Evaluation of the Interagency Standardized Monitoring Program Sampling Technique in Backwaters of the Colorado River in the Grand Valley, Colorado.

prepared by

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Executive Summary

We sampled backwaters in the Grand Valley reach of the Colorado River, CO, to estimate bias and precision of the Interagency Standardized Monitoring Program (ISMP) sampling technique to detect presence and estimate abundance of centrarchid fishes. This was accomplished by sampling backwaters with the relatively low effort ISMP seine-sampling approach, followed by relatively intensive depletion or capture-recapture (DMR) sampling. Presence-absence and abundance data gathered with each technique were then compared to determine bias and precision of ISMP.

A total of 46 backwaters were sampled in 1997 and 1998. A total of 108,542 fish were captured in those samples, most of which were non-native cyprinids sand shiner *Notropis stramineus* (41 %), red shiner *Cyprinella lutrensis* (26 %), and fathead minnow *Pimephales promelas* (20 %). Largemouth bass and green sunfish represented 4.9 % of all fishes captured. Most largemouth bass were less than 120 mm total length (TL), but individuals up to 263 mm TL were captured. Green sunfish captured were generally less than 80 mm TL, but individuals up to 227 mm TL were captured.

Overall, the ISMP sampling approach underestimated the number of backwaters occupied by largemouth bass and green sunfish by about 50 %. In other words, ISMP detected those centrarchid species in only every other backwater in which they occurred. Results of a logistic regression model suggested that the probability of detecting bass and sunfish in backwaters with the ISMP sampling technique was relatively low even when each was relatively abundant. When ISMP sampling detected largemouth bass and green sunfish in Colorado River

backwaters, abundance of those taxa was also underestimated. The ISMP density estimates for largemouth bass were about 1/3 (30 %) of DMR estimates. Similarly, density estimates for green sunfish derived from ISMP sampling were also about 1/3 (34 %) of DMR estimates. Detection and abundance estimation of centrarchids was not an original goal of ISMP sampling, and the technique does not appear to be useful for such.

The ISMP sampling technique detected the presence of the three abundant non-native cyprinids in backwaters nearly 100 % of the time. The ISMP density estimates of those three species were biased low and were, on average, 66 to 79 % of DMR estimates. The ISMP and DMR abundance estimates for cyprinid species were positively correlated with each other at moderate levels (r^2 = 0.42 to 79) which reflected some concordance between the two techniques.

We also analyzed the relationship between the presence and abundance of centrarchid species and three non-native cyprinids and habitat variables. Largemouth bass and green sunfish were most common in backwaters that were relatively large, deep, and had cover. Red and sand shiner, and fathead minnow were ubiquitous in backwaters and their abundance was poorly correlated with habitat variables. We also discussed the efficacy of fish removal as a management technique to enhance rare fish species in the Upper Colorado River basin.

A new, and likely more rigorous sampling protocol needs to be developed which will more reliably estimate the distribution and abundance of centrarchids in backwaters of the Colorado River in the Grand Valley. However, additional data and information is needed to develop a sampling program to effectively monitor centrarchid abundance. Key features of such a sampling program include identifying which parameters to measure, and then determining the desired level of accuracy and precision of those parameters. Only then can a sampling program be designed to deliver the information that is needed. Other key information needs include obtaining a better understanding of the dispersal and population ecology of centrarchids in the Grand Valley reach of the Colorado River and defining their role in regulating the abundance of rare native fishes. Such information would help determine if efforts to enhance floodplain sport fisheries were influencing riverine centrarchid populations, and assist managers in allocating resources to strategies that most effectively improve the status of endangered and other native fishes.

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INTRODUCTION

The demise of endangered fishes native to the Colorado River Basin has been attributed mainly to habitat change, and effects of non-native fishes which compete with and prey upon native taxa (Carlson and Muth 1989, Minckley and Deacon 1991). In the upper Colorado River Basin, non-native green sunfish *Lepomis cyanellus* and largemouth bass *Micropterus salmoides* may represent a substantial source of mortality for early life stages of endangered fishes because they are predaceous and occupy the same low velocity shoreline and backwater habitat. However, distribution and abundance patterns of non-native predaceous centrarchids in riverine habitats are poorly understood, as are factors that regulate their establishment and dispersal.

In the Grand Valley reach of the Colorado River, Colorado, numerous floodplain ponds adjacent to the river support populations of predaceous warm water fishes. Floodplain ponds are being actively managed to improve fishing opportunity and may represent a chronic source of green sunfish and largemouth bass that escape and colonize riverine backwaters used by rare native fishes (Martinez et al. 2001). A monitoring program that accurately tracked abundance of these non-native centrarchids in riverine backwaters would be a means to determine trends in escapement (Colorado Division of Wildlife et al. 1996).

Annual sampling (monitoring) has been conducted in the Colorado River in the Grand Valley since 1982 and the Interagency Standardized Monitoring Program (ISMP) was implemented in 1986 (McAda et al. 1994). The ISMP was developed to monitor population trends of endangered Colorado pikeminnow *Ptychocheilus lucius* and humpback chub *Gila* *cypha* in the Upper Colorado River Basin (McAda et al. 1994). The young-of-year (YOY) Colorado pikeminnow portion of ISMP employs seining in autumn to sample fishes in a subset of the backwaters present in four main Upper Colorado River reaches, including one in the Colorado River in the Grand Valley. The main goal of that sampling was to "provide an annual index of the relative reproductive success of Colorado pikeminnow and survival of the young fish through their first growing season" (McAda et al. 1994). Abundance data for fishes other than the target endangered ones were also gathered. However, it was unknown if the ISMP protocol was capable of detecting the presence and estimating abundance and size-structure of centrarchids with the accuracy and precision needed to monitor trends in fish escapement from floodplain ponds. This was especially true given that ISMP seine sampling was more suited to capture open-water cyprinids than cover-dwelling centrarchids (Larimore 1961, Dauble and Grey 1980, Bayley et al. 1989). Therefore, the goal of this study was to quantify the bias of the relatively low effort ISMP sampling to detect the presence and estimate the abundance of fishes in backwaters. This study had a collateral benefit because we quantified the abundance of select non-native fishes and removed large numbers of them from the Colorado River. Reducing the negative effects of non-native fishes by removing them from backwaters is a goal of the Recovery Program for Endangered Fishes in the Upper Colorado River Basin (Tyus and Saunders 2000). Data gathered in this study was also used to examine the efficacy of mechanical removal as a tool to control non-native fishes in backwaters.

STUDY AREA

Backwaters were sampled in a 55 km-long reach of the Colorado River, CO in the Grand Valley from the Grand Valley Diversion to just downstream of the Loma boat ramp (Fig. 1). The study reach was divided into four sub-reaches, two upstream of the Gunnison River and two downstream. The most upstream sub-reach (sub-reach 1) was from river kilometer (RK) 298.2 downstream to RK 285.8, sub-reach 2 was from RK 285.7 downstream to the confluence with the Gunnison River at RK 274.2, sub-reach 3 was from RK 274.1 to RK 258.6, and reach sub-4 was from RK 258.5 to RK 243.1. River gradient was relatively low and substrate consisted mostly of cobble and gravel, which was overlain with silt and sand in low velocity backwaters (VanSteeter and Pitlick 1998). River discharge was relatively high and variable during autumn 1997, but was lower and more stable in autumn 1998 (Fig. 2).

METHODS

Field sampling

We implemented a double sampling approach (Thompson 1992) in backwaters where fish species richness and fish density was estimated by each of two techniques in autumn of 1997 and 1998. The first was the quantitative but relatively low effort two seine haul ISMP approach (ISMP sampling), and the second was a relatively high effort 3-pass seine depletion or multiple pass capture-recapture approach (DMR sampling). The goal of such sampling was to quantify the bias of presence/absence and abundance data derived from ISMP sampling compared to that gathered with the relatively higher effort, and presumably, more precise and accurate DMR sampling. Backwaters chosen for sampling during this study were a minimum of 30 m^2 in surface area, had minimum depth of 10 cm if turbid or 30 cm if clear, and were not flowing, as per ISMP selection standards. Each backwater was blocknetted at the mouth and the fish community sampled with two non-overlapping ISMP seine hauls (Fig. 3). The hauls were typically made near the mouth and nearer the apex and were usually transverse to the long axis of the backwater. Fish in ISMP samples were identified and enumerated in the field or preserved in 10 % formalin for processing in the laboratory. Area seined was measured.

The backwater fish community was then sampled again using a more intensive 3-pass seine depletion or capture-recapture approach. In seine depletion backwaters, seine hauls (4.6 m long seine, 3 mm mesh) were made in sufficient number to sample nearly the entire area of the backwater on each of three passes; the same number of seine hauls (effort) was made on each sampling pass. Fish captured on each pass were placed in separate live baskets and were enumerated or preserved for laboratory analysis when all sampling passes were completed. Before preservation all samples were scanned for native fishes which were enumerated and released. Preserved samples were identified and enumerated at the Larval Fish Laboratory, Colorado State University, Fort Collins.

Capture-recapture sampling involved capturing fish on one or two consecutive days (passes) with some combination of seining or fyke nets and was followed with a final pass which employed fyke nets, electrofishing, or both. Fyke nets were used in 1997 but were found relatively inefficient because they captured few fish, were size and species selective, and hence, were not used in 1998 sampling. Green sunfish and largemouth bass sampled on all but the final pass were marked with a unique fin clip. In backwaters where capture-recapture sampling was employed, other fish species were incidentally captured and enumerated and were included in estimates of species richness if one of the sampling passes was by seining. In backwaters where capture-recapture sampling targeted centrarchid abundance estimates, abundance estimates for non-centrarchid species were not computed.

Backwater length and five widths were measured to estimate backwater area. Mean backwater depth was estimated from three depth measurements obtained at each of three transects. Habitat characteristics such as presence of woody debris, deep water, undercut banks, overhanging or submerged vegetation, and substrate were described for each backwater. Those characteristics were used to assign a score of 1, 2, or 3, which represented an index of habitat quality ranging from simple to complex.

In addition to autumn sampling, eight backwaters were sampled in spring of 1998 in order to fulfill the obligation of removing fish from as many backwaters as possible. Backwaters were sampled by seining or electrofishing with enough effort to encompass the surface area once. All fishes were placed in a live basket, native fish were enumerated and released, and non-natives were preserved for identification and enumeration in the laboratory. Six of the eight backwaters had been sampled the previous autumn.

Presence/absence and abundance estimation analyses and comparisons

A main goal of comparing presence/absence estimates derived from low effort ISMP sampling and higher effort DMR sampling was to determine if ISMP estimates were biased. This was accomplished by comparing the number of backwaters where a particular species was detected by ISMP sampling to the number of backwaters where it was detected by DMR sampling. If ISMP sampling was unbiased, the expectation was that each technique would detect each species the same number of times. We also wanted to understand the relationship between the probability of detection of each species by the ISMP technique as a function of estimated fish abundance (from DMR sampling) in the backwater. To accomplish this, we used logistic regression (PROC GENMOD, SAS Institute 1993) with a logit link and a binomial error distribution to model the probability of detection of a species as a function of its estimated abundance (see below for abundance estimation techniques). A statistically significant effect would indicate that detection probability for a particular species was proportional in some form to its estimated abundance. The logistic equation was then re-arranged to predict detection probabilities at a range of fish abundance values. That information would be useful to evaluate how many fish would need to be present in a backwater to achieve a desired probability of detection.

Abundance estimates were attempted using either capture-recapture or removal sampling. For capture-recapture DMR sampling, estimates were computed using a Lincoln-Petersen estimator for two-pass data or model M_t for three-pass data, which assumes a time-varying probability of capture (program CAPTURE,White et al. 1982). Abundance estimates for removal DMR sampling were calculated by maximum likelihood techniques. Because the ultimate goal of this research was to determine bias of estimates obtained by ISMP sampling relative to DMR sampling, abundance estimates had to be converted to fish densities for equitable comparisons. The ISMP data were converted by dividing the number of fish captured in the two seine hauls by the area seined. For DMR sampling, estimated abundance of each fish species in each backwater was divided by the total area of the backwater. Both ISMP and DMR density estimates were multiplied by 10, resulting in number of fish per 10 m^2 of backwater area.

A main premise of making comparisons between density estimates was that the high-effort DMR sampling should provide relatively accurate and precise estimates relative to the low-effort ISMP estimates. For the sake of estimating the bias of the ISMP sampling technique, we consider the estimates derived from DMR sampling to be the "true" estimates (unbiased, no variance) of presence and abundance of fishes in backwaters. We acknowledge that there is error in such abundance estimates and quantify that variation with profile likelihood confidence limits, but assume that the error was small relative to that for the two-seine haul ISMP technique. Comparison of the proportion of ISMP density estimates that fell within the 95 % confidence intervals of DMR estimates would thus provide a conservative measure of the bias of the ISMP technique relative to DMR. Specific goals of comparisons between estimates of detection rates and density derived from ISMP and DMR data were:

1) quantify the bias of the ISMP technique to detect presence of green sunfish, largemouth bass, and three abundant non-native cyprinid species (fathead minnow *Pimephales promelas*, sand shiner *Notropis stramineus*, red shiner *Cyprinella lutrensis*) in each backwater, and
2) quantify the bias of the ISMP technique to estimate the density of two centrarchid and three cyprinid species in each backwater.

If data from DMR sampling in individual backwaters was too sparse to compute abundance estimates in CAPTURE, the total number of fish captured was used as an abundance estimate. Thus, no confidence limits were calculated for those estimates.

Fish community and habitat relationships

We also explored the relationship between biotic and physical habitat variables and the presence and abundance of green sunfish, largemouth bass, and the three non-native cyprinids. Probability of fish presence as a function of four habitat variables, backwater area, mean depth, maximum depth, the qualitative index of habitat complexity, and the year effect, was explored with a binomial regression model with a logit link function. Abundance (density) of green sunfish, largemouth bass, and the three non-native cyprinids as a function of four habitat variables was explored with a general linear model (GLM). Backwater area^2, mean depth, maximum depth, and a qualitative index of habitat complexity were the independent variables in the analysis. Because fish abundance data are divided by backwater surface area to yield fish density, the backwater area covariate is expressed as a squared term to avoid confounding. The response variable, estimated fish density (fish/10m^2), was transformed as log (x + 1). In models that predicted non-native cyprinid density, predator density (the sum of the green sunfish and largemouth bass densities in each backwater) was used as an additional covariate.

We also assessed the relationship between fish species richness in backwaters as a function of four habitat variables, backwater area, mean depth, maximum depth, the qualitative index of habitat complexity. A GLM that assumed a normal error distribution was used. We also included river kilometer to determine if spatial location affected fish species richness in backwaters. For the purpose of this analysis, a composite estimate of backwater species richness was generated from the results of ISMP and DMR sampling.

We also plotted density estimates of the two centrarchids and three non-native cyprinids obtained during 1986 to 1999 during the regular ISMP sampling that was conducted by other investigators (e.g., McAda et al. 1994-1999). This was done to determine if abundance levels of those five species in 1997 and 1998 were abnormal relative to historical levels and to understand if any long-term trends were evident in the ISMP data.

RESULTS

1997 Sampling

A total of 21 backwaters was sampled in the Grand Valley reach of the Colorado River from 9 September to 11 November 1997. The 21 backwaters represented nearly every accessible backwater in the reach that met ISMP criteria and had an estimated surface area of 15,978 m^2. Backwater habitat was unevenly distributed among the sub-reaches. Sub-reach 1 contained six backwaters, sub-reach 2 had two backwaters, and sub-reaches 3 and 4 contained six and seven backwaters, respectively. High water (150-300 m^3/sec) in the Colorado River throughout autumn 1997 limited backwater availability to some extent throughout the study area (Fig. 2).

Fish abundance in fifteen backwaters was estimated using depletion techniques and fish abundance in the remaining six was estimated using capture-recapture. Sampling effort included 516 seine hauls, 310 minutes of electrofishing, and 24 (24-hour) fyke-net sets. The 42 ISMP seine hauls completed in the 21 backwaters (2 per backwater) encompassed an average of 18 % (5 to 42 %) of the surface area of each backwater (Table 1).

Sampling detected a total of five native and 15 introduced fishes and a total of 37,900 fish were sampled from backwaters (Appendix I). Non-native species represented 94.4 % of all fishes captured and sand shiners (41 %), red shiners (25 %) and fathead minnows (19 %) were the most abundant taxa (Fig. 4). Native species represented 5.6 % of the total catch; roundtail chub, *Gila robusta*, was the most abundant taxon (1.8 %, n = 707). One Colorado pikeminnow (TL approx. 35 mm TL) was captured and released in 1997 in a sub-reach 3 backwater located approximately 3.2 kilometers downstream of the confluence with the Gunnison River.

Centrarchids were 4.9 % of the total number of fish captured; these were mainly green sunfish (4.0 %) and largemouth bass (0.8 %). In all, 1,522 green sunfish (19 to 227 mm TL) and 321 largemouth bass (32 to 263 mm TL) were removed from the 21 backwaters sampled in the Grand Valley reach of the Colorado River in autumn 1997.

1998 Sampling

A total of 24 different backwaters was sampled in the Grand Valley reach of the Colorado River from 15 September to 17 November 1998. The 24 backwaters represented nearly every accessible backwater habitat in the reach and had an estimated surface area of 16,229 m^2. Backwater habitat was again unevenly distributed among the reaches. Sub-reach 1 contained ten backwaters, sub-reach 2 had one backwater, and sub-reaches 3 and 4 contained seven and six backwaters, respectively. One backwater in sub-reach 1 was sampled twice (samples 4.1 and 4.2), once each by capture-recapture and depletion techniques, because centrarchid abundance was very high. Thus, a total of 25 abundance estimates were available for the 24 backwaters sampled.

Fish abundance in 22 backwaters was estimated using depletion techniques. Fish abundance in the remaining two backwaters and the sub-reach 1 duplicate backwater was estimated using capture-recapture. Sampling effort included 530 seine hauls, and 1,097 minutes of electrofishing. The 50 ISMP seine hauls completed in the 25 backwater samples encompassed an average of 22 % (5 to 94 %) of the surface area of each backwater.

Sampling detected a total of five native and 13 introduced fishes and samples contained a total of 70,642 fish (Appendix II). Native fishes comprised 2.0 % of the total catch (Figure 5); the most abundant native species was speckled dace *Rhinichthys osculus* (0.7 %; n = 560). One Colorado pikeminnow (approx 35 mm TL) was captured and released in the Colorado River in 1998 in a sub-reach 3 backwater approximately eight kilometers downstream of the confluence with the Gunnison River.

Non-native species represented 97.9 % of all fishes captured and sand shiners (41 %), red shiners (26 %) and fathead minnows (21 %) were again the most abundant taxa. Centrarchids were 5.1 % of the total number of fish captured; those were mainly green sunfish (3.0 %) and largemouth bass (1.9 %). In all, 2,176 green sunfish (16 to 174 mm TL) and 1,366 largemouth bass (45 to 245 mm TL) were removed from the 24 backwaters sampled in the Grand Valley reach of the Colorado River in autumn 1998. Most largemouth bass captured in backwater samples in both years were relatively small (< 120 mm TL) and likely represented age-0 fish (Figs. 6 and 7). We encountered a few bass larger than 120 mm TL (Age 1+), and these fish appeared to be relatively healthy and in good condition. Green sunfish collected in samples were also dominated by relatively small fish (≤ 80 mm TL) that were likely age-0, although relatively large specimens were captured occasionally (Figs. 8 and 9).

Additional sampling was conducted in eight backwaters in spring 1998. A total of 3,338 fish were removed from the eight backwaters with the most abundant species being sand shiner, fathead minnow, red shiner, and green sunfish (Table 2). Only a single largemouth bass was captured in backwater 4, the location where bass were very abundant in autumn 1998.

ISMP performance

The lower effort ISMP technique detected the presence of green sunfish and largemouth bass in relatively few backwaters compared to the higher effort DMR sampling. The ISMP sampling technique detected largemouth bass in 14 backwaters where DMR sampling detected the species in 30 backwaters (7 of 14 in 1997, and 7 of 16 in 1998, Table 3). If we assume that presence of largemouth bass was estimated without error by DMR sampling (e.g., no bass were present in the remaining 16 backwaters sampled), ISMP sampling detected the presence of bass only 47 % of the time. The ISMP sampling failed to detect largemouth bass in the second sampling effort in backwater 4 (sample 4.1) in 1998, a location where estimated bass abundance was the second-highest (N = 338) recorded in the entire study.

Green sunfish were detected by ISMP sampling in 23 backwaters but were found in 40 backwaters during DMR sampling (11 of 18 in 1997, and 12 of 22 in 1998). Thus, presence of green sunfish was detected by ISMP sampling only 58 % of the time.

