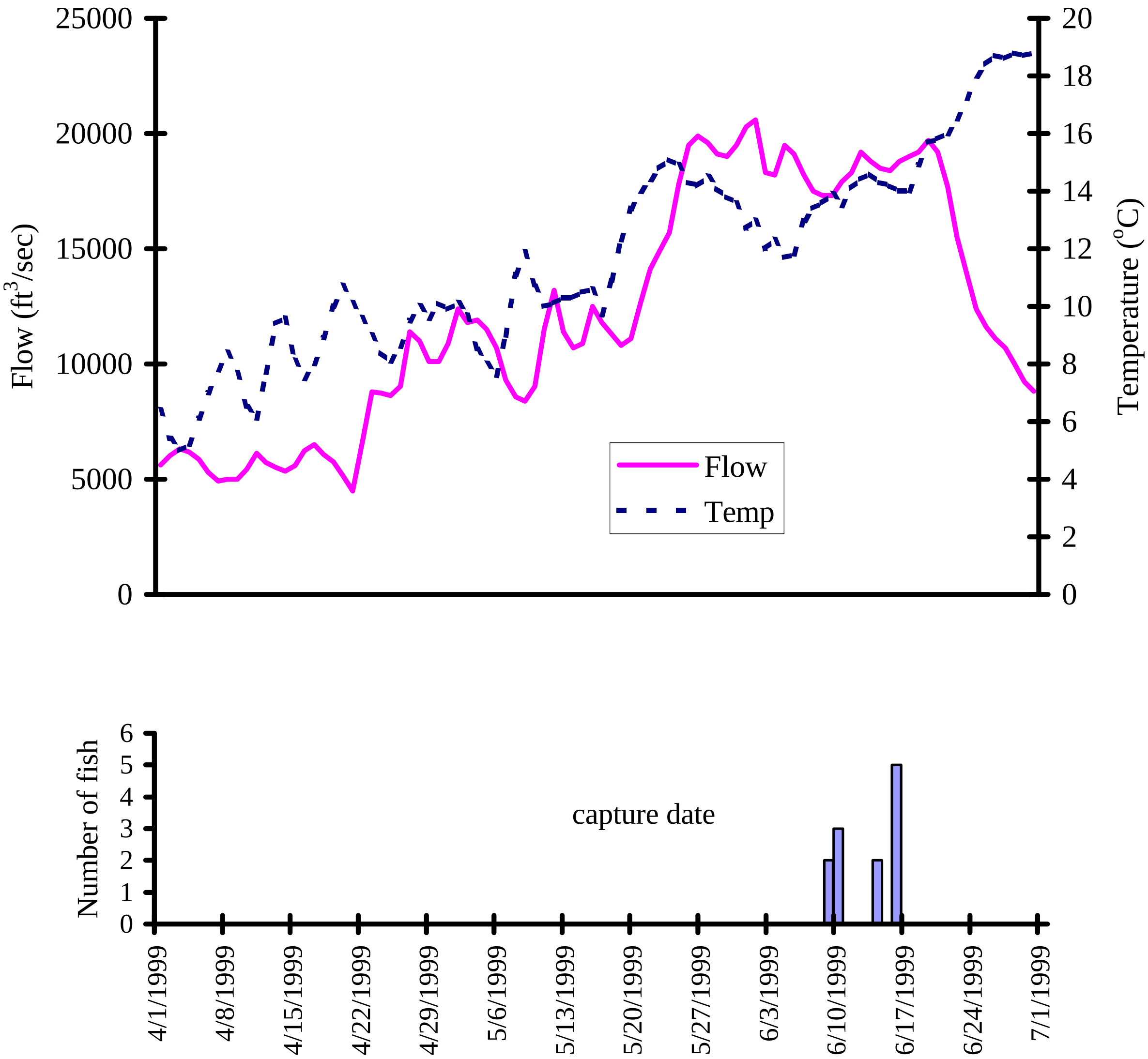