The logistic regression analysis to determine the relationship between the probability of detection of largemouth bass as a function of their estimated abundance (density) yielded a statistically significant effect ($p < 0.0001$). That relationship had the form:

$$\text{logit } Y = -1.781 + 3.065(\textit{largemouth bass density}), \quad (1)$$

where largemouth bass density was number of fish per 10 m^2. Habitat complexity was not a significant effect in this model. Re-ordering the logistic equation to yield probability of detection given an investigator-chosen largemouth bass density was of the form:

$$p_y = \frac{1}{1 + exp(1.781 - 3.065(\textit{largemouth bass density}))} \quad (2)$$

where largemouth bass density was number of fish per 10 m^2. This relationship assumes average backwater depth and habitat features for backwaters in the Colorado River in the Grand Valley. Solutions to the logistic regression equation over a range of bass abundance values suggested that the probability that the ISMP technique would detect bass in a backwater was relatively low even when bass were abundant (Fig. 10). For example, a 50 % probability of detection was achieved only after largemouth bass abundance exceeded 0.58 fish per 10 m^2 surface area in an average size backwater. Assuming that the average backwater surface area in the Grand Valley in 1997 and 1998 was 718 m^2, this equates to an abundance level of 42 bass to achieve a 50 % probability of detection. The positive intercept in this relationship suggested that there was a small probability of detecting bass with ISMP sampling when estimated abundance was low.

A similar logistic regression analysis conducted for green sunfish suggested that detection probabilities of ISMP sampling increased as green sunfish density increased ($p < 0.0001$). Habitat complexity was not a significant effect in this model, which had the form:

$$\text{logit } Y = -1.5935 + 2.7317(\textit{green sunfish density}), \quad (3)$$

where green sunfish density was number of fish per 10 m^2. Re-ordering the logistic equation to yield probability of detection given an investigator-chosen green sunfish density value is of the form:

$$p_y = \frac{1}{1 + exp(1.5935 - 2.7317(\textit{green sunfish density})} \tag{4}$$

where green sunfish density was number of fish per 10 m^2.

This relationship again assumes the average backwater condition (e.g., surface area, depth) in the Colorado River in the Grand Valley. Solutions to the logistic regression equation over a range of green sunfish density values suggested that the probability that the ISMP technique would detect sunfish in a backwater was relatively low even when green sunfish were abundant (Fig. 11). For example, a 50 % probability of detection in backwaters was achieved only after green sunfish abundance exceeded 0.58 per 10 m^2 backwater surface area, the same value as for bass. Again assuming that the average backwater surface area in the Grand Valley in 1997 and 1998 was 718 m^2, this translates into an abundance level of 42 green sunfish in the backwater in order to achieve a 50 % probability of detection. The positive intercept in this relationship suggested that there was a small probability of detecting green sunfish with ISMP sampling when estimated abundance was low. A more reliable 90 % probability of detection level for largemouth bass and green sunfish was achieved only after their density in backwaters exceeded 1.4 per 10 m^2, or 101 fish in a 718 m^2 backwater.

We did not compare the relative efficiency of ISMP sampling to DMR sampling to detect presence of red and sand shiners and fathead minnows. This was because these abundant species were found in nearly every backwater sampled, regardless of the technique used.

The lower effort ISMP technique tended to consistently underestimate the density of largemouth bass in backwaters compared to estimates derived from higher effort DMR sampling (Figs. 12 and 13). Averaged over 1997 and 1998, density of largemouth bass estimated from ISMP sampling was only 30 % (0 to 181 %) of the density of largemouth bass estimated by DMR sampling. In only 4 of the 30 backwaters where bass were found did ISMP density estimates exceed DMR estimates. For the 15 backwaters for which 95 % confidence intervals could be calculated for largemouth bass DMR density estimates, only one ISMP estimate fell within the confidence limits and the remainder fell below.

Similar to largemouth bass, the lower effort ISMP technique tended to consistently underestimate the density of green sunfish in backwaters compared to estimates derived from higher effort DMR sampling (Figs. 14 and 15). On average, density of green sunfish estimated from ISMP sampling equaled only 34 % of the density of green sunfish estimated by DMR sampling (0 to 260 %). In only 5 of 41 cases did the ISMP density estimate exceed that from DMR sampling. For the 22 backwaters for which 95 % confidence intervals could be calculated for green sunfish DMR density estimates, only three ISMP estimates fell within that interval.

The ISMP abundance estimates for non-native cyprinids were generally less biased relative to DMR estimates than for centrarchid estimate comparisons. On average, density of red shiner estimated from ISMP sampling equaled 79 % of the density of red shiner estimated by DMR sampling (0 to 343 %, Figs. 16 and 17). Twelve out of 37 ISMP density estimates exceeded those estimated by DMR sampling. For the 34 backwaters for which 95 % confidence intervals could be calculated for red shiner DMR density estimates, only one ISMP estimate fell within those intervals. The correlation between ISMP and DMR density estimates for red shiner over the two sample years was positive, albeit relatively low ($r^2 = 0.42$, $p < 0.0001$, n = 38).

Density of sand shiners estimated from ISMP sampling equaled 67 % of the density of sand shiners estimated by DMR sampling (0 to 183 %, Figs. 18 and 19) and eleven of 41 ISMP density estimates exceeded those estimated by DMR sampling. For the 33 backwaters for which 95 % confidence intervals could be calculated for sand shiner DMR density estimates, only one ISMP estimate fell within those intervals. The correlation between ISMP and DMR density estimates for sand shiner over the two sample years was positive and relatively high ($r^2 = 0.79$, $p < 0.0001$, n = 38), but these and other correlations may be over- influenced by a few relatively large values.

On average, density of fathead minnow estimated from ISMP sampling equaled 66 % of the density of fathead minnow estimated by DMR sampling (0 to 230 %, Figs. 20 and 21). Out of 38 estimates, nine ISMP density estimates exceeded those from DMR sampling. For the 36 backwaters for which 95 % confidence intervals could be calculated for fathead minnow DMR density estimates, only six ISMP estimates fell within those intervals. The correlation between ISMP and DMR density estimates for fathead minnow over the two sample years was positive, albeit relatively low ($r^2 = 0.56$, $p < 0.0001$, n = 38).

The proportion of fish removed from depletion backwaters on each pass was calculated (number captured per pass/estimated fish abundance) for three cyprinid and two centrarchid species in order to estimate the total number of fish removed by successive passes (Table 4, Appendices IV and V). Over the study period, an average of 54 % of the cyprinids that occurred in backwaters were removed on the first sampling pass. On the second and third sampling passes, an additional 21 and 12 % of the total number of cyprinids were removed from backwaters, for a total of 87 % over the three removal sampling passes. First pass removal rates for cyprinid species were slightly higher in 1997 than in 1998, but average total removal rates were similar among years. Over the study period, an average of about 50 % of the green sunfish that occurred in backwaters were removed on the first sampling pass. An additional 30 and 12 % of the estimated total number of green sunfish in the backwater were removed on subsequent passes, for an average total removal rate of 92 %. Apparent removal rates were even higher for largemouth bass, averaging 58 % on the first pass and nearly 98 % over all passes. The estimated proportion of centrarchid fishes removed by depletion sampling may be somewhat inflated because the estimated proportion of fish removed was sometimes 100 % for backwaters where those species were rare and all specimens were captured on only a single sampling pass. However, depletion sampling conducted by electrofishing in backwaters 23 and 24 in 1998, where centrarchids were abundant, suggested that 48 % of green sunfish and 60 % of largemouth bass were removed on the first pass. A total of 87 % of the green sunfish and 94 % of the largemouth bass were removed with three depletion sampling passes, which suggested that average removal rates calculated over all backwaters were reasonably accurate.

Fish community and habitat relationships

Presence of largemouth bass and green sunfish in backwaters was generally positively associated with backwaters that were large and relatively deep, and were negatively associated with backwaters that had relatively simple habitat (e.g., little cover). The best fit logistic regression model for largemouth bass suggested that average depth and surface area were positively associated with presence of largemouth bass (Table 5). Inexplicably, maximum depth was negatively, albeit weakly, associated with presence of largemouth bass.

The best fit logistic regression model for green sunfish suggested that average depth and surface area were positively associated with presence of green sunfish. Presence of green sunfish was negatively associated with relatively simple habitat. A candidate model with a similar Akaike's Information Criterion (AIC) score retained only average depth and surface area as covariates. A similar analysis was not conducted with the three non-native cyprinid species because they were found in nearly every backwater in the study area.

The general linear model (GLM) analysis suggested that largemouth bass density was positively correlated with average backwater depth and surface area^2, but negatively associated with backwater maximum depth and relatively simple habitat (Table 6). The negative coefficient for the *year1997* variable reflected the lower numbers of largemouth bass captured in that year. The GLM for green sunfish produced essentially the same results; density was positively correlated with average backwater depth and surface area^2, but negatively associated with backwater maximum depth and relatively simple habitat. The negative coefficient for the *year1997* variable reflected the lower numbers of green sunfish captured in that year. Recall that because fish abundance data are divided by backwater surface area to yield fish density, use of surface area as a independent covariate would confound this analysis. Therefore, any positive or negative relationship of backwater size to fish abundance is reflected in the surface area^2 term.

The fit of individual general linear models for red and sand shiner, and fathead minnow abundance as a function of habitat variables and predator abundance were very low (R^2 = 0.18 to 0.29) and the overall models were not statistically significant (p-values = 0.13 to 0.48). A GLM fitted to the pooled cyprinid abundance data (R^2 = 0.17; overall model fit, p = 0.006), in the absence of the non-significant predator abundance covariate, yielded limited inferences about the relative importance each habitat variable to predict cyprinid abundance. Cyprinid abundance was positively associated with average depth and relatively simple habitat, and negatively, but weakly associated with surface area^2 and maximum depth. The weak negative relationship of fish density to surface area^2 suggested that smaller backwaters tended to support higher densities of cyprinids. Similar to the centrarchid GLM models, the negative coefficient for the *year1997* variable in the cyprinid GLM reflected the lower numbers of those species captured in that year.

Species richness relationships

The 1997 ISMP sampling detected 14 species in the study area while DMR sampling detected 20 (Table 3). In 1998, ISMP sampling detected 14 species in the study area while DMR sampling detected 17. On average, ISMP sampling detected only 66 % of the species that occurred in individual backwaters relative to those detected by DMR sampling (Table 7). As expected, cryptic (e.g., ictalurids) or rare taxa were the ones most frequently overlooked by ISMP sampling.

Pooled ISMP and DMR sampling results for individual backwaters suggested that an average of 10 fish species (range 5 to 16) occurred in each backwater in the study area during 1997 and 1998 (Table 7). The best fit regression model of species richness as a function of habitat variables suggested a positive association with river kilometer, surface area, and maximum depth. The river kilometer attribute suggested that, on average, two more species would occur in the most upstream backwater compared to the most downstream one. The surface area ($p = 0.003$) and maximum depth ($p = 0.0008$) variables were more statistically significant than river kilometer ($p = 0.02$) in predicting species richness.

Comparisons with historical ISMP data

Abundance of largemouth bass, green sunfish, and the three non-native cyprinids in ISMP samples collected in the Grand Valley since 1986 were plotted to determine if there were trends in those populations (Figs. 22 and 23). Largemouth bass occurred in the Grand Valley reach of the Colorado River in most years since 1986 and appeared to be steadily increasing in abundance since 1993. Green sunfish abundance was generally much higher than for largemouth bass over the period of sampling and exhibited a more erratic abundance pattern since 1986. The highest recorded abundance of green sunfish ever was in 1998, but it was difficult to determine if abundance of that taxon was stable or increasing over time.

Abundance of non-native cyprinids fathead minnow, red shiner, and sand shiner in ISMP samples collected in the Grand Valley since 1986, suggested that abundance varied dramatically over time, especially for the latter two taxa (Fig. 23). Sand shiner abundance was more stable since 1986, but all species were relatively more abundant in samples collected in the late 1980's and early 1990's compared to more recent years such as 1997 and 1998.

DISCUSSION

The main goal of this study was to estimate bias and precision of the ISMP sampling program to detect presence and estimate abundance of centrarchid fishes in backwaters of the Colorado River. Overall, the ISMP sampling approach underestimated the number of backwaters occupied by largemouth bass and green sunfish by about 50 %. In other words, ISMP detected those centrarchid species in only every other backwater in which they occurred. When ISMP sampling detected largemouth bass and green sunfish in Colorado River backwaters, abundance of those taxa was underestimated compared to more reliable removal or capture-recapture sampling. Details of analyses that led to these findings are discussed below. Although detection and abundance estimation of centrarchids was not an original goal of ISMP sampling, managers needed to understand whether this approach could be useful for such. The results of this study suggest that a more intensive monitoring program needs to be developed to achieve the goal of more accurate estimates of distribution and abundance of centrarchids in backwaters of the Colorado River.

ISMP performance

The logistic regression analysis suggested that relatively large numbers of the target centrarchid species needed to be present for ISMP sampling to simply *detect* the species with a relatively modest probability of 0.5. The ISMP sampling technique sometimes failed to detect centrarchids, especially largemouth bass, even when they were quite common (e.g., backwater # 4.2, Fig. 13).

When ISMP seining detected largemouth bass and green sunfish in Colorado River backwaters, ISMP consistently underestimated their density. The ISMP density estimates for largemouth bass were about 1/3 (30 %) of DMR estimates. Similarly, density estimates for green sunfish derived from ISMP sampling were also about 1/3 (34 %) of DMR estimates. If ISMP sampling was a reliable surrogate for DMR sampling, one would expect that estimates derived from both techniques in the same backwater would consistently track each other.

We recognize that there is variability in all abundance estimation techniques, including those derived by DMR sampling. Therefore, we quantified variability about DMR estimates with profile-likelihood confidence limits to determine if ISMP estimates fell within those bounds. In spite of the fact that confidence limits about DMR estimates were sometimes quite large, few ISMP estimates fell within those bounds. That evidence, coupled with the finding of a consistent negative bias of ISMP abundance estimates, makes us even less confident about the ability of ISMP to detect and estimate abundance of centrarchids in backwaters.

Several factors may be responsible for the bias and imprecision of ISMP estimates to detect and estimate abundance of centrarchids in backwaters. As the literature has demonstrated (Larimore 1961, Moyle and Nichols 1973, Dauble and Grey 1980, Bayley et al. 1989), centrarchids occur primarily in deeper water and are associated with cover in streams. Those associations were supported in our analysis of fish abundance as a function of habitat variables. Because deep, cover-filled areas are patchily distributed in backwaters, they may be missed with the low effort ISMP technique or avoided altogether because they are difficult to seine with traditional techniques. Lack of efficient sampling in such areas would result in reduced probability of capture and underestimation of centrarchid abundance. Some centrarchids also have large body size and are faster swimming than cyprinids and thus, may evade capture with a seine more easily. This is especially true in larger backwaters, where fish have more room to escape. Because the number of ISMP seine hauls made for each backwater was typically constant (N = 2), the proportion of the backwater area seined declined as backwater size increased. This likely also resulted in lower detection rates and underestimation of centrarchid abundance.

The ISMP protocol detected the presence of the three abundant non-native cyprinids more reliably than for centrarchids. Non-native cyprinids were generally an order of magnitude or more abundant than centrarchids in backwaters which likely enhanced detection rates. Those cyprinid species were also more inclined to occur in relatively shallow water that was free of cover, which likely also increased detection probabilities.

The average ISMP abundance estimates for the three cyprinid species were 66 to 79 % of the abundance levels derived from DMR sampling. Thus, performance of the ISMP protocol for cyprinids was better than the 30 to 34 % level that ISMP achieved for centrarchids. The ISMP and DMR abundance estimates for cyprinid species were positively correlated at moderate levels of significance which reflected some concordance between the two techniques. At the scale of individual backwaters, accuracy of ISMP density estimates for cyprinid species was relatively poor when compared to DMR estimates. Evidence for this was from the low frequency that ISMP abundance estimates fell within the confidence bounds calculated about DMR abundance estimates. Out of a total of 103 confidence limits available from DMR sampling for all three cyprinid species, only eight ISMP estimates (8 %) fell within those bounds.

Poor agreement between cyprinid abundance estimates derived from ISMP and DMR sampling could be due to several factors. Cyprinid species are often found in schools, which may place fish in areas where ISMP seine hauls are not made. Large concentrations of these species are sometimes also found in shallow, warm channel margins. If the limited amount of ISMP sampling does not occur where such aggregations exist, abundance estimates are likely to be biased low. On the other hand, some proportion of the estimates should be biased high if such aggregations were encountered, and that was the case in this study.

The generally poor agreement between ISMP and DMR sampling has implications for ISMP seining conducted to estimate abundance of YOY Colorado pikeminnow in backwaters. However, because few Colorado pikeminnow (N = 2) were captured in this reach during 1997 and 1998, we were unable to fully evaluate accuracy and precision of ISMP to estimate YOY Colorado pikeminnow abundance. Those results did concur with results of ISMP sampling conducted since 1986 (McAda et al. 1994 to 1999) that YOY Colorado pikeminnow were rare in this reach. If one assumes that habitat preferences of YOY Colorado pikeminnow were similar to non-native cyprinids, one might expect that ISMP should detect Colorado pikeminnow at relatively high rates when abundant. Similarly, ISMP abundance estimates would likely be positively correlated with true abundance of Colorado pikeminnow. This was the conclusion of Haines et al. (1998), who found that an ISMP-like abundance estimation approach was positively, but only weakly correlated with estimates from a more rigorous abundance estimation technique.

The ISMP sampling technique was also evaluated by Trammel and Chart (1999). However, the scope and methods of sampling used in that study were different enough to prevent comparisons of results of this study (pers. comm. T. Chart). The main difference in the methods was that the Trammel and Chart samples were collected in an area confined to the area normally sampled in a single seine haul. Our sampling was conducted at a scale such that one could make inferences from seine haul estimates of presence and abundance to the entire backwater.

A rigorous evaluation of the accuracy and reliability of the ISMP approach to estimate juvenile Colorado pikeminnow abundance should be conducted if the Recovery Program desires ISMP abundance estimates for this life stage to be more than order of magnitude approximations. Such an evaluation should consider not just the reliability of abundance estimates within a backwater, but the distribution and frequency of backwaters sampled within a larger reach-scale as well. This is important because distribution and abundance patterns of Colorado pikeminnow shift within and between years. The present ISMP sampling program employs sampling on relatively large river reaches (177 to 193 km) which gives good spatial coverage for widely distributed populations, but has relatively low within-reach sampling intensity (e.g., McAda et al. 1994). Conversely, abundance estimation procedures are within-backwater intensive but are often restricted to relatively small river reaches of 10 to 20 km (Haines et al. 1998). A program that combines the merits of both approaches would seem necessary to develop a more rigorous approach.

Fish community and habitat relationships

Centrarchids were found in backwaters more frequently, and were more abundant in, backwaters that were large, relatively deep, and had more complex habitat. These results verify the findings of previous investigators, who found centrarchids in streams generally associated with deeper water and cover (Larimore 1961, Dauble and Grey 1980, Bayley et al. 1989). Another reason centrarchids may be relatively common in large, deep backwaters is that such places are likely more stable and persist longer in the face of flow fluctuations than small, shallow backwaters. Compared to cyprinids, which occur in mainstem as well as backwater habitat, largemouth bass and green sunfish may require stable and persistent low velocity habitat to survive in large numbers in the Colorado River Basin. It follows that high spring peak flows that inundate backwaters may be important to re-set backwater fish communities (Gido et al. 1997) and may function to reduce the number of centrarchid fishes present.

Examination of the abundance patterns of green sunfish and largemouth bass since 1986 in all ISMP sampling reaches throughout the Upper Colorado River Basin (Mcada et al. 1994 to 1999) suggested that centrarchids were much less common in the other three ISMP sampling reaches than in the Grand Valley reach. A plausible explanation for this pattern is that the Grand Valley reach of the Colorado River is the only ISMP sampling reach that is adjacent to a relatively large population center and has extensive gravel pit pond development. These ponds are often stocked with sport fish such as largemouth bass which may escape and populate riverine backwaters (Martinez, 1999). Because many backwaters in the Grand Valley form in the same places each year, it should be expected that backwaters that are proximal to source populations would act as sinks for centrarchid species.

Abundant non-native sand and red shiners and fathead minnows were found in nearly every low velocity backwater habitat sampled in the Grand Valley reach of the Colorado River. Further, abundance of these three species was not closely correlated with any habitat variables. The cosmopolitan distribution of these species and lack of strong relationships between abundance and habitat variables suggests that these taxa are habitat generalists, (Bramblett and Fausch 1991, Fausch and Bramblett 1991, Cross and Collins 1995). The mobile nature of these species, and their relatively high reproductive potential suggests these taxa recover quickly when populations in backwaters are reduced. Any inferences regarding cyprinid abundance and habitat relationships should be made with caution because the statistical fit of individual covariates and the overall cyprinid GLM were poor. Poor model fit also suggests that some other unmeasured abiotic or biotic variables may be better predictors of cyprinid abundance in backwaters.