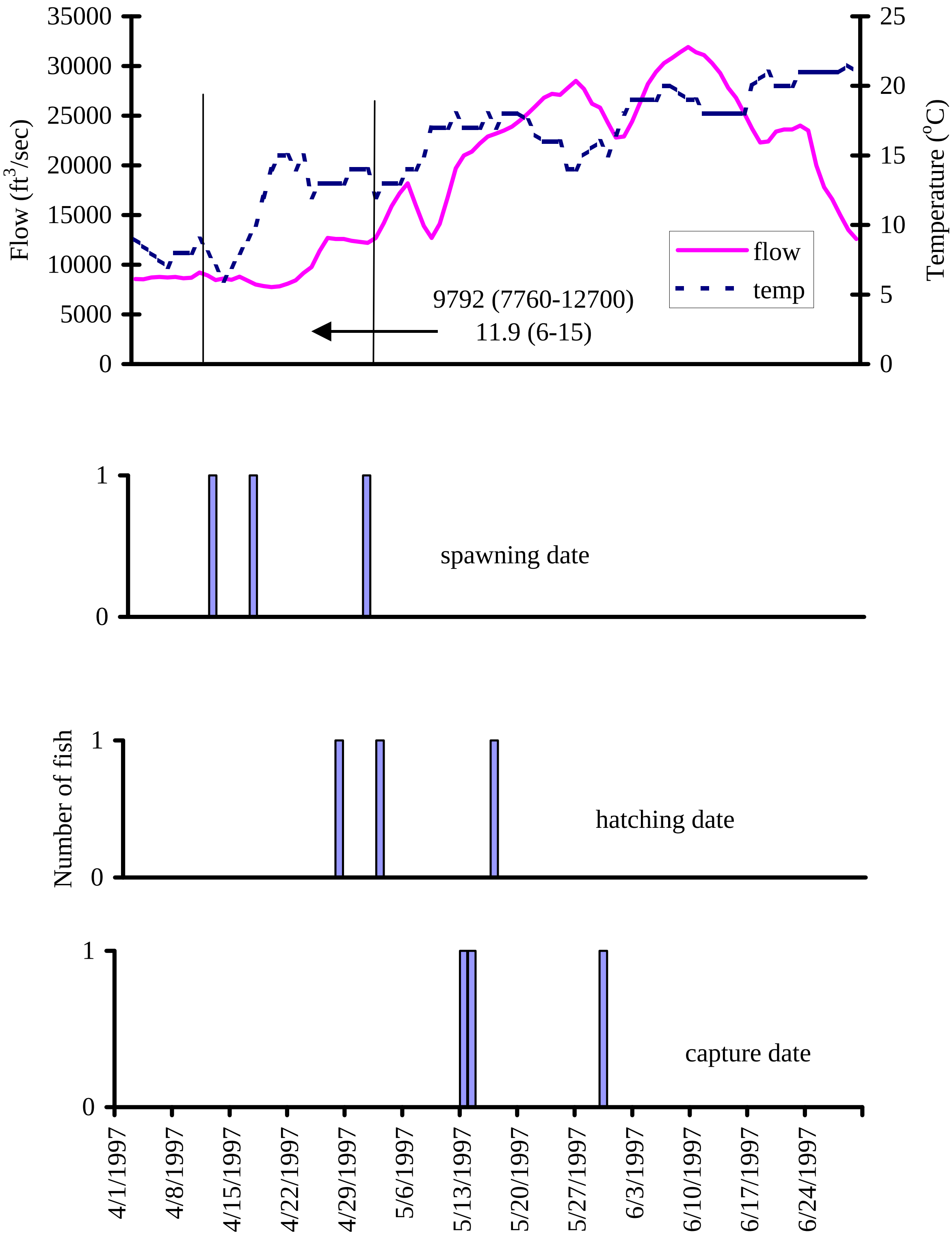