Species richness relationships

As with presence and abundance estimation, ISMP sampling tended to underestimate species richness of the fish community in backwaters of the Colorado River. As expected, rare species tended to be those that went undetected by the relatively low-effort ISMP technique.

Habitat characteristics played a role in determining fish species richness in backwaters. More fish species were found in backwaters that were relatively large and deep, which may be surrogate measures of backwater stability or longevity in this system where flow fluctuations were common. The positive relationship between species richness and river kilometer suggested that more species occurred in upstream than in downstream backwaters. It is possible that upstream backwaters were more proximal to source locations for relatively rare species, and thus supported more species. It is also possible that the upstream reach had more diverse habitat or provided thermal environments more accommodating for a larger number of species than downstream.

Fish community composition and removal efforts

Sampling conducted during this study verified previous findings that suggested backwater fish communities were dominated by small-bodied non-native cyprinids, namely sand and red shiners, and fathead minnows (Haines and Tyus 1990, McAda et al. 1994). Overall, non-native fishes represented 95 and 98 % of backwater fish communities in 1997 and 1998, respectively. A surprising result was that each of the three abundant cyprinids was represented in nearly equal proportions in samples collected in consecutive years 1997 and 1998. This was especially remarkable given that nearly twice as many fish were captured in 1998 compared to 1997.

Reasons for large differences in numbers of fish captured in 1997 and 1998 were not clear, especially since the number of backwaters sampled (21 in 1997, 24 in 1998), backwater surface area sampled (15,978 m^2 in 1997, 16,229 m^2 in 1998), and number of seine hauls used to collect samples (516 in 1997, 530 in 1998) were very similar. Backwaters were relatively stable in late summer and autumn 1998 compared to 1997, due to lower and less fluctuating flows, which may have promoted higher fish density in backwaters in 1998.

Strength of year-classes of fishes in backwaters may also have been affected by events prior to our sampling such as spring runoff levels. For example, McAda and Kaeding (1989) and McAda and Ryel (1999) previously found that abundance of cyprinids such as non-native red and sand shiners and fathead minnows was reduced in years of relatively high spring runoff. Spring peak runoff was much higher in 1997 (about 736 m^3/s), the year when fish abundance was lower, compared to 1998, when fish abundance was higher and the spring runoff peak was lower (about 425 m^3/s). Flow fluctuations were also more common in autumn 1997 than in autumn 1998.

It is interesting to note that in spite of the high level of fish removal effort expended in 1997, the number of fish captured in backwaters the following year nearly doubled. This occurred even after estimated fish removal rates from individual backwaters approached or exceeded 90 % for many species. In making these assertions about removal rates we are assuming that probability of capture of fish is not reduced during seining on successive passes, which would have resulted in underestimation of fish abundance by removal estimators (Riley and Fausch 1992). Several plausible explanations exist for the apparent increase in fish abundance from 1997 to 1998. First, it may suggest that the fishes that we think occupy mostly backwater habitat, may in fact occupy other riverine habitat in large numbers, and hence, were unavailable for capture during our sampling efforts. This may mean that long-lasting depletion efforts require intensive sampling efforts on multiple sampling passes within a growing season, rather than just on a single pass. Another explanation may be that the reproductive capability of the fish remaining after 1997 sampling was too high and overwhelmed removal efforts. Even a relatively small number of these animals has high reproductive capability because of high fecundity and potential for multiple or continuous spawning (e.g., Gale 1986). A third explanation may be that fish recolonized the depleted reach between sampling sessions. Taken together, this suggested that even relatively intense removal efforts will effect only a temporary reduction in abundance of target species. It also suggested that removal efforts should be implemented just prior to the appearance of the life stage(s) of the native endangered species that is expected to benefit the most. For example, early summer fish removal may benefit larvae of summer spawning Colorado pikeminnow the most, while early life history stages of spring spawning razorback sucker may benefit most from fish removal conducted prior to spring runoff.

A particularly sobering thought regarding the efficacy of fish removal from backwaters is the high level of effort needed to accomplish the task. The total backwater area sampled during intensive autumn sampling was little more than the area occupied by three football fields side-by-side (about 16,000 m^2), and occurred in a river reach of about 55 km. Although other things were being accomplished during sampling that wouldn't necessarily occur during routine fish removal efforts, that effort took about six weeks of time with a crew of 3-4 individuals. Our depletion efforts removed about 90 % of fish from backwaters in three sampling passes. Unfortunately, while the number and proportion of fish removed is indisputably large, effects of removal appeared to be small because fish abundance in 1998 was as high or higher than in 1997.

Evaluation of the effectiveness of fish removal as a management tool to benefit native fishes will minimally require an understanding of the level of removal necessary to benefit the target native species, and whether that level of removal is possible or even desirable given limited resources. Nevertheless, the Grand Valley seems an ideal place to conduct fish control efforts because of an apparent decline in abundance of YOY Colorado pikeminnow (Haynes et al. 1984, McAda et al. 1994). It is also an ideal area because abundance of centrarchid fishes in backwaters is higher there than in any other reach where ISMP backwater sampling occurs (McAda et al. 1994 to 1999).

Most centrarchids captured in backwaters were relatively small fish, and although we did not attempt age estimation, they likely represented age-0 fish. We were unable to determine whether these supposed age-0 largemouth bass and green sunfish originated from fish spawning in riverine backwaters, if they dispersed from floodplain ponds, or some combination of the two. There were individuals of each species captured in riverine backwaters that were certainly of a size capable of reproducing. The largest number of bass we captured was in upstream backwater 4 in 1998. That backwater was large, and likely offered some low velocity refugia even during high flow periods, so it is possible that bass may have spawned in the backwater. Although there is an irrigation return inflow near that site, lack of an upstream floodplain pond (pers. obs. P. Martinez) makes it more likely that bass captured in that backwater were in fact spawned there. Backwaters associated with the river channel often have associated off-channel wetlands which may serve as a source for riverine bass, especially during high flow periods.

It was interesting to note that in spring 1998 sampling in backwater 4, only a single largemouth bass was captured. However, by autumn 1998, large numbers of bass were present. That suggested either a large colonization event by bass in late spring or reproduction in summer 1998. Low numbers of bass in the backwater in spring may have been a function of poor survival overwinter. Unfortunately, we did not sample that backwater in autumn 1997, so we do not know if bass abundance was low prior to the spring 1998 sample or if overwinter survival was low. Understanding the overwinter survival rates of bass and other non-native fishes in backwaters may have important implications for the efficacy of removal of these fishes from backwaters.

Understanding the ultimate source of bass found in riverine backwaters may require employing novel approaches to solve this difficult problem. Stable isotope analysis may be able to define differences in signatures of prey consumed in floodplain areas compared to backwaters, and thus identify the origin of bass (Martinez et al. 2001). Otolith analysis may be yet another way to evaluate the point of origin of bass found in riverine backwaters. Floodplain ponds likely warm earlier in the year than the Colorado River and would promote earlier spawning by bass, compared to riverine spawning fish. Otolith analysis may permit estimation of hatching dates of young bass captured in backwaters, which when correlated with riverine water temperatures, may allow assignment of likely place of origin. It may also be possible to employ specialized sampling techniques to capture larvae or use observations to document spawning activity by adults in backwaters.

Distinguishing whether the centrarchids captured in backwaters originated from the floodplain or *in situ* is important because different management actions would be needed to reduce the abundance of fish from each source (Martinez, 1998). For example, if the majority of bass originate in the floodplain, pond isolation or screening of ponds or returns may be necessary to reduce dispersal at the source. Alternatively, efforts to reduce effects of bass produced in riverine backwaters may involve ongoing removal of young or adults.

Summary

A new, and likely more rigorous sampling protocol needs to be developed which will more reliably estimate the distribution and abundance of centrarchids in backwaters of the Colorado River in the Grand Valley. However, additional data and information is needed to develop a sampling program to effectively monitor centrarchid abundance. A well-designed monitoring program should explicitly identify, *a priori*, the parameter or parameters to be measured, and then define the accuracy and precision of the parameter estimates needed for decision making. Only then can a sampling program be designed to deliver such. This of course assumes that the monitoring program has given proper consideration to other important issues such as specification of explicit goals, geographical context of sampling, the statistical power of such sampling to detect trends in the status of a population, and how the information that is gathered will be used in a decision-making context. These and other conceptual and technical details are discussed in Thompson et al. (1998) and Noon et al. (1998).

The data gathered in this study was needed to determine efficacy of the ongoing ISMP sampling to detect changes in population levels of predaceous centrarchids, species which may negatively affect populations of endangered fishes in the Colorado River (Colorado Division of Wildlife et al., 1996). It seems clear that ISMP sampling is not adequate to detect the presence, or estimate the abundance, of these centrarchid fishes. Therefore, a first step toward improving the ISMP is for the Recovery Program to carefully define the accuracy and precision of abundance estimates needed to better manage centrarchid populations in the Grand Valley. Once such criteria are in place, a sampling program could be designed to meet these criteria. Existing data, including some gathered in this study, and new data would be needed to test the accuracy and precision of a new sampling program.

A monitoring program to more reliably estimate abundance of centrarchids and other species may be very beneficial. First, the Recovery Program would have a reliable means to determine if management actions to enhance floodplain sport fisheries were influencing riverine centrarchid populations. Such information would minimally guide decisions about stocking and screening criteria in floodplain ponds. A second benefit would be to provide an independent evaluation of the effects of ongoing fish removal efforts in backwaters of the Grand Valley and other reaches in the Colorado River Basin. Third, efficacy of the existing ISMP sampling to estimate abundance of juvenile Colorado pikeminnow may be enhanced. Such data would enhance the ability of managers to better determine recovery status of that species in the Colorado River Basin.

It would also be useful to understand more about the dispersal and population ecology of centrarchids in the Grand Valley area. The importance of defining source populations of species such as largemouth bass has already been discussed. Further studies should define the level of impact caused by known levels of centrarchids in backwaters of the Colorado River. A number of approaches including bio-energetics modeling and experimental studies in backwaters could be used to obtain such information. Such data would play a critical role in defining whether predaceous fishes have the potential to regulate abundance of endangered fish in backwaters. Such information should also give guidance on the levels of fish removal needed in the Grand Valley and other reaches to effect higher survival of certain life stages of endangered and other native fishes. Finally, such information will illuminate the importance of the effects of non-native fishes relative to other potential impacts or management actions, such as habitat and flow modification.

CONCLUSIONS

, The present ISMP sampling program, which was designed to estimate abundance of YOY Colorado pikeminnow, underestimated the number of backwaters occupied by largemouth bass and green sunfish by about 50 %.

, When ISMP sampling detected largemouth bass and green sunfish in Colorado River backwaters, ISMP density estimates were only 32 % of the more reliable DMR abundance estimates for those taxa.

- The present ISMP program estimated the presence and abundance of non-native cyprinids in backwaters more reliably than for centrarchids.
- The strength of inferences made should guide use of ISMP data to determine trends in fish abundance over time.
- An expanded, more intensive monitoring program is needed to track trends in centrarchid abundance over time in backwaters of the Grand Valley.
- The ISMP sampling technique underestimated species richness in backwaters. Large and deep backwaters supported more species than small and shallow ones and species richness declined in a downstream direction.
- Even though a high percentage of fish in backwaters were removed in 1997, fish abundance was as high or higher in 1998. Mechanical removal of fishes in backwaters may effect only a temporary reduction in fish abundance.
- Understanding the origin of centrarchids in backwaters of the Colorado River is important to determining management actions to reduce their effects.

RECOMMENDATIONS

- Collect additional data and information to develop a new monitoring protocol for estimating the distribution and abundance of centrarchids in the Grand Valley reach of the Colorado River. Several essential components of a monitoring program should be defined by the Recovery Program. These include identifying specific goals and objectives for the program, identifying stressors to the system, and development of a conceptual model that links relevant ecosystem components and processes. That process should facilitate selection of appropriate indicators to be monitored. Only then can a sampling program be developed to adequately measure the selected indicators. A final step in development of the monitoring program is how to identify when a significant response has been achieved and how that information will be linked to a decision-making process.

, Develop a methodology that estimates the desired parameters of existing centrarchid populations to the degree needed.

, Obtain a better understanding of the dispersal and recruitment processes of centrarchids in backwaters of the Colorado River.

, Evaluate the efficacy of non-native fish removal from backwaters. Data gathered in this and other investigations should be used to assess the effectiveness of mechanical removal as a management tool in the Colorado River basin.

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Table 1.-- Backwater surface area and percentage of surface area sampled by the Interagency Standardized Monitoring Program technique in the Grand Valley reach of the Colorado River, CO, 1997-1998.

1997				1998			
BW #	Backwater surface area (m^2)	ISMP sampling area (m^2)	% Sampled	BW #	Backwater surface area (m^2)	ISMP sampling area (m^2)	% Sampled
1	734	113	15	1	291	36	12
2	1159	83	7	2	1007	75	7
3	1448	106	7	3	42	27	65
4	342	99	29	4.1	1666	104	6
5	432	88	20	4.2	1580	97	6
6	1225	98	8	5	233	65	28
7	290	80	28	6	422	78	19
8	210	88	42	7	137	36	26
9	545	45	8	8	642	101	16
10	256	35	14	9	50	47	94
11	275	64	23	10	305	68	22
12	138	39	28	11	311	78	25
13	1806	125	7	12	1252	66	5
14	412	89	22	13	221	66	30
15	887	61	7	14	700	83	12
16	601	69	11	15	314	57	18
17	2888	135	5	16	194	30	15
18	1224	164	13	17	136	40	30
19	337	92	27	18	691	69	10
20	99	27	27	19	228	47	21
21	670	139	21	20	1037	61	6
				21	228	73	32
				22	401	104	26
				23	2100	56	3
				24	2042	135	7
Mean	761	88	18		649	68	22

Table 2.-- Fish captured in eight backwaters sampled in the Grand Valley reach of the Colorado River, CO, spring 1998. Backwater numbers correspond to fall 1997 numbers (except 4 and SP1). Backwater 4 was sampled in autumn 1998, backwater SP1 was sampled only in spring 1998.

	Backwater #								
Backwater #	1	4	7	13	14	17	20	SP1	Total
red shiner		157	3	113	3	141	186	67	670
sand shiner		347	30	459	9	164	159	47	1215
fathead minnow		52		143	74	364	143	63	839
largemouth bass		1		2		4			7
green sunfish	2	37	1	17	1	186	7	20	269
bluegill									0
black crappie						1			1
yelllow perch									0
white sucker		14		27		28	1	9	79
brassy minnow									0
western mosquitofish						2		3	5
plains killifish						1			1
black bullhead		3			1	14		2	20
common carp				1		13		3	17
channel catfish						1			1
flannelmouth sucker		46		28	10	8	3	2	97
bluehead sucker		28	6	31	3	4		7	79
speckled dace		3	10	7	3	2	3	6	34
roundtail chub		1*	1	1		1			3
Colorado pikeminnow		1*							0
mountain whitefish			1						1
									3338

* Denotes adult fish

Table 3.-- Comparison of frequencies of detection for fish species in backwaters for depletion and mark-recapture (DMR) and Interagency Standardized Monitoring Program (ISMP) sampling techniques, in the Grand Valley reach of the Colorado River, CO, 1997-1998. Number of backwaters sampled in 1997 was 21, number sampled in 1998 was 25. Detection rates were calculated by dividing the number of times ISMP sampling detected a species by the number of times DMR sampling detected the species and multiplying by 100.

	1997			1998		
Fish species	DMR	ISMP	ISMP detection rates (%)	DMR	ISMP	ISMP detection rates (%)
Non-native						
red shiner	21	21	100	22	18	82
fathead minnow	21	20	95	24	19	79
sand shiner	20	19	95	22	22	100
green sunfish	18	11	61	22	13	59
white sucker	16	9	56	18	13	72
largemouth bass	14	7	50	16	7	44
western mosquitofish	12	2	17	21	15	71
black bullhead	9	2	22	12	3	25
common carp	9	3	33	9	4	44
brassy minnow	7	3	43	0	1	100
channel catfish	4	0	0	0	0	
bluegill	3	0	0	5	0	0
black crappie	3	0	0	3	1	33
yellow perch	1	0	0	0	0	
plains killifish	1	0	0	3	1	33
Native						
flannelmouth sucker	19	14	74	19	12	63
bluehead sucker	17	9	53	12	6	50
speckled dace	16	10	63	21	11	52
roundtail chub	12	11	92	18	9	50
Colorado pikeminnow	1	0	0	1	0	0
		Mean	43 %		Mean	53%

Table 4.-- Proportion of red shiner, sand shiner, fathead minnow, green sunfish, and largemouth bass removed on successive sampling passes in backwaters of the Grand Valley reach of the Colorado River, CO, 1997 and 1998. Proportions for individual backwaters were calculated by dividing the number of fish captured by the estimated abundance of each fish species in each backwater (Appendices 4 and 5). Means of those proportions calculated for all backwaters are presented below. Totals for green sunfish and largemouth bass are biased due to all estimated fish (proportion = 1.0) being captured in some backwaters.

Species	Pass	1997	1998
red shiner			
	1	0.61	0.45
	2	0.18	0.24
	3	0.10	0.10
total		0.89	0.79
sand shiner			
	1	0.61	0.47
	2	0.18	0.22
	3	0.11	0.17
total		0.89	0.86
fathead minnow			
	1	0.55	0.54
	2	0.21	0.22
	3	0.12	0.14
total		0.87	0.89
green sunfish			
	1	0.48	0.51
	2	0.31	0.30
	3	0.12	0.12
total		0.90	0.93
largemouth bass			
	1	0.57	0.58
	2	0.21	0.30
	3	0.19	0.10
total		0.97	0.98

Table 5.-- Parameter estimates for best-fit logistic regression models for predicting probability of presence of largemouth bass and green sunfish as a function of habitat variables. Model selection was by Akaike's Information Criterion (AIC). Standard errors and p-values (chi-square) for the parameter estimates are presented parenthetically. *Hab1*, *Hab2* and *Hab3*, are qualitative assessments of habitat that range from simple (1) to complex (3). *Hab3* has no parameter estimate because dummy variables are needed for only n - 1 categories.

	Parameter estimates					
Logistic model	*Intercept*	*Maximum depth*	*Average Depth*	*Surface area*	*Hab1*	*Hab2*
Largemouth bass presence	1.512 (2.267, 0.50)	-8.19 (4.46, 0.07)	13.69 (6.57, 0.04)	0.002 (0.0011, 0.06)	-2.724 (1.832, 0.13)	-1.721 (1.585, 0.28)
Green sunfish presence	19.67 (2.902, 0.001)	---	21.77 (11.22, 0.05)	0.0029 (0.002, 0.19)	-25.03 (1.374, 0.0001)	-23.43

Table 6.-- Parameter estimates for general linear models (GLM) for log (n+1) density (fish/10m^2) of red shiner, sand shiner, and fathead minnow (combined), and largemouth bass and green sunfish as a function of several habitat variables and year (1997 or 1998). Standard errors and p-values for the parameter estimates are presented parenthetically. *Hab1*, *Hab2*, and *Hab3*, are qualitative assessments of habitat that range from simple (1) to complex (3). *Hab3* and *year98* have no parameter estimates because dummy variables assigned by the GLM are needed for only n-1 categories.

	Parameter estimates							
General linear model	*Intercept*	*Maximum depth*	*Average depth*	*Surface area* ^{2}	*Hab1*	*Hab2*	*year97*	Overall Model (p-value, R^2)
Cyprinid density model	3.09	-2.09	1.51	-0.000000294	0.101	0.603	-0.459	
	(0.721, 0.001)	(1.39, 0.14)	(1.53, 0.32)	(1.4*10^{-7}, 0.04)	(0.475, 0.83)	(0.398, 0.13)	(0.275, 0.10)	(0.04, 0.11)
largemouth bass	0.654	-0.749	0.636	0.000000126	-0.448	-0.337	-0.075	
density model	(0.196, 0.002)	(0.38, 0.05)	(0.49, 0.20)	(0.4 * 10^{-7}, 0.004)	(0.154, 0.004)	(0.136, 0.02)	(0.102, 0.47)	(0.0009, 0.43)
green sunfish	0.583	-0.3	0.55	0.000000183	-0.402	-0.21	-0.041	
density model	(2.277, 0.04)	(0.53, 0.57)	(0.69, 0.43)	(0.6 * 10^{-7}, 0.003)	(0.218, 0.07)	(0.192, 0.28)	(0.144, 0.78)	(0.0006, 0.44)

Table 7.-- Number of species detected in each backwater by depletion, mark-recapture (DMR) and Interagency Standardized Monitoring Program (ISMP) sampling techniques in the Grand Valley reach of the Colorado River, CO, 1997-1998. ISMP detection rates were calculated by dividing the number of species in a backwater detected using ISMP sampling by the number of species detected using DMR sampling and multiplying by 100.

	1997				1998		
Backwater #	DMR	ISMP	ISMP detection rates	Backwater #	DMR	ISMP	ISMP detection rates
1	8	7	88	1	10	9	90
2	12	7	58	2	na	8	
3	16	8	50	3	4*	8	200
4	14	9	64	4.1	9	4	44
5	12	5	42	4.2	9	4	44
6	11	8	73	5	10	8	80
7	13	10	77	6	12	10	83
8	10	8	80	7	10	7	70
9	15	7	47	8	12	10	83
10	11	9	82	9	10	9	90
11	9	7	78	10	10	4	40
12	11	8	73	11	14	11	79
13	15	5	33	12	14	10	71
14	11	8	73	13	7	8	114
15	5	4	80	14	12	6	50
16	9	7	78	15	11	5	45
17	na	8		16	6	1	17
18	12	6	50	17	10	5	50
19	5	3	60	18	14	5	36
20	9	6	67	19	9	7	78
21	9	5	56	20	11	2	18
				21	7	2	29
				22	7	4	57
				23	16	7	44
				24	13	11	85
Mean	11	7	65		10	7	67

* backwater very small, ISMP seine hauls sampled entire surface area (42 m^2) on first pass

"na" indicates backwaters where centrarchids were targeted for capture-recapture abundance estimation, so data are inappropriate for species richness estimation.

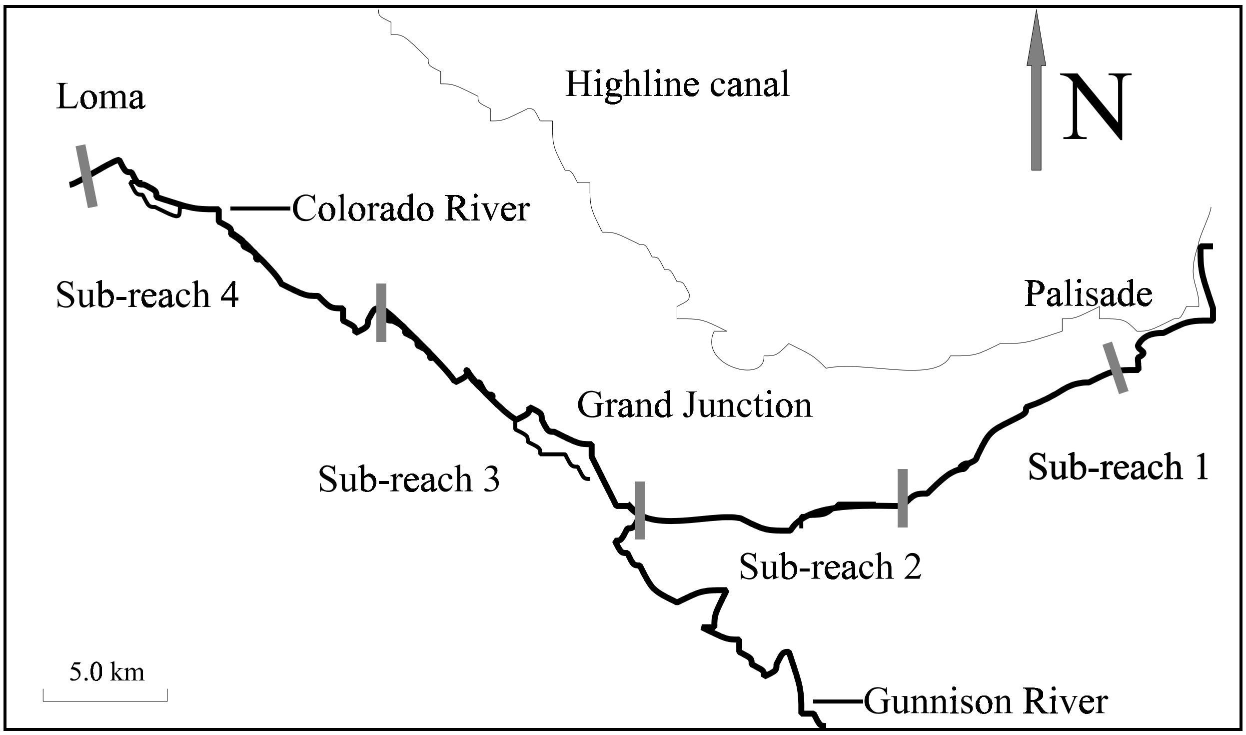
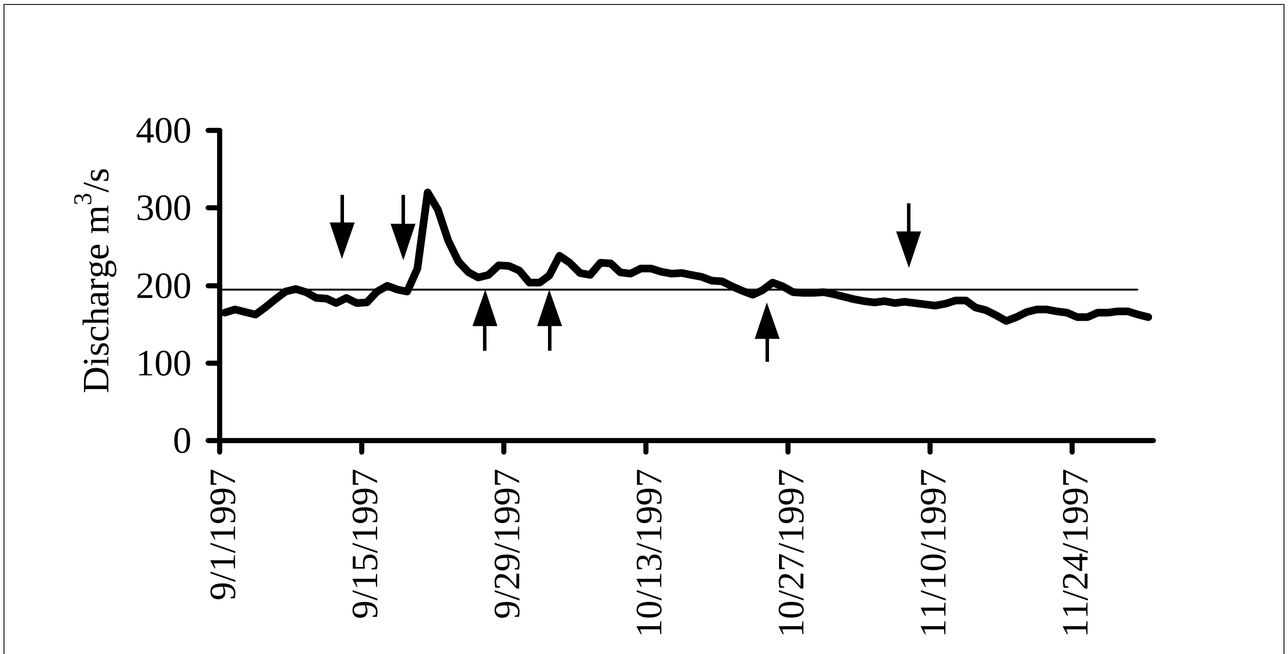


Fig. 1– Map of study area in the Grand Valley portion of the Colorado River, CO, 1997-1998. Sub-reach 1, River Kilometer (RK) 298.2- 285.8 (just below Palisade); sub-reach 2, RK 285.7 - 274.2 (confluence with Gunnison River); sub-reach 3, RK 274.1 - 258.6; sub-reach 4, RK 258.5 - 243.1 (Loma).



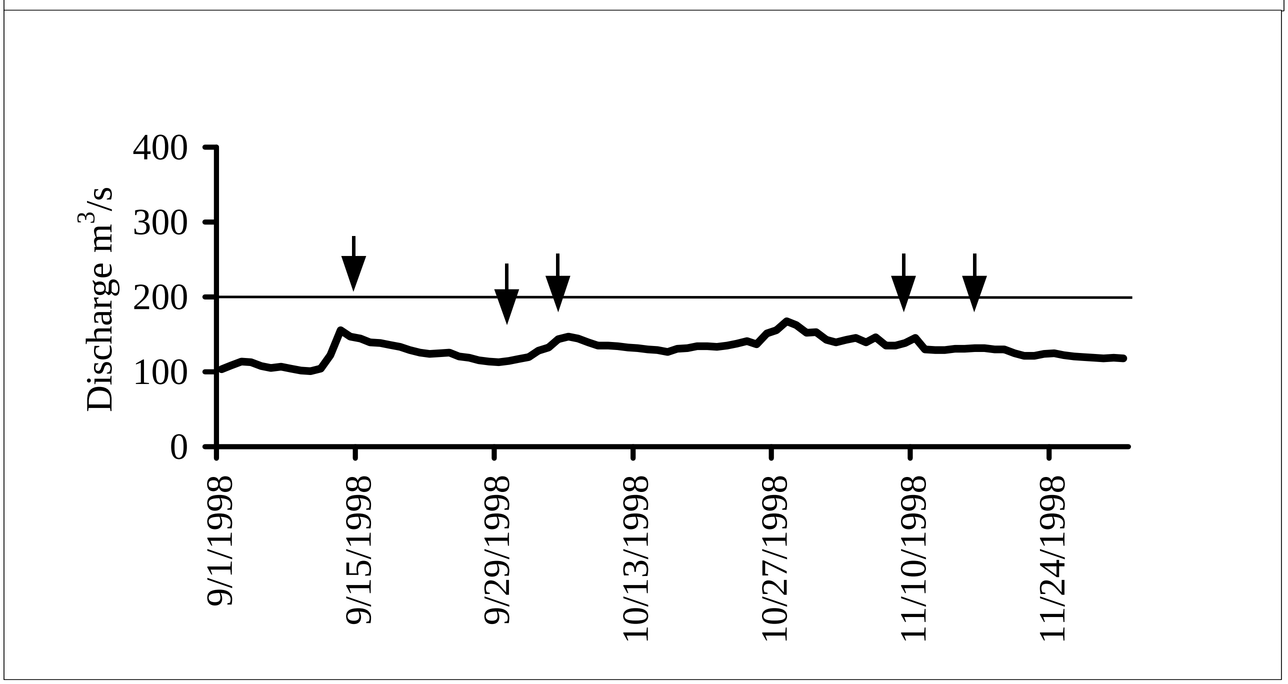


Fig. 2-- Discharge of the Colorado River (m^3/s, gage # 09163500), autumn 1997 (top), and autumn 1998 (bottom). Arrows denote sampling periods. The 200 m^3/s flow level is shown to facilitate comparisons.

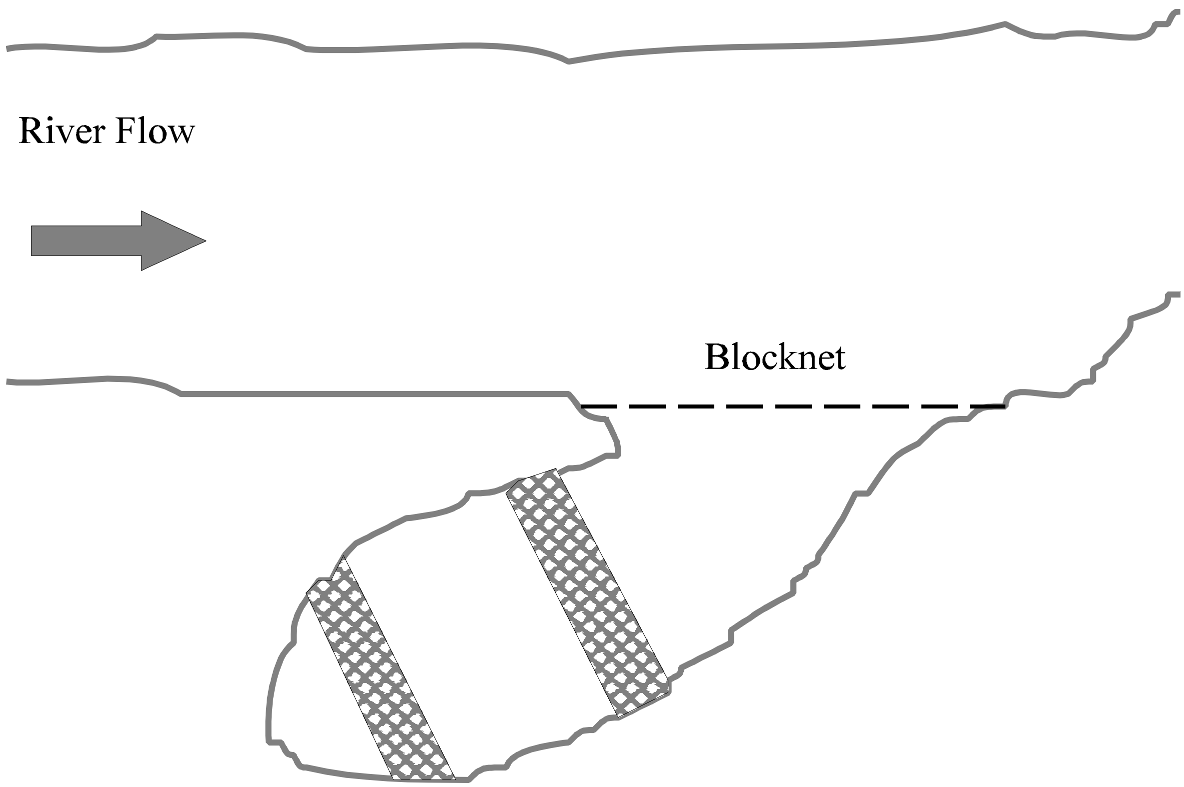


Fig. 3-- Schematic of backwater sampling design in the Grand Valley reach of the Colorado River, CO, 1997-1998. Shaded regions depict a typical area seined by the Interagency Standardized Monitoring Program technique seine hauls. A block net covered the mouth of the backwater throughout ISMP and depletion, mark-recapture sampling to prevent fish movement.

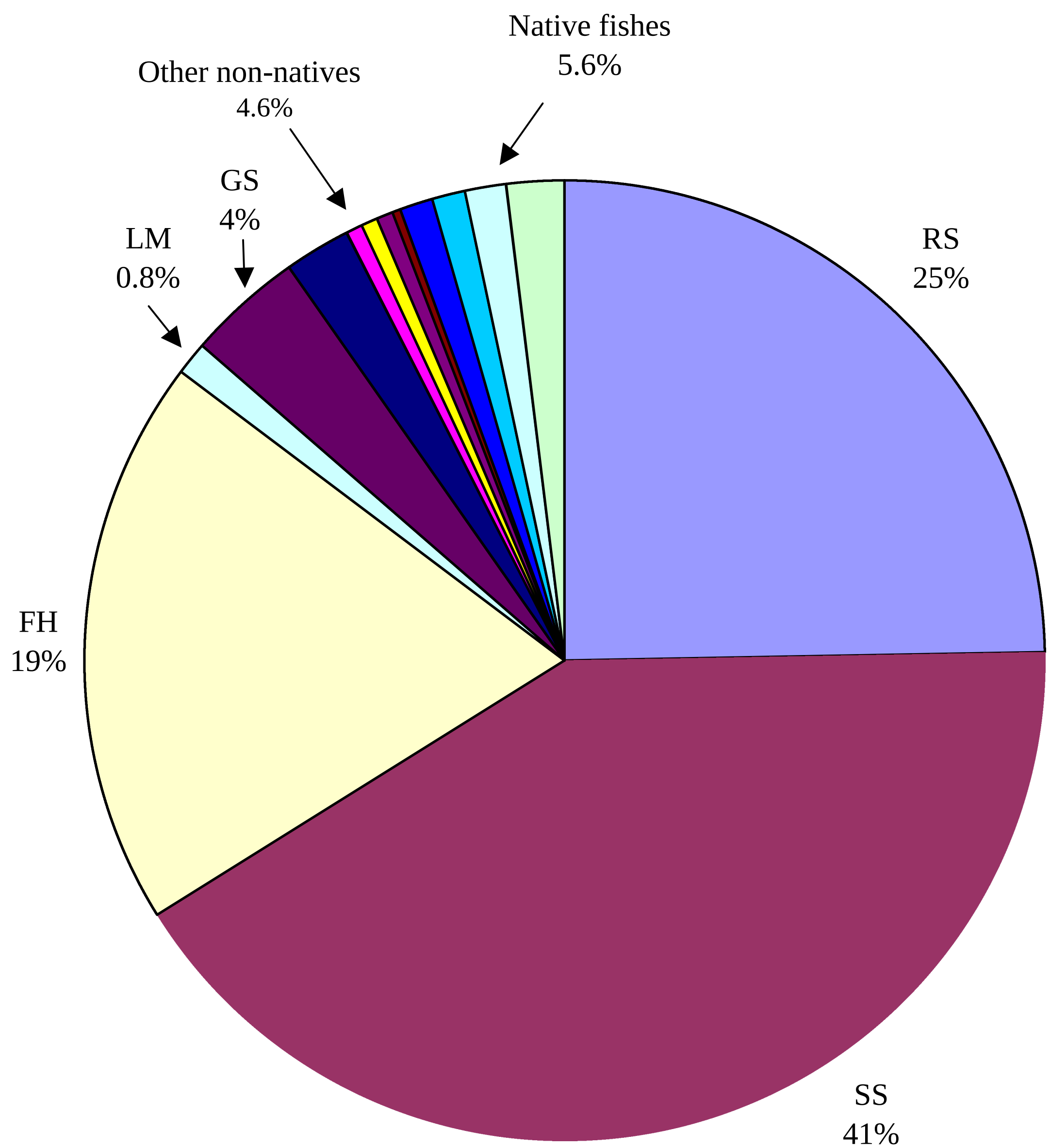


Fig. 4-- Composition of fishes from 21 backwater samples in the Grand Valley reach of the Colorado River, CO, autumn 1997. A total of 35,765 non-native fishes was removed from these backwaters.

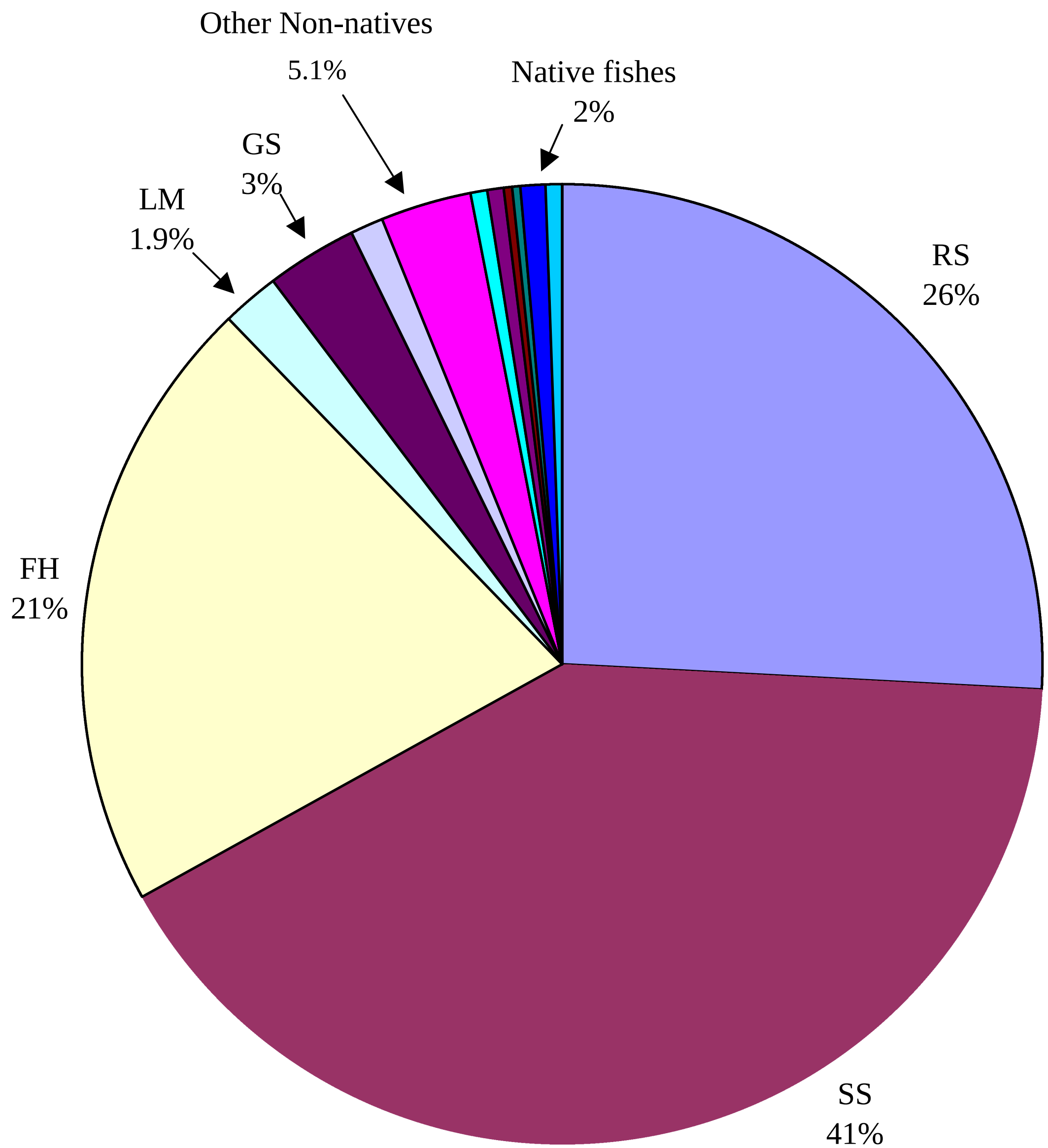


Fig. 5-- Composition of fishes from 25 backwater samples in the Grand Valley reach of the Colorado River, CO, autumn 1998. A total of 69,211 non-native fishes was removed from these backwaters.