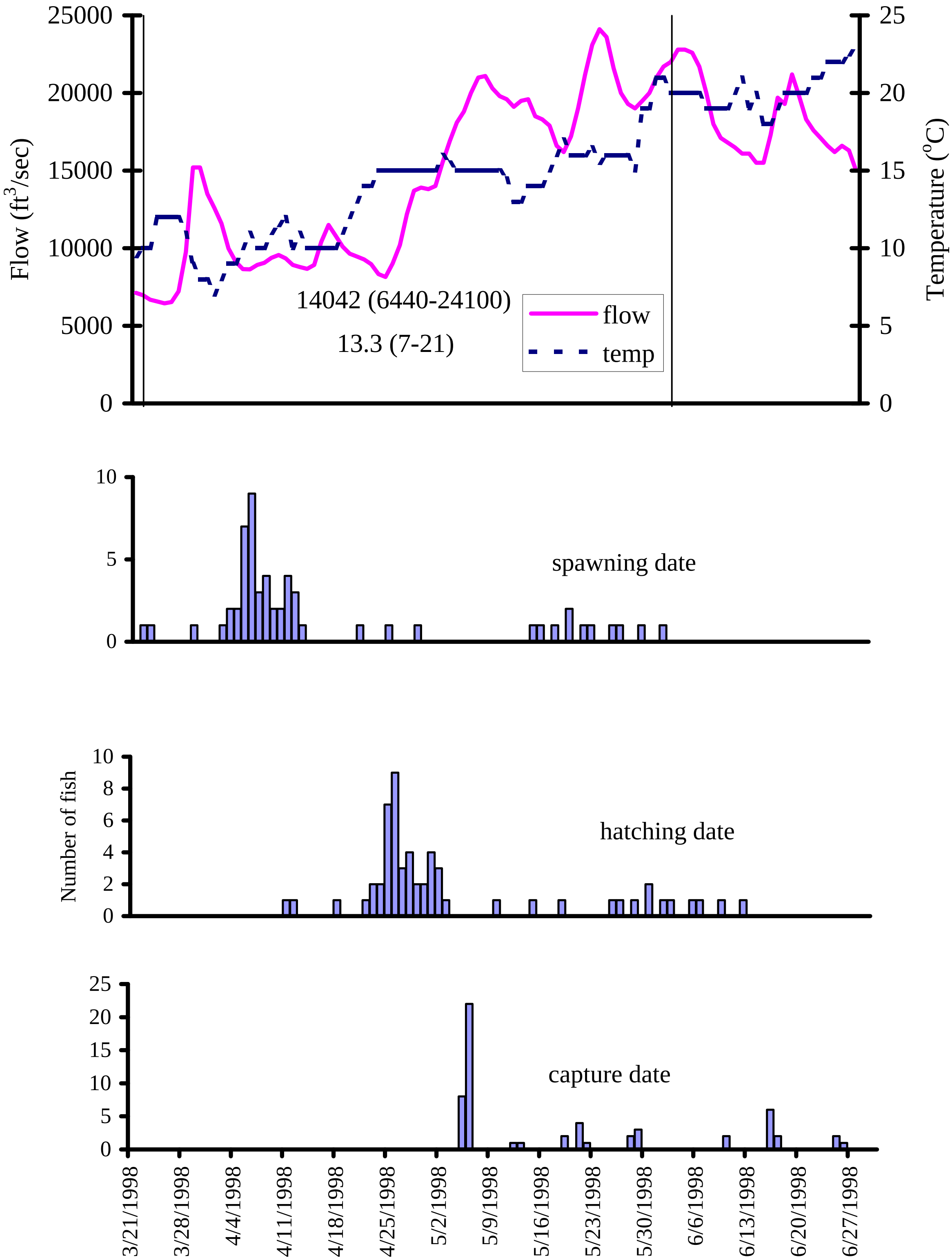