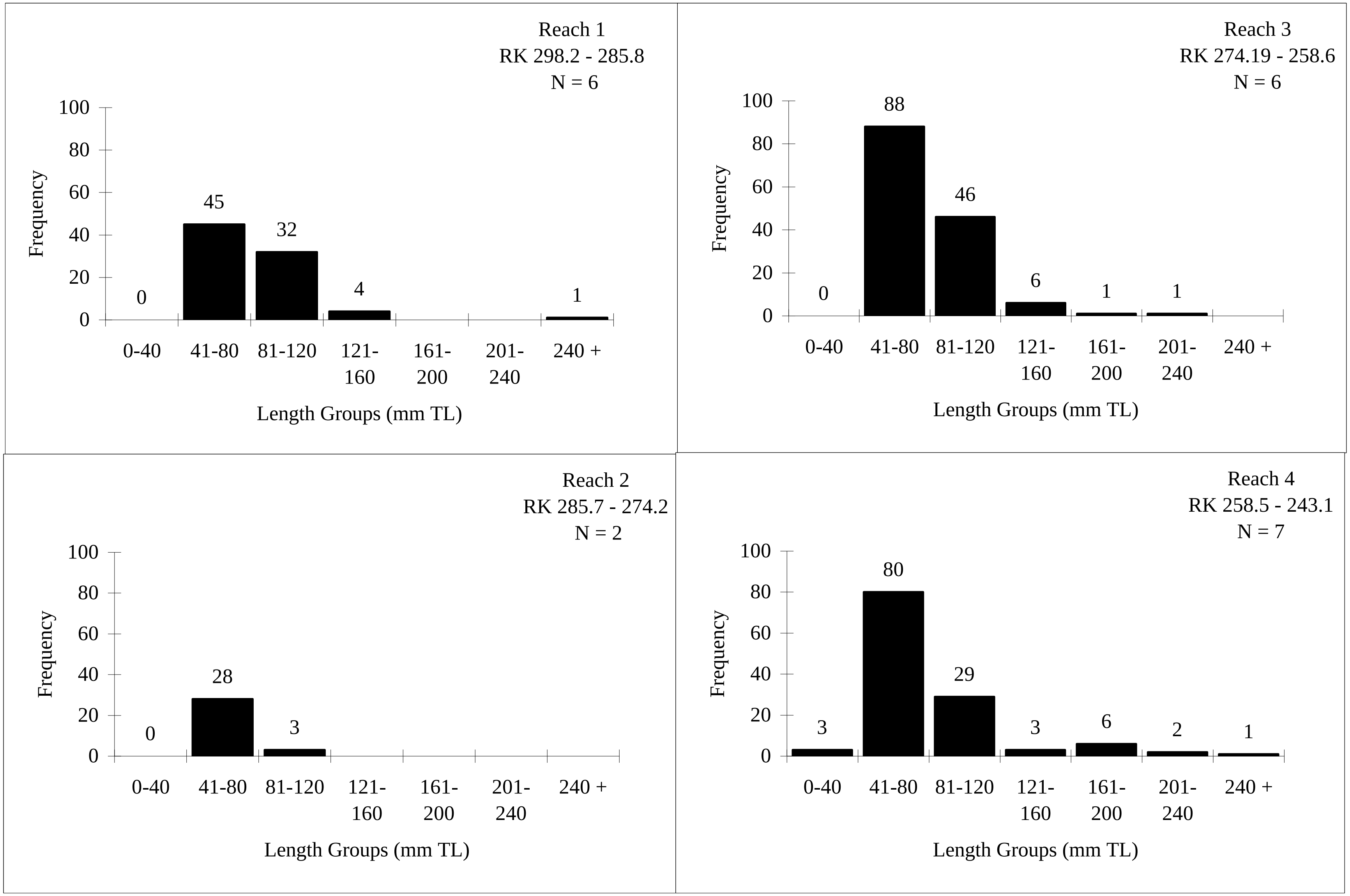


Fig. 6-- Length frequency histograms for largemouth bass captured in the Grand Valley reach of the Colorado River, CO, autumn 1997. N = the number of backwaters sampled in each reach.

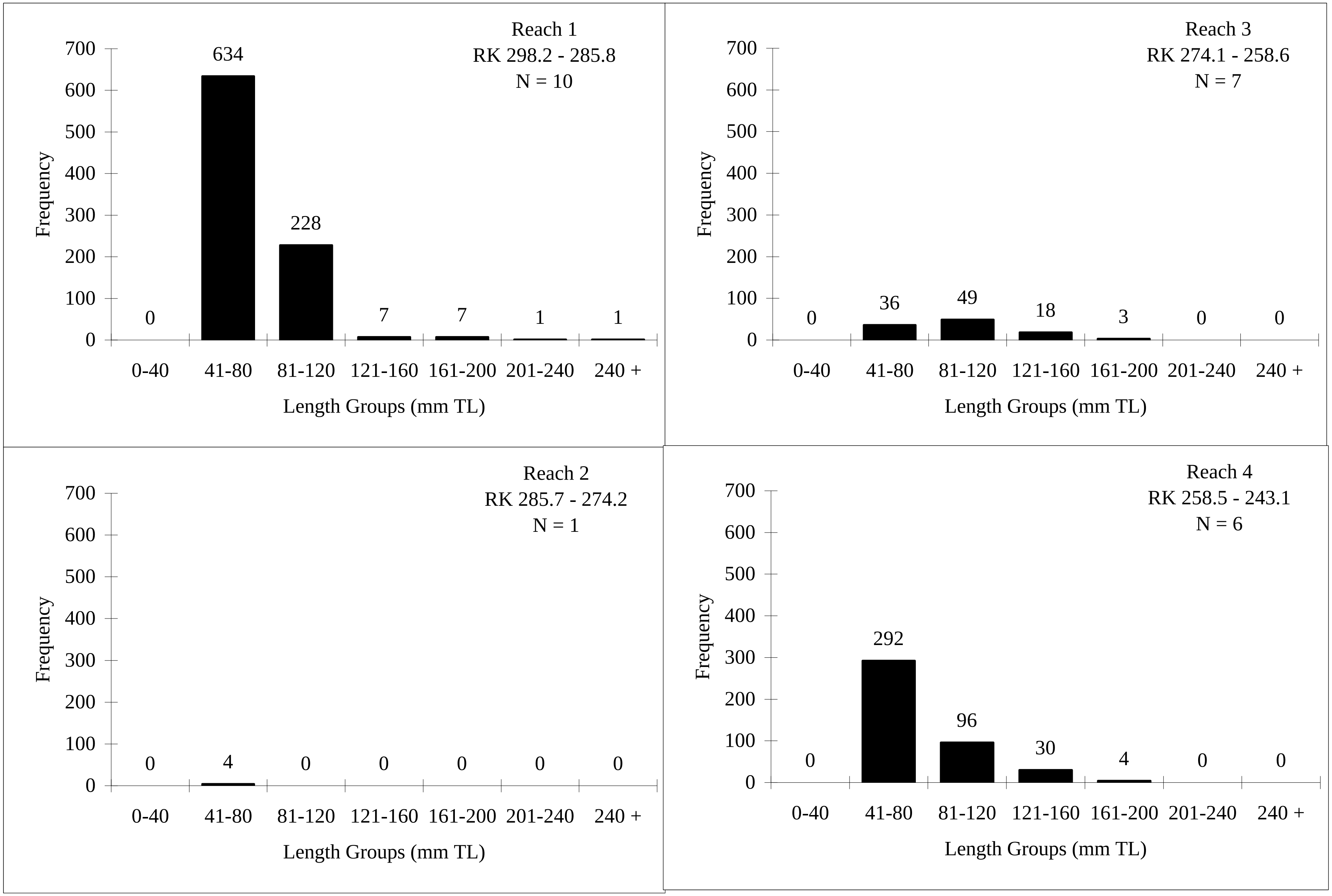


Fig. 7-- Length frequency histograms for largemouth bass captured in the Grand Valley reach of the Colorado River, CO, autumn 1998. N = the number of backwaters sampled in each reach.

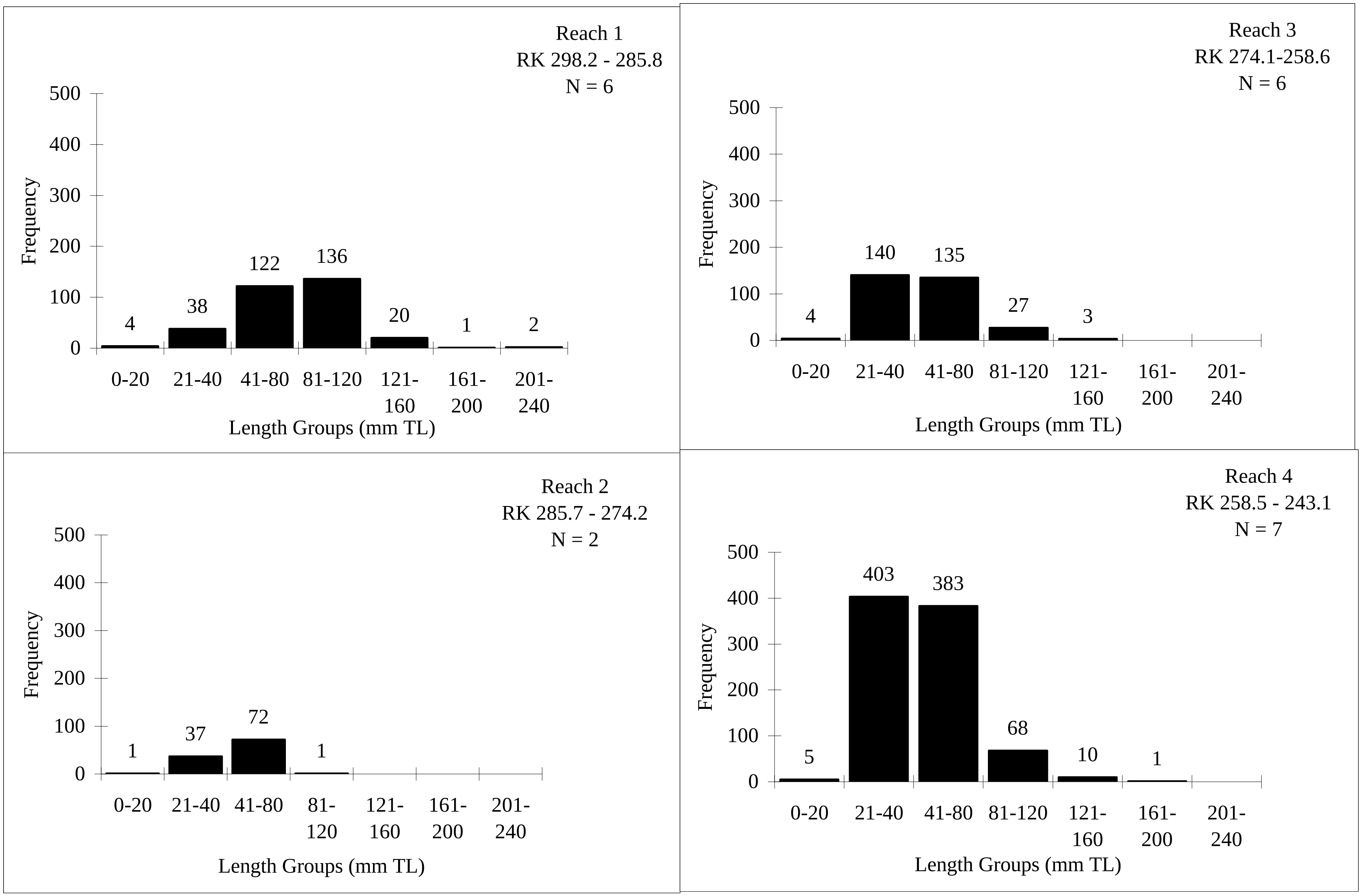


Fig. 8-- Length frequency histograms for green sunfish captured in the Grand Valley reach of the Colorado River, CO, autumn 1997. N = the number of backwaters sampled in each reach.

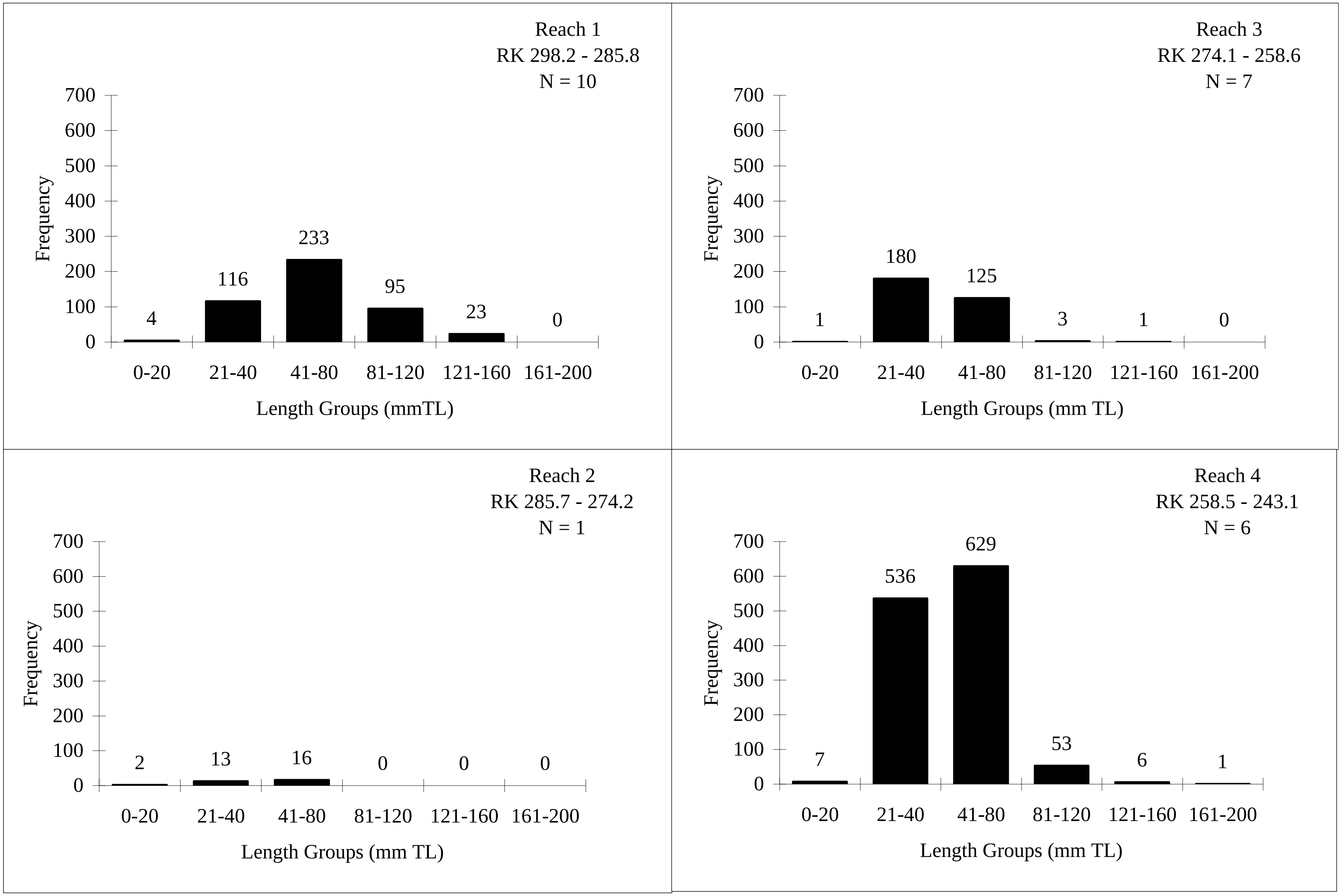


Fig. 9-- Length frequency histograms for green sunfish captured in the Grand Valley reach of the Colorado River, CO, autumn 1998. N = the number of backwaters sampled in each reach.

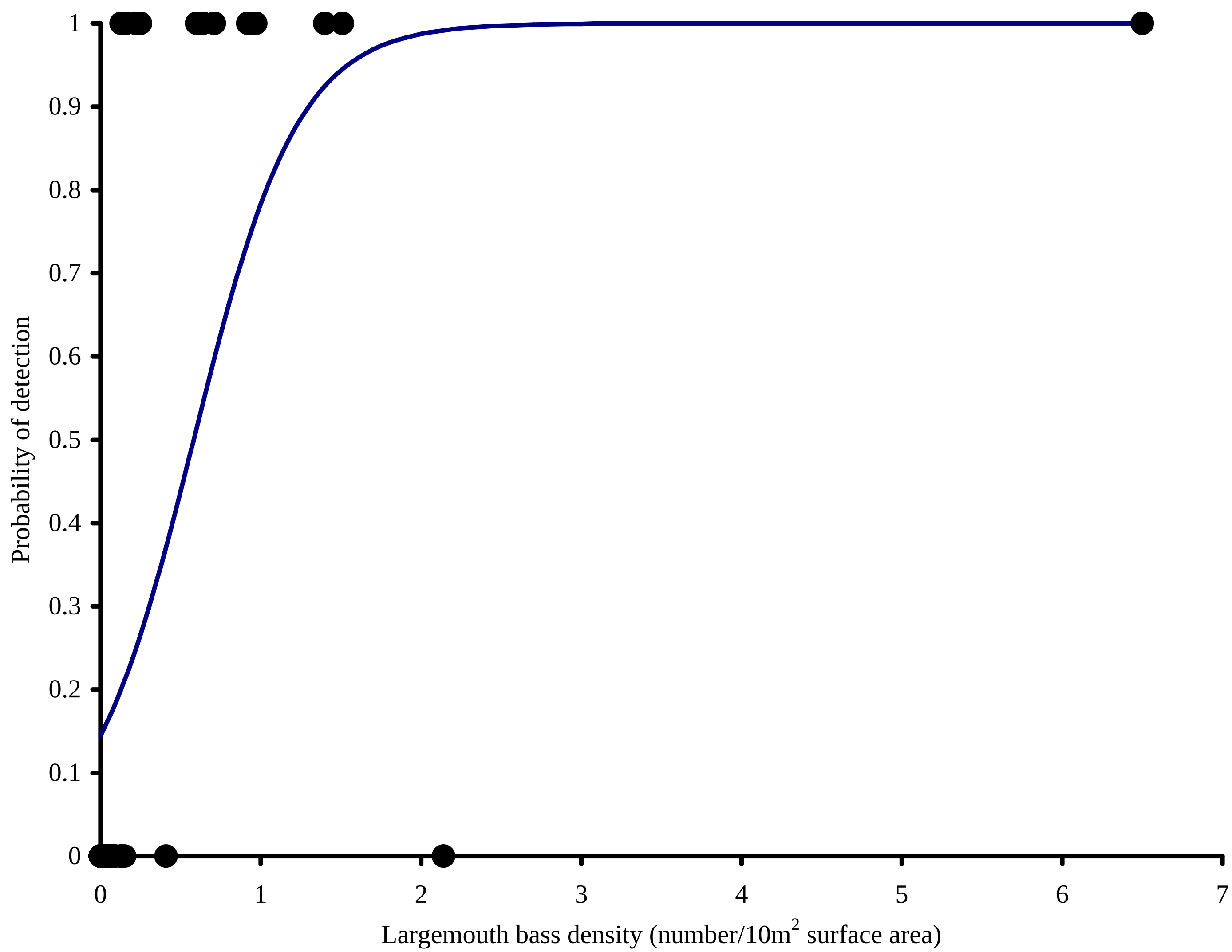


Figure 10.--Logistic regression of predicted probability of detection of largemouth bass as a function of estimated fish density in backwaters in the Grand Valley reach of the Colorado River, CO.

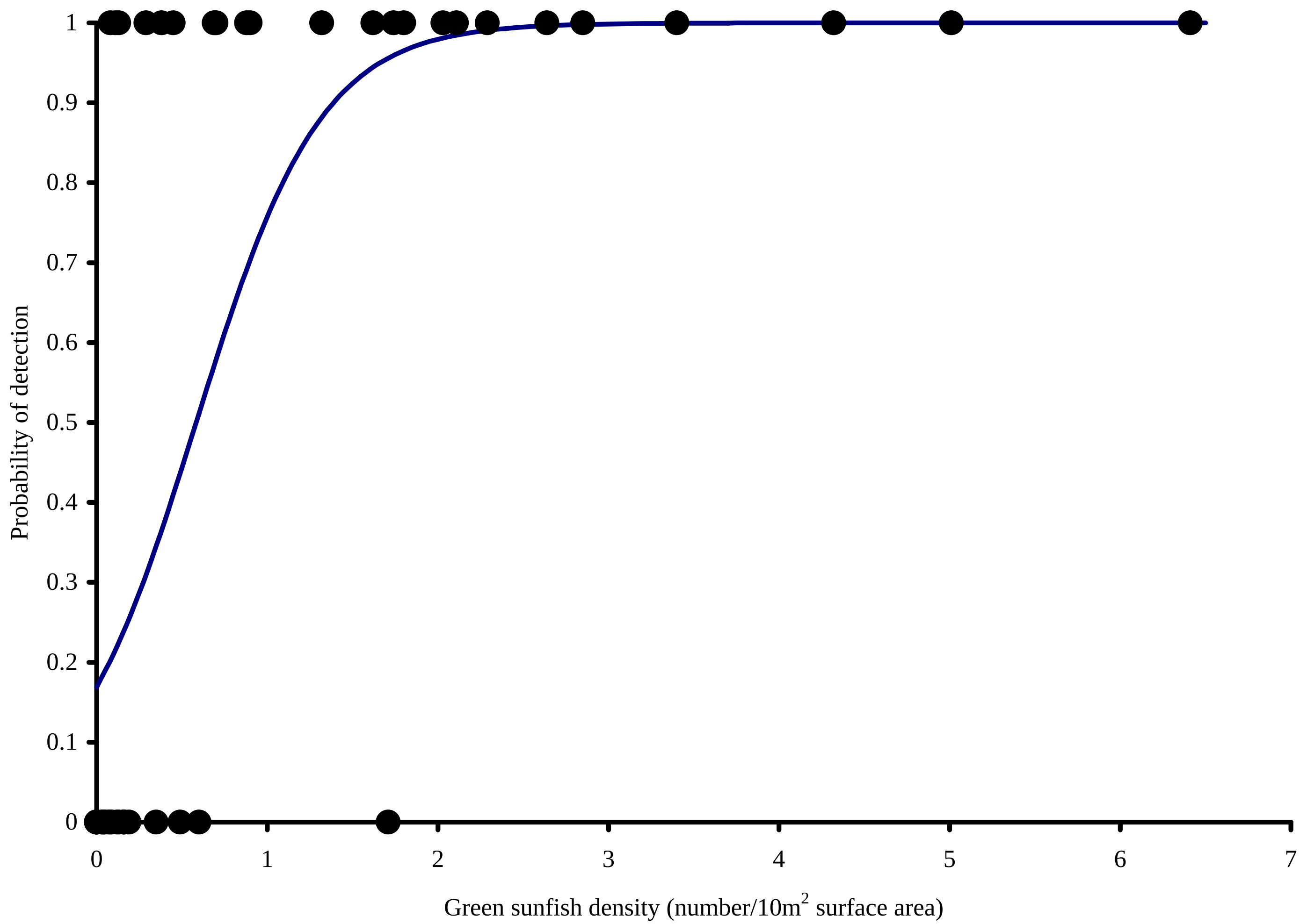


Figure 11.--Logistic regression of predicted probability of detection of green sunfish as a function of estimated fish density in backwaters in the Grand Valley reach of the Colorado River, CO.

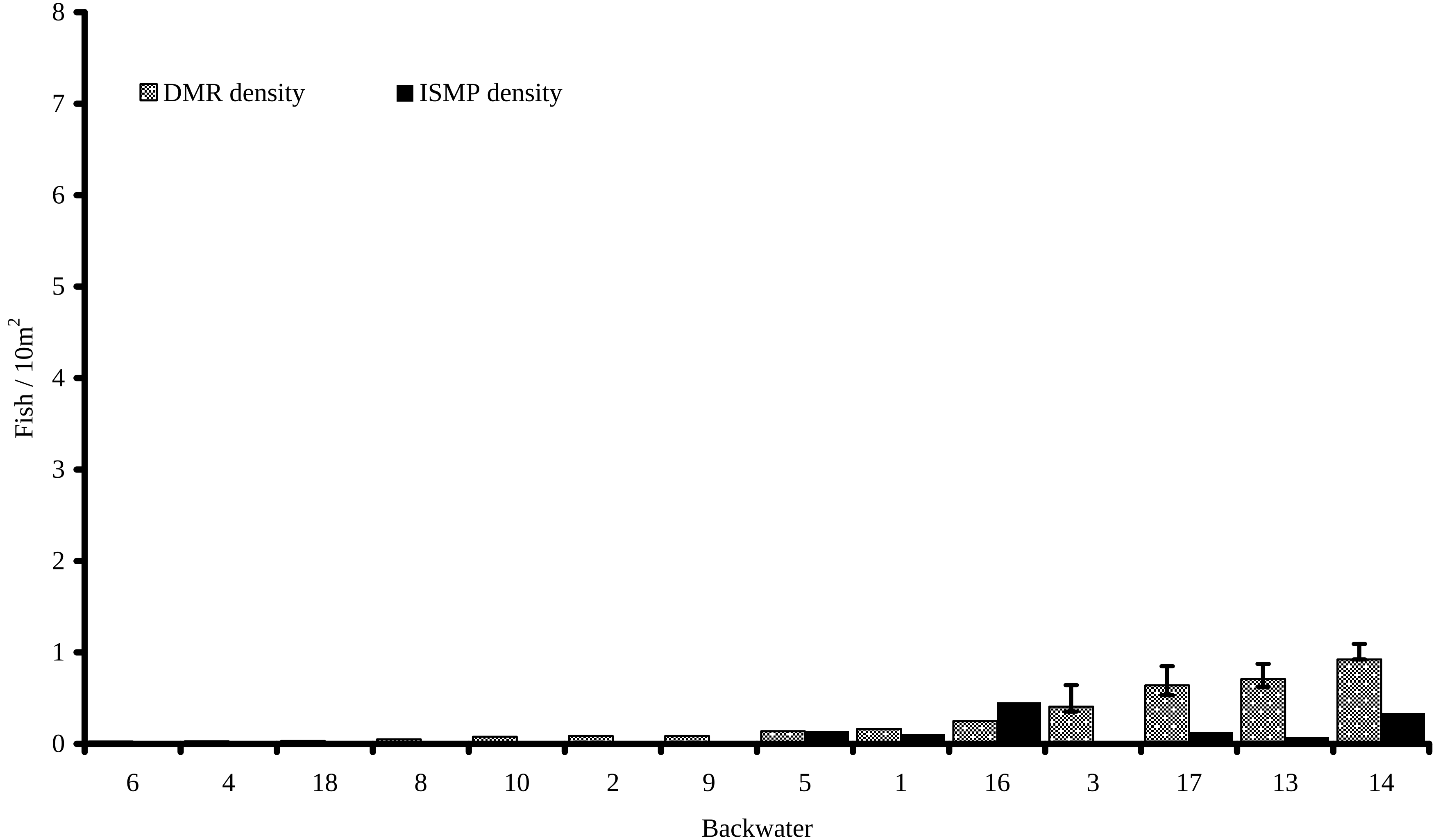


Fig. 12-- Density (fish / 10 m^2) of largemouth bass in backwaters in the Grand Valley reach of the Colorado River, CO, 1997, estimated by depletion, mark-recapture (DMR) and by the Interagency Standardized Monitoring Program (ISMP) methods. Error bars on DMR estimates are 95% profile likehood confidence limits. Confidence limits were not estimated for some DMR estimates because those represent the total number of fish captured.

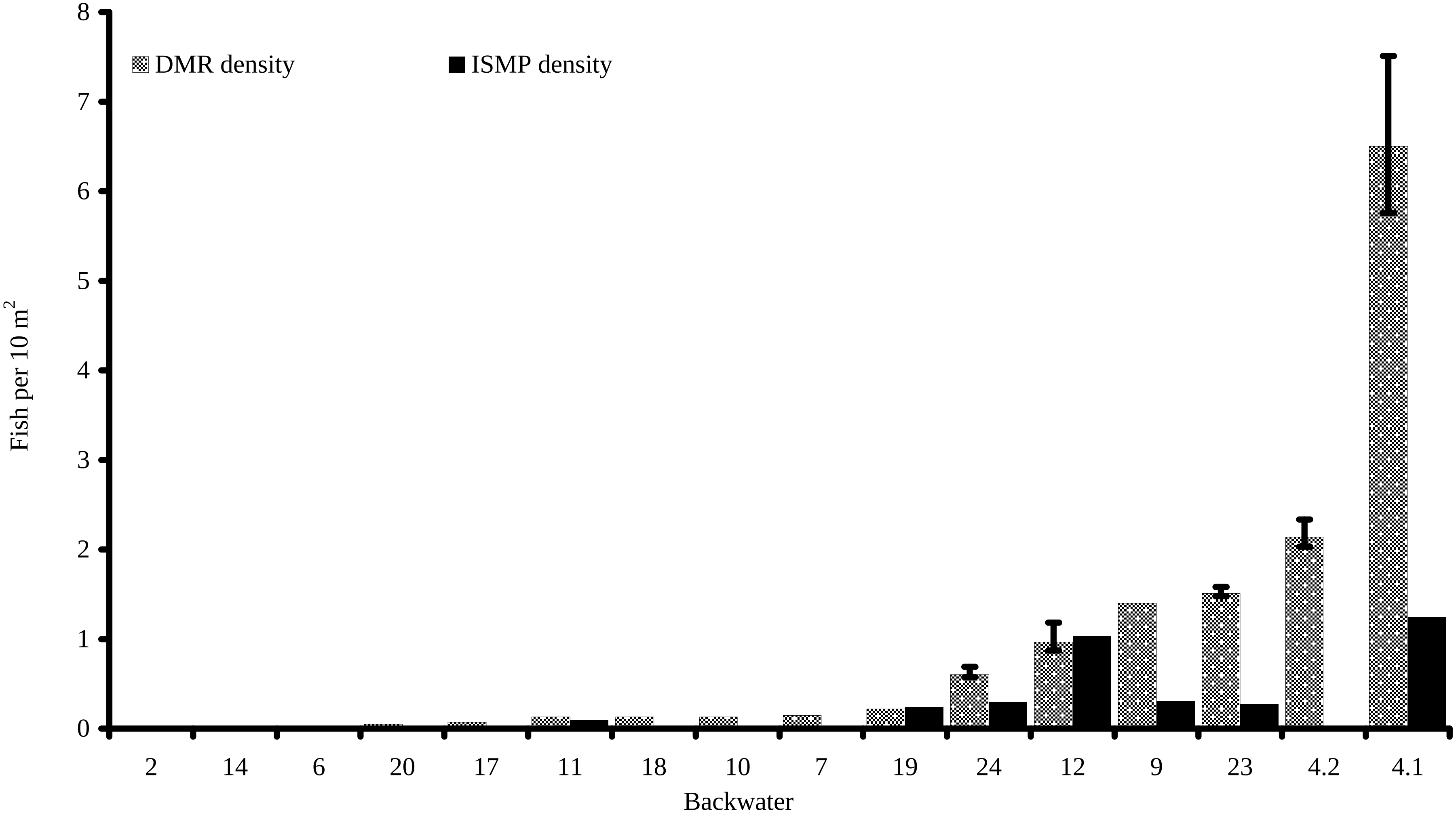


Fig. 13-- Density (fish /10 m^2) of largemouth bass in backwaters in the Grand Valley reach of the Colorado River, CO, 1998, estimated by depletion, mark-recapture (DMR) and by the Interagency Standardized Monitoring Program (ISMP) methods. Error bars on DMR estimates are 95% profile likehood confidence limits. Confidence limits were not estimated for some DMR estimates because those represent the total number of fish captured.

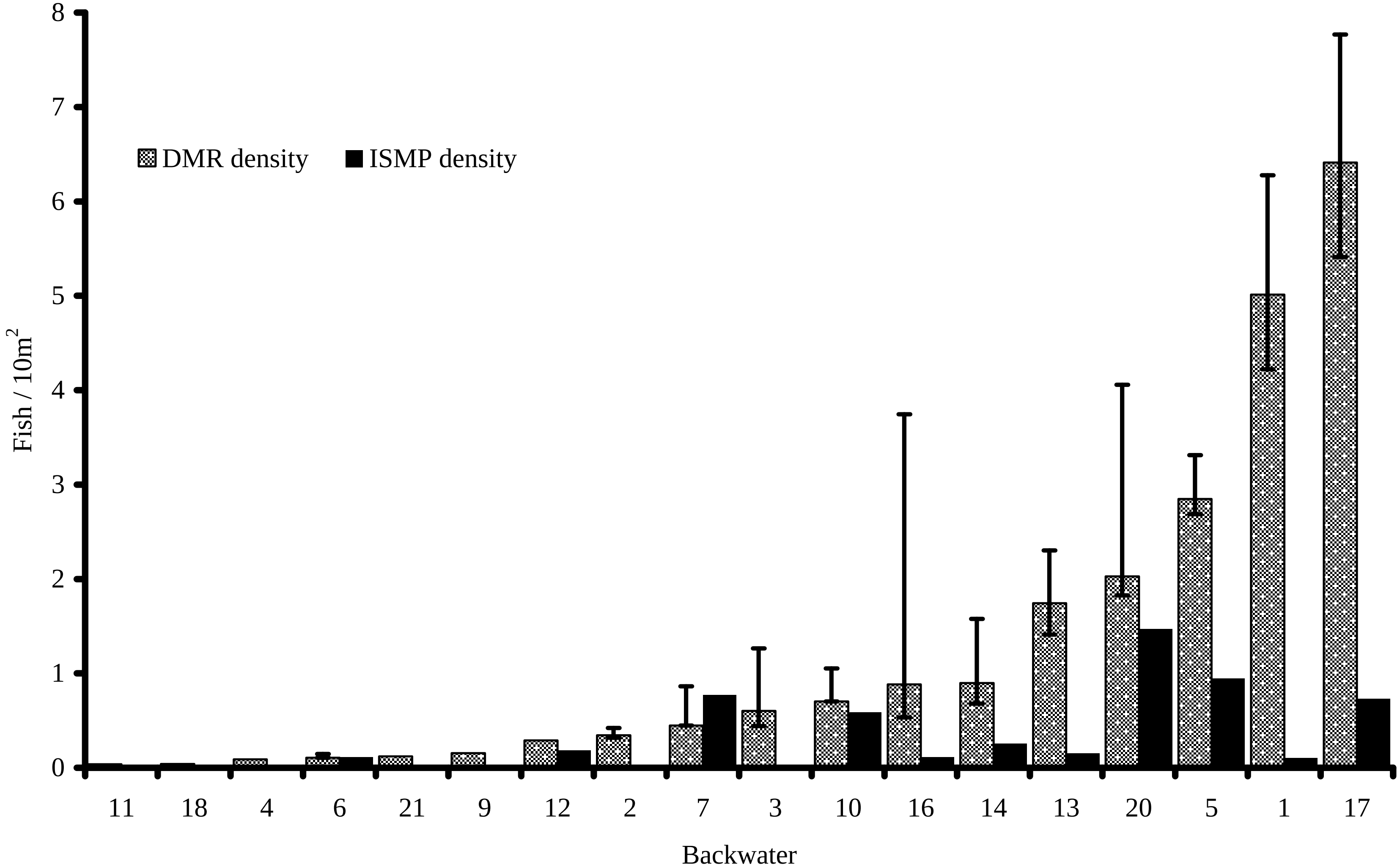


Fig. 14-- Density (fish/10 m^2) of green sunfish in backwaters in the Grand Valley reach of the Colorado River, CO, 1997, estimated by depletion, mark-recapture (DMR) and by the Interagency Standardized Monitoring Program (ISMP) methods. Error bars on DMR estimates are 95% profile likehood confidence limits. Confidence limits were not estimated for some DMR estimates because those represent the total number of fish captured.

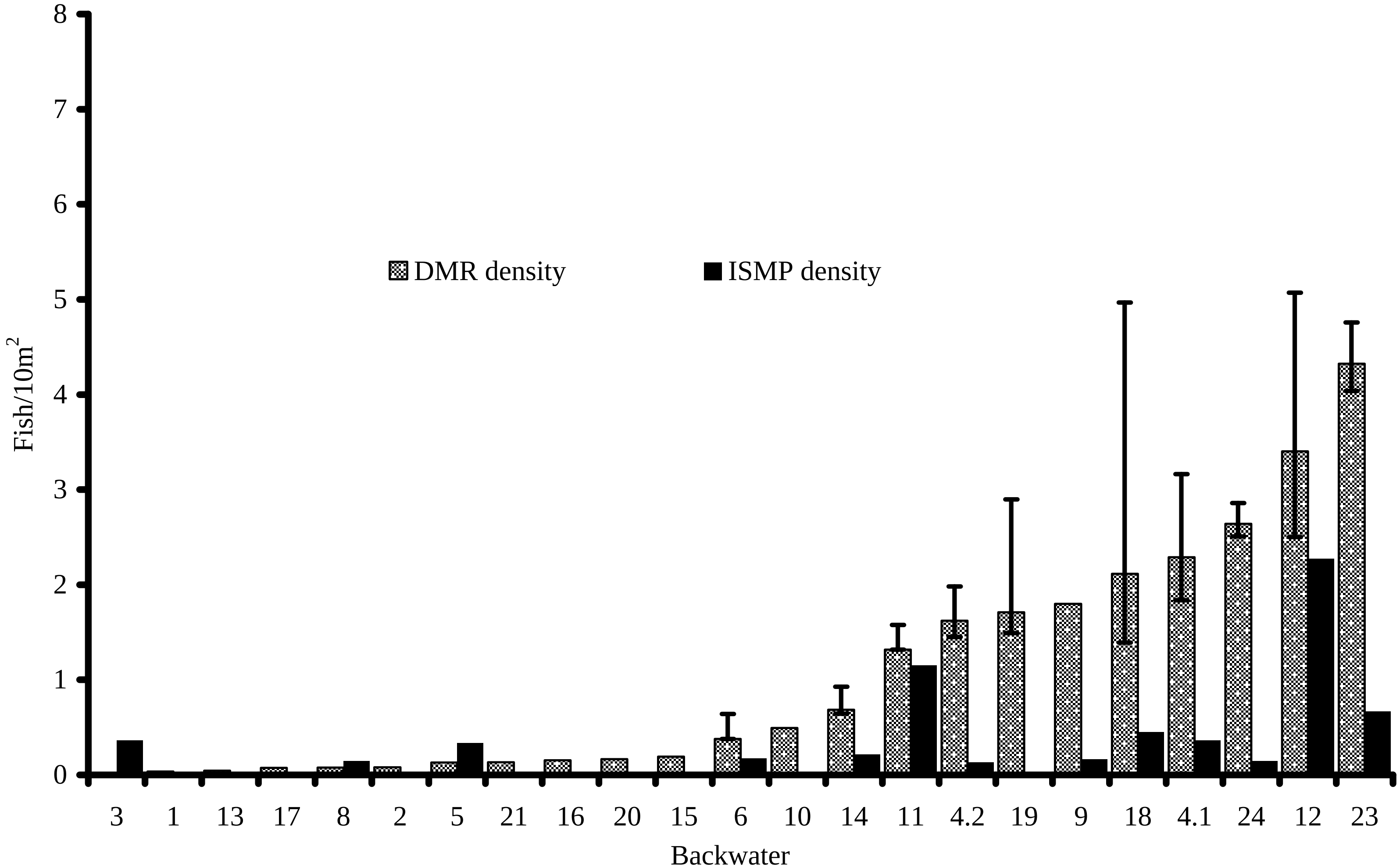


Fig. 15-- Density (fish/10 m^2) of green sunfish in backwaters in the Grand Valley reach of the Colorado River, CO, 1998, estimated by depletion, mark-recapture (DMR) and by the Interagency Standardized Monitoring Program (ISMP) methods. Error bars on DMR estimates are 95% profile likehood confidence limits. Confidence limits were not estimated for some DMR estimates because those represent the total number of fish captured.