Figure 11. Timing of capture, hatching, and spawning of razorback suckers relative to flow and water temperature regimes in the lower Green River, 1997 to 1999. Vertical lines in the upper panel demarcate flow and temperature regimes during spawning; values indicated for the window indicate mean (range) flow (upper) and temperature (lower) conditions.

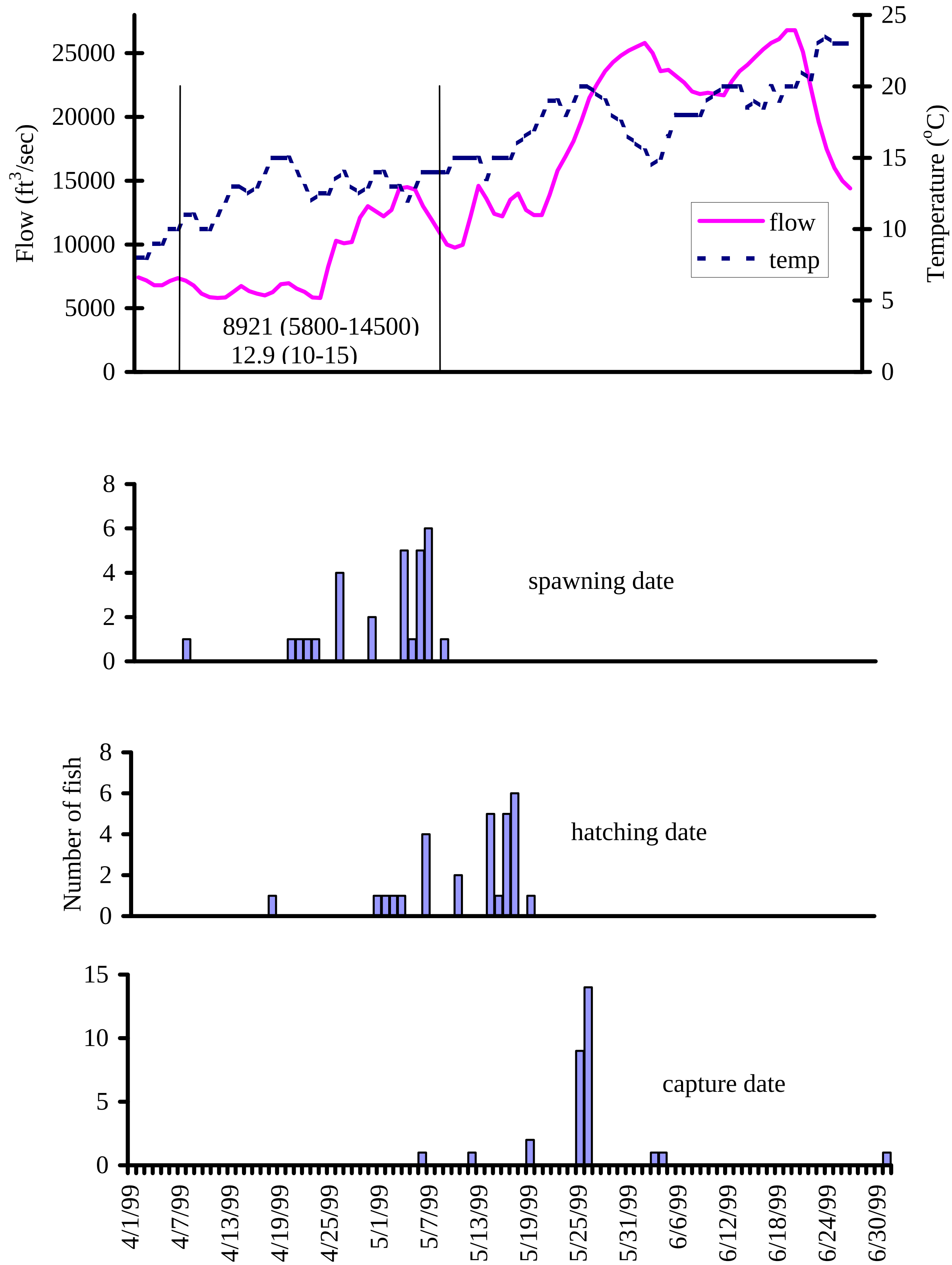
1997 Lower Green River



1998 Lower Green River



1999 Lower Green River



APPENDIX I.–Basinwide monitoring program razorback sucker light-trap sampling localities, middle Green River, 1996 to 1999.

Locality (RK)	1996	1997	1998	1999
Yampa River				
Echo Park, Pool Creek (553.3)	X		X	
Middle Green River				
Brush Creek (490.2)				X
Cliff Creek (487.3)	X	X	X	X
Stewart Lake (482.5)		X		X
Stewart Lake drain (481.5)	X	X	X	X
Sportsmans drain (477.1)		X	X	
Leota # 3 (416.8)		X		
Leota # 5 (415.5)		X		
Leota # 10 (412.3)		X		
Leota boat landing (410.7)		X		
Shepard canal (408.1)		X		
Shepard # 2 (407.5)		X		
Shepard Bottom inlet (406.6)		X		
Old Charlie Wash inlet (405.5)	X		X	
Greasewood Corral (405.4)	X		X	X
Old Charlie Wash outlet (401.5)	X		X	

APPENDIX II.–Basinwide monitoring program razorback sucker light-trap sampling localities, lower Green River, 1996 to 1999. Sample number in the "near Green River" localities represents the number of distinct sample locations in each reach; not every site was sampled in each year. At each other Green River locality, one to several samples were collected per year. Samples at the San Rafael River locality represented collections made at or near the mouth in the Green River and just upstream in the San Rafael itself.

Locality (RK)	1996	1997	1998	1999
Green River valley				
Near Green River (209.2, N = 6)	X	X	X	
(202.8 to 206, N = 8)	X	X	X	
(196.3 to 201.2, N = 12)	X	X	X	
(181.9 to 191.5, N = 3)	X			
(177 to 181.9, N = 5)	X		X	X
(161 to 175.4, N = 6)	X		X	X
San Rafael confluence (156.1)	X	X	X	X
White Wash (153.7)	X	X	X	X
Red Wash (152.9)	X	X	X	X
Blue Wash (152.1)	X	X	X	X
Millard Canyon (54.2)	X	X	X	X
Anderson Bottom (50.7)	X	X	X	
Anderson Bottom (49.9)			X	X
Bonita Bend (49.9)	X			
Below Bonita Bend (49.1)	X			
Holeman Canyon (45.1)	X	X	X	X