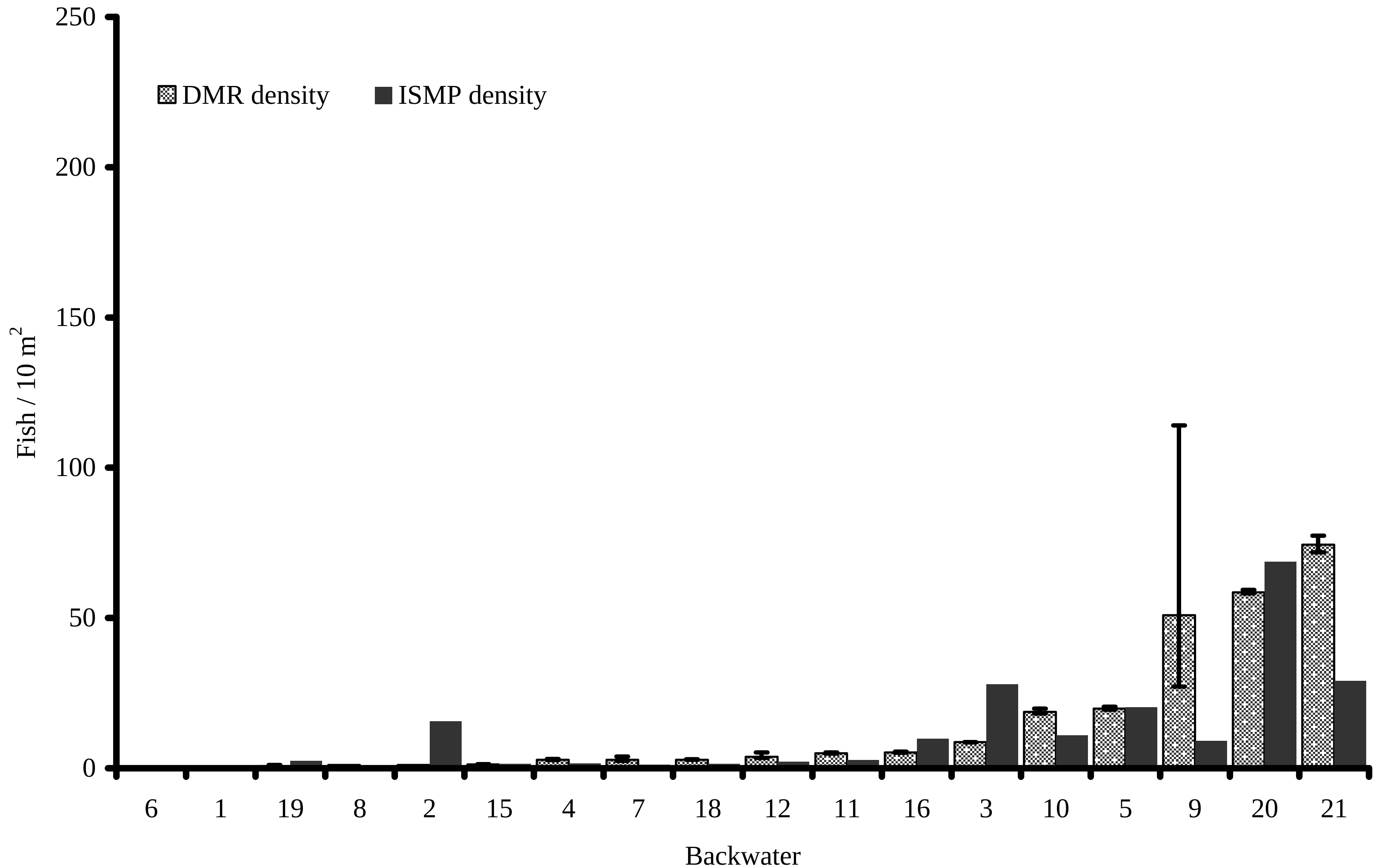


Fig. 16--Density (fish/10 m^2) of red shiners in backwaters in the Grand Valley reach of the Colorado River, CO, 1997, estimated by depletion, mark-recapture (DMR) and by the Interagency Standardized Monitoring Program (ISMP) methods. Error bars on DMR estimates are 95% profile likehood confidence limits. Confidence limits were not estimated for some DMR estimates because those represent the total number of fish captured.

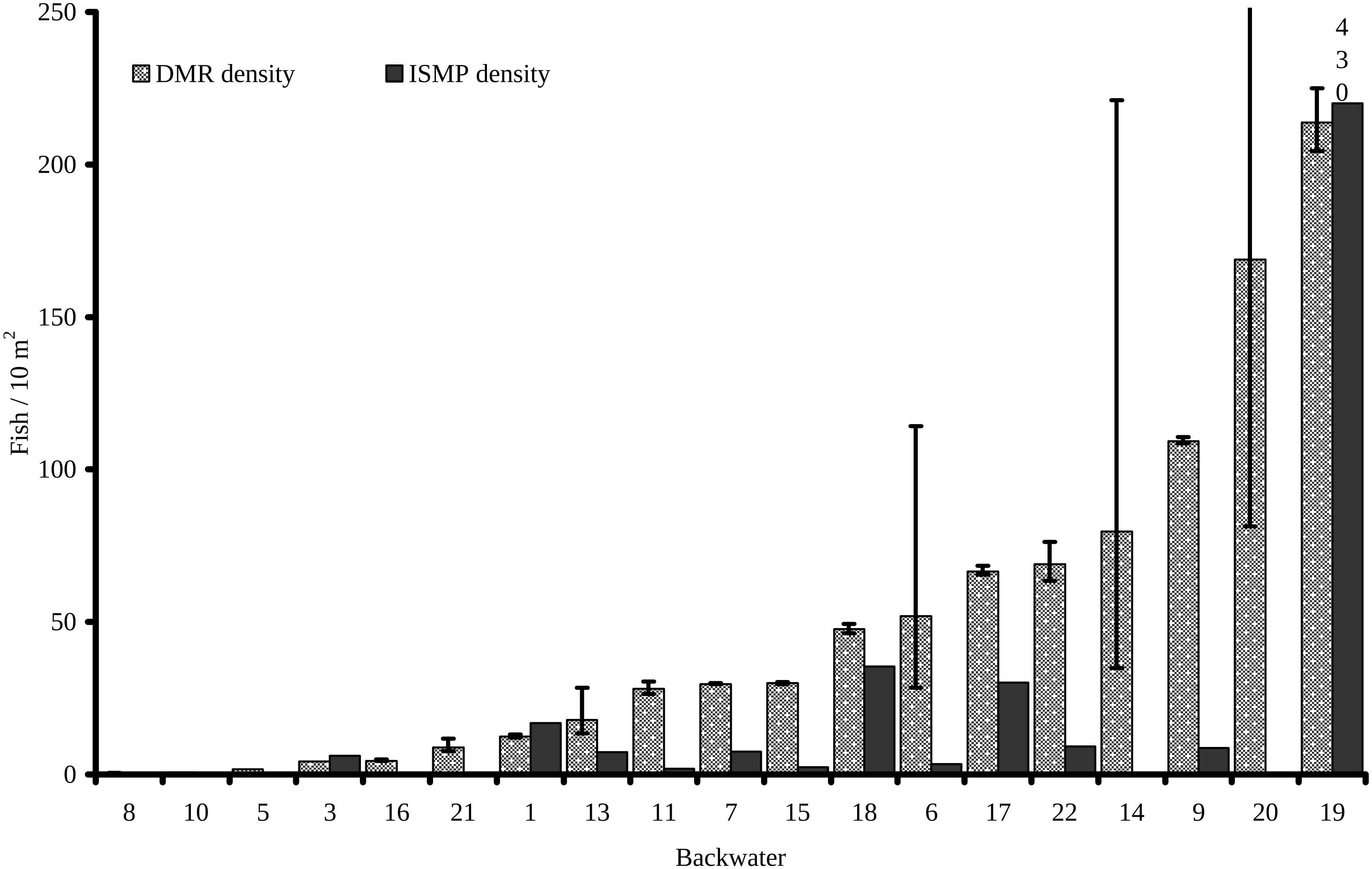


Fig. 17-- Density (fish/10 m^2) of red shiners in backwaters in the Grand Valley reach of the Colorado River, CO, 1998, estimated by depletion, mark-recapture (DMR) and by the Interagency Standardized Monitoring Program (ISMP) methods. Error bars on DMR estimates are 95% profile likehood confidence limits. Confidence limits were not estimated for some DMR estimates because those represent the total number of fish captured.

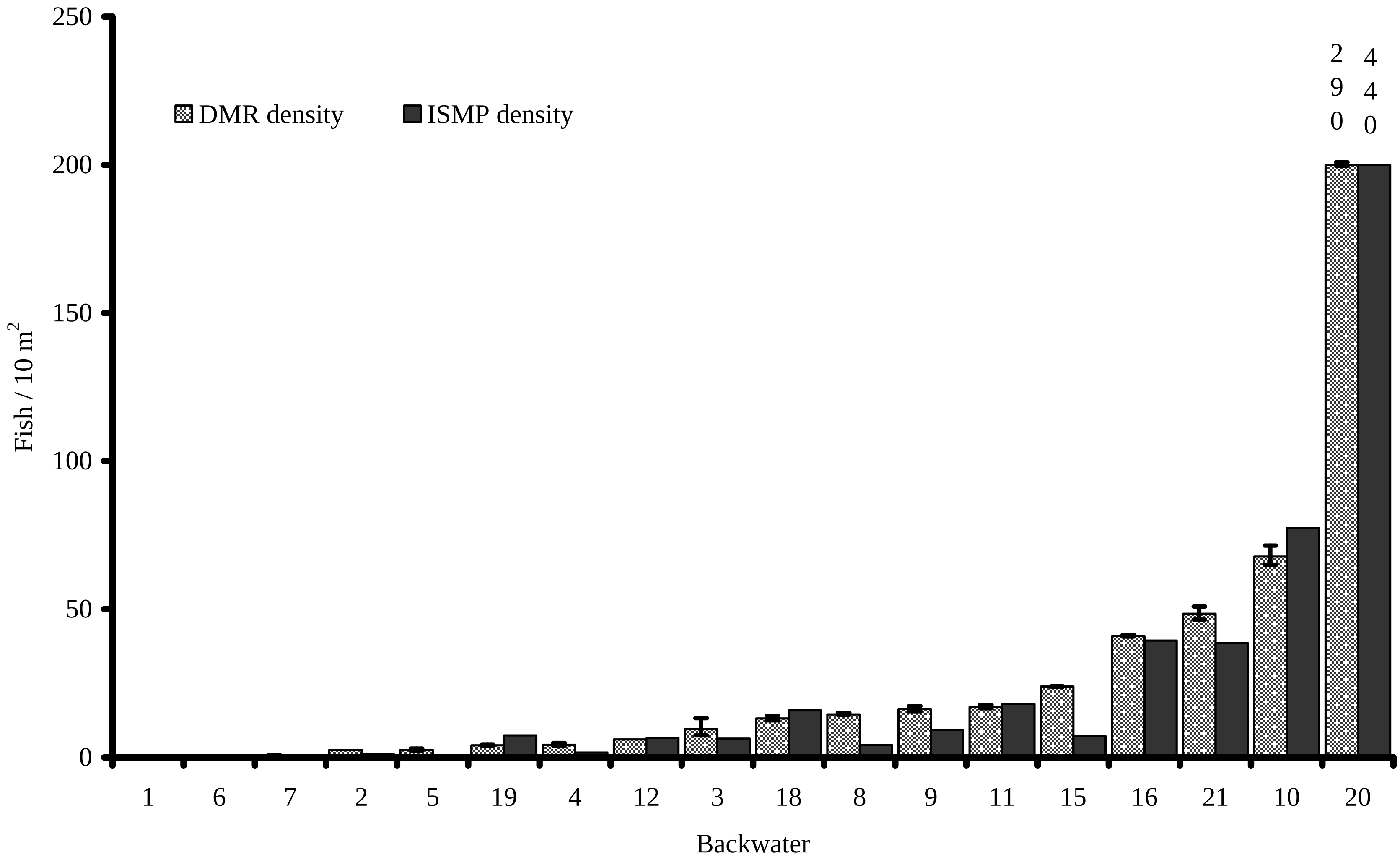


Fig. 18-- Density (fish / 10 m^2) of sand shiners in backwaters in the Grand Valley reach of the Colorado River, CO, 1997, estimated by depletion, mark-recapture (DMR) and by the Interagency Standardized Monitoring Program (ISMP) methods. Error bars on DMR estimates are 95% profile likehood confidence limits. Confidence limits were not estimated for some DMR estimates because those represent the total number of fish captured.

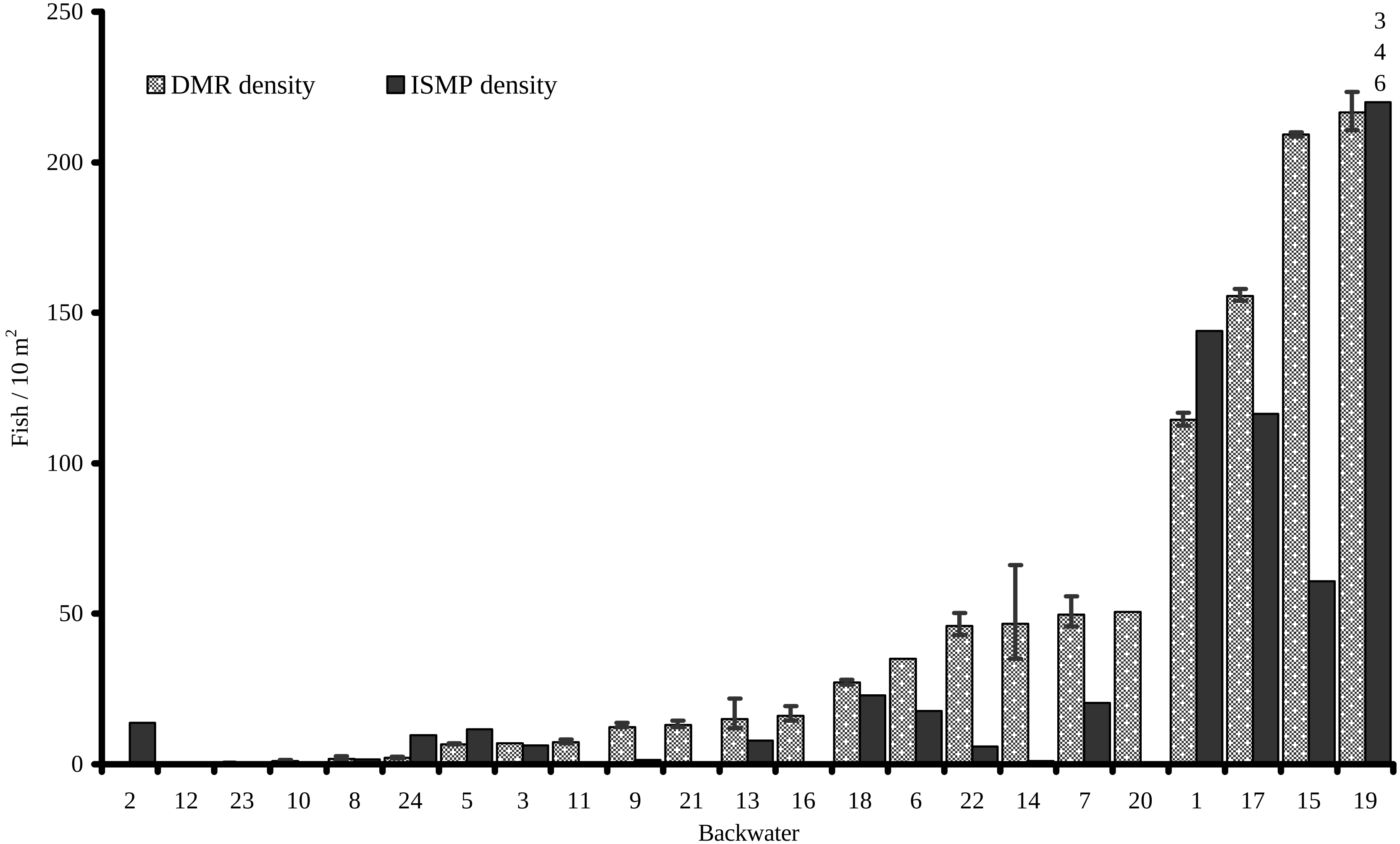


Fig. 19-- Density (fish/10 m^2) of sand shiners in backwaters in the Grand Valley reach of the Colorado River, CO, 1998, estimated by depletion, mark-recapture (DMR) and by the Interagency Standardized Monitoring Program (ISMP) methods. Error bars on DMR estimates are 95% profile likehood confidence limits. Confidence limits were not estimated for some DMR estimates because those represent the total number of fish captured.

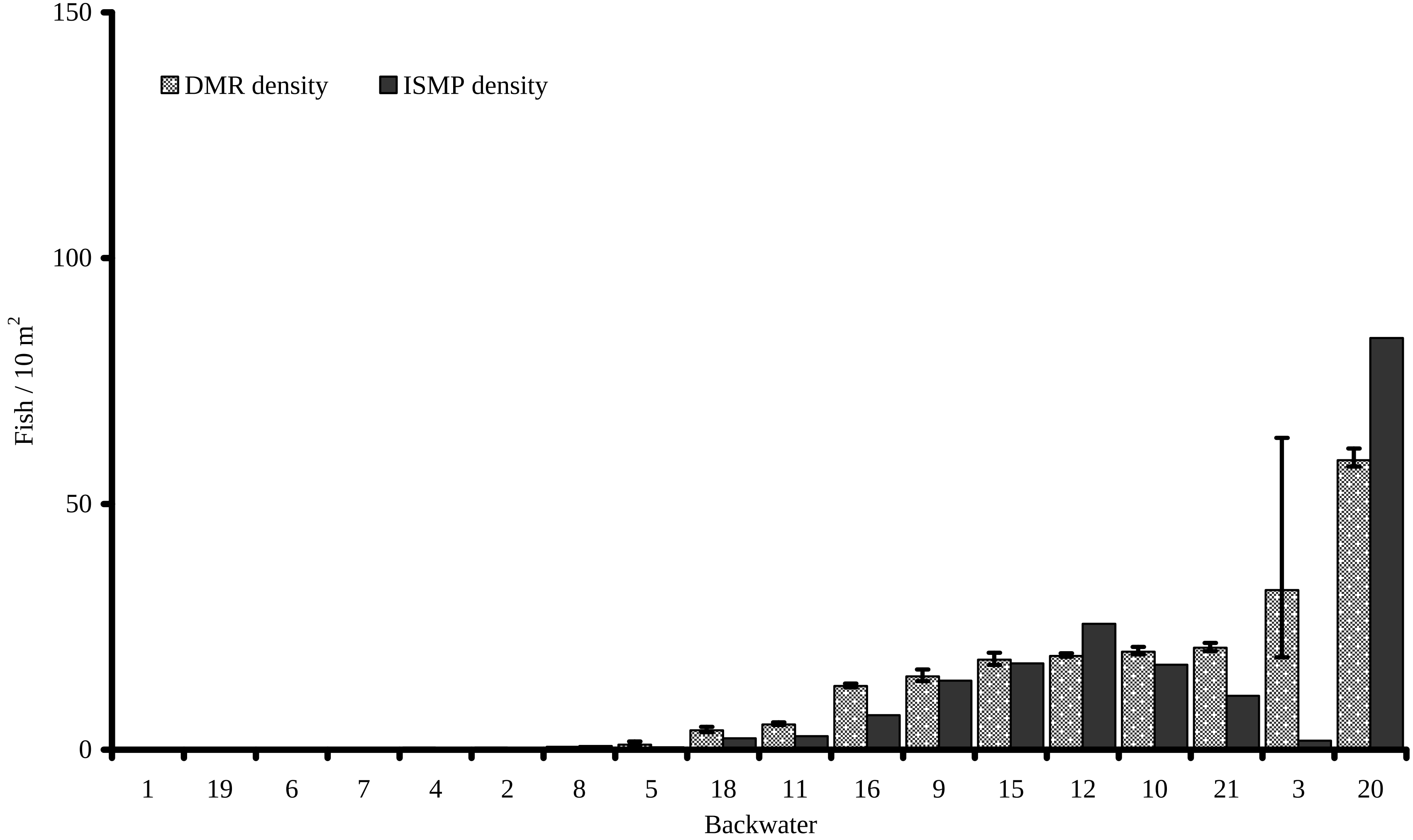


Fig. 20-- Density (fish/10 m^2) of fathead minnows in backwaters in the Grand Valley reach of the Colorado River, CO, 1997, estimated by depletion, mark-recapture (DMR) and by the Interagency Standardized Monitoring Program (ISMP) methods. Error bars on DMR estimates are 95% profile likehood confidence limits. Confidence limits were not estimated for some DMR estimates because those represent the total number of fish captured.

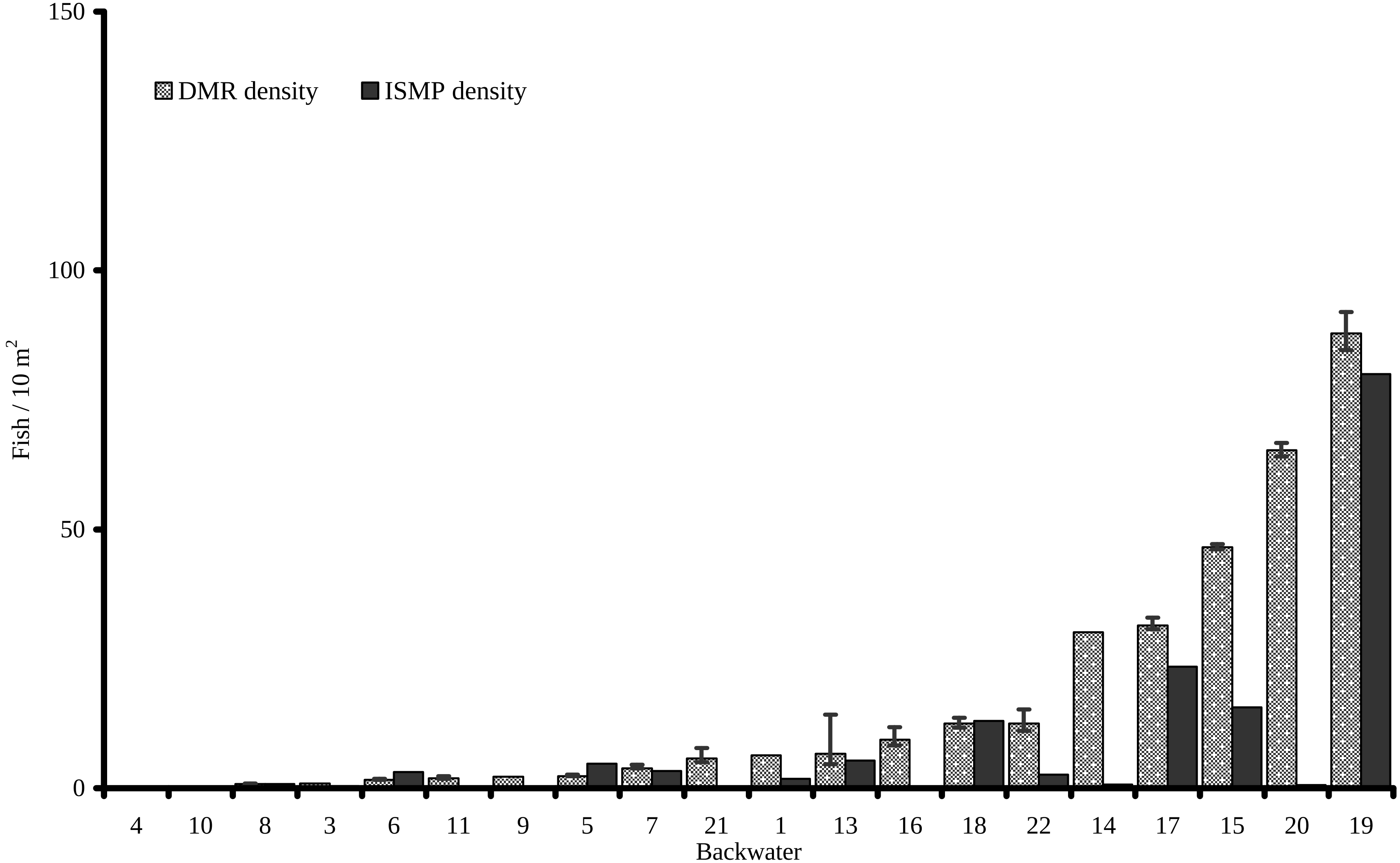


Fig. 21--Density (fish/10 m^2) of fathead minnows in backwaters in the Grand Valley reach of the Colorado River, CO, 1998, estimated by depletion, mark-recapture (DMR) and by the Interagency Standardized Monitoring Program (ISMP) methods. Error bars on DMR estimates are 95% profile likehood confidence limits. Confidence limits were not estimated for some DMR estimates because those represent the total number of fish captured.

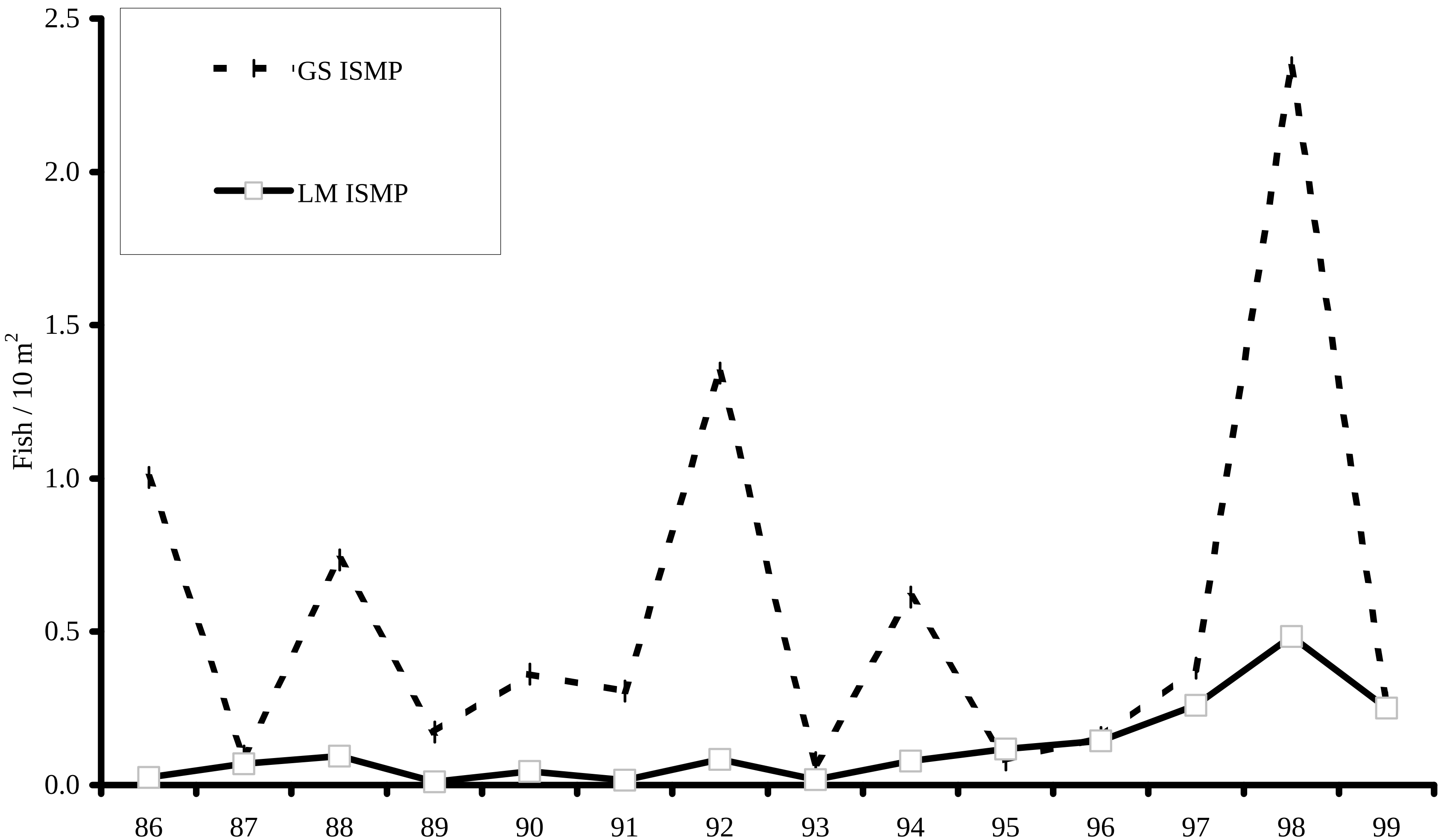


Fig. 22-- Density (fish/10m^2) estimates for largemouth bass and green sunfish gathered by the Interagency Standardized Monitoring Program (ISMP) from 1986 to 1999, in the Grand Valley reach of the Colorado River, CO.

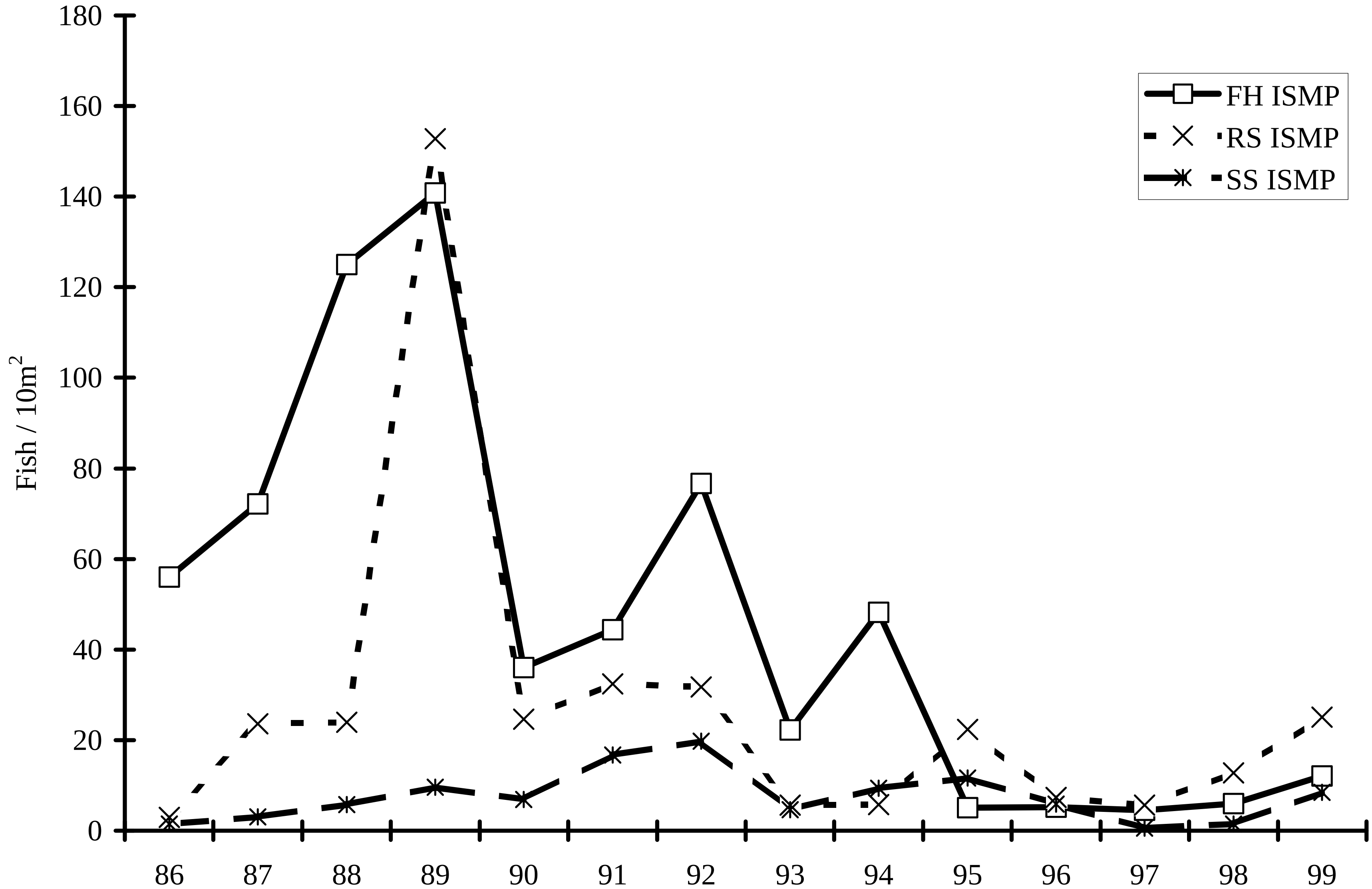


Fig. 23--Density (Fish / 10 m^2) estimates for red shiner, sand shiner, and fathead minnow gathered by the Interagency Standardized Monitoring Program (ISMP) from 1986 to 1999, in the Grand Valley reach of the Colorado River, CO.

Appendix I.-- Total fish captured during the Interagency Standardized Monitoring Program evaluation research in the Grand Valley reach of the Colorado River, CO, Autumn 1997.

Backwater		Surface	Non-natives														Natives				
(RK)	Sample	Area	RS	SS	FH	LM	GS	BG	BC	YP	WS	BM	GA	PK	BB	CP	CC	FM	BH	SD	CH	CS
1	ISMP 1				1																	
	ISMP 2		8		1	1	1				1					1					1	
(286.4 R)	Mark Pass 1	734	7		2						10				4						4	
	Mark Pass 2		8		1						4				5						1	
	Mark Pass 3		23		1	12	167				19				34			1				
2	ISMP 1				1													1	1			
	ISMP 2		121	8	1													6	4	1	2	
(291.4 L)	Mark Pass 1	1159	73	178	37		1				8				3			18	8	1	6	
	Mark Pass 2		57	113	14							7						7	10		2	
	Mark Pass 3				1	10	16				1											
3	ISMP 1				3						27											
	ISMP 2		268	61	15						54	1						6		1	41	
(293.7 L)	Depletion 1	1448	775	319	467	26	23		1		346	59	2		1	2	1	25	23	3	207	
	Depletion 2		140	63	283	11	21				127	27	7		1	2		4	4		73	
	Depletion 3		56	230	396	11	12				145	11	23		2			4	7	7	21	
4	ISMP 1		1	7	1						2							2		1	1	
	ISMP 2		11	8	1						4	2						2	1		1	
(287.4 M)	Depletion 1	342	51	65	10	1	1				2	5			2	1	1	25	5	13	8	
	Depletion 2		21	38	2		2				2	3				1		5		2	6	
	Depletion 3		7	13	1						1	1			1	1		3	1	1	2	
5	ISMP 1				2		10									2						
	ISMP 2		145		2	1										1						
(284.2 R)	Depletion 1	432	437	58	19	4	59								62	23		2	2	2		
	Depletion 2		151	23	6	2	31								17	10		1				
	Depletion 3		74	16	8		12								14	7					1	
6	ISMP 1														1						1	
	ISMP 2		4	1			1				3							6	4			
(289.2 L)	Mark Pass 1	1225	12	8	8						3	1						18	11	3	53	
	Mark Pass 2		10	3	3						7							22	3		15	
	Mark Pass 3		11	20	9	3	13				28							32	10		17	
7	ISMP 1		10	1	2	5	3				1					1		2			1	
	ISMP 2		1	1	1	1	3						9					2				
(284.5 R)	Depletion 1	290	29	10	2	10	3				1		8			3		1	3		3	
	Depletion 2		17	3	1	7	2				1	1	2			2			1		1	
	Depletion 3		10	2	1	2	1				1		1			2				3	1	
8	ISMP 1		2	14	1							1						19	14	22	6	
	ISMP 2		4	14	3							1						2	4	6	5	
(287.2 R)	Depletion 1	210	15	201	4	1					3	1						15	10	55	11	
	Depletion 2			39	4						2							6	1	9	5	
	Depletion 3		1	28																12	3	

Appendix I.-- continued.

Backwater		Surface	Non-natives														Natives				
(RK)	Sample	Area	RS	SS	FH	LM	GS	BG	BC	YP	WS	BM	GA	PK	BB	CP	CC	FM	BH	SD	CH	CS
9	ISMP 1		6	6	45						1							2	1		5	
	ISMP 2		35	36	18						3							15	9		16	
(274.2 R)	Depletion 1	545	231	438	366	3	4	1			24		15	1		2		22	97	18	54	
	Depletion 2		289	208	114	2	5				7		5			3		8	26	9	36	
	Depletion 3		186	124	150						5		4			1	1	5	32	7	24	
10	ISMP 1		14	101	27		1				1							2	2		1	
	ISMP 2		22	153	31		1				1							5	4	7	1	
(272.1 R)	Depletion 1	256	247	611	265		12				7		13					17	48	71	11	
	Depletion 2		118	402	106		2				4		6					9	21	26	6	
	Depletion 3		43	173	47	2	4				1							2	7	10	3	
11	ISMP 1		25	30	8													1		14	2	
	ISMP 2		1	38	5													2	5	20	3	
(272.3 L)	Depletion 1	275	86	249	83								1					5	13	47	31	
	Depletion 2		11	74	25		1											1		22	6	
	Depletion 3		12	49	14														4	8	2	
12	ISMP 1		3	18	70		1											5	2	2	1	
	ISMP 2		4	8	31														9	1	1	
(258.9 R)	Depletion 1	138	25	52	129		3				2		2					2	23	4	4	
	Depletion 2		5	4	16							1							3		1	
	Depletion 3		9	2	14								1					1	1			
13	ISMP 1			1	1																1	
	ISMP 2		7												1							
(270.3 L)	Mark Pass 1	1806	56	9	39	4	6	1			5		27		2	2		7	8			1
	Mark Pass 2						22	1							44							
	Mark Pass 3					60	173	1	3	1	3				9	6						
14	ISMP 1		12	1	36		1				1								1			
	ISMP 2		3		11		1				1	1						1				
(263.7 R)	Mark Pass 1	412	76	6	233		12				1		19		1	1		1				
	Mark Pass 2						5								6	2						
	Mark Pass 3					27	18		1									1				
15	ISMP 1		11	52	133															5		
	ISMP 2			2	2																	
(255.8 R)	Depletion 1	887	73	1785	630														6	15		
	Depletion 2		15	130	219																	
	Depletion 3		9	140	274															1		
16	ISMP 1		84	331	53	4	1											1		1		
	ISMP 2		2	10	5																	
(248.7 L)	Depletion 1	601	152	1644	461	7	11						10		2			4				
	Depletion 2		48	278	112	2	8						4		5			2				
	Depletion 3		20	161	100	2	8								4			1	1			

Appendix I.-- continued.

Backwater		Surface	Non-natives															Natives				
(RK)	Sample	Area	RS	SS	FH	LM	GS	BG	BC	YP	WS	BM	GA	PK	BB	CP	CC	FM	BH	SD	CH	CS
17	ISMP 1			2		2	6				1							2		1		
	ISMP 2		2	19	1		4															
(248.6 L)	Mark Pass 1	2888				2	168	2														
	Mark Pass 2					92	632	2														
18	ISMP 1		6	82	1																	
	ISMP 2		13	123	23						1				2				1			
(248.7 L)	Depletion 1	1224	210	572	180	1	2						1		3			1	1	4		
	Depletion 2		68	315	93	2	1				5				1					28		
	Depletion 3		34	200	73	1	2								1		1	2		8		
19	ISMP 1		4	38	1																	
	ISMP 2		9	19																		
(251.2 L)	Depletion 1	337	5	54	2															3		
	Depletion 2		4	16	2						1									2		
	Depletion 3		1	6																		
20	ISMP 1		7	428	54		1											2		1		
	ISMP 2		183	761	174		3											7		2		
(246.8 R)	Depletion 1	99	302	1423	223		8				2		4					25	1	5		
	Depletion 2		61	190	50		1						1					3				
	Depletion 3		18	49	47		4											1				
21	ISMP 1		402	594	161															6		
	ISMP 2		41	8	8								19							1		
(247.0 L)	Depletion 1	670	1829	1019	593		7						19					1		48		
	Depletion 2		937	536	290		1				1		8						1	16		
	Depletion 3		699	387	157								15					1	1	13		
	Totals	**15978**	**9,336**	**15,712**	**7,321**	**321**	**1,522**	**8**	**5**	**1**	**881**	**123**	**226**	**1**	**228**	**76**	**4**	**404**	**455**	**568**	**707**	**1**

Species Key:

RS = red shiner; *Cyprinella lutrensis*
SS = sand shiner; *Notropus stramineus*
FH = fathead minnow; *Pimephales promelas*
LM = largemouth bass; *Micropterus salmoides*
GS = green sunfish; *Lepomis cyanellus*
BG = bluegill; *Lepomis macrochirus*
BC = black crappie; *Pomoxis nigromaculatus*
YP = yellow perch; *Perca flavescens*
WS = white sucker; *Catostomus commersoni*
BM = brassy minnow; *Hybognathus hankinsoni*
GA = western mosquitofish; *Gambusia affinis*
PK = plains killifish; *Fundulus zebrinus*
BB = black bullhead; *Ameiurus melas*
CP = common carp; *Cyprinus carpio*
CC = channel catfish; *Ictalurus punctatus*
FM = flannelmouth sucker; *Catostomus latipinnis*
BH = bluehead sucker; *Catostomus discobolus*
SD = speckled dace; *Rhinichthys osculus*
CH = roundtail chub; *Gila robusta*
CS = Colorado pikeminnow; *Ptychocheilus lucius*

Appendix II.-- Total fish captured during the Interagency Standardized Monitoring Program evaluation research in the Grand Valley reach of the Colorado River, CO, autumn 1998.

Backwater		Surface	Non-natives													Natives				
(RK)	Sample	Area	RS	SS	FH	LM	GS	BG	BC	WS	BM	GA	PK	BB	CP	FM	BH	SD	CH	CS
1	ISMP 1	291	71	428	5						3	1				8	6	3	2	
292.22	ISMP 2		4	132	2							1						2		
	Depletion 1		186	1557	160		1					2				8	3	36	9	
	Depletion 2		32	535	6											3	1	6	8	
	Depletion 3		45	371	11					2		2				4	3	2	6	
2	ISMP 1	1007	77	131	28					1						27	12	12	52	
291.41	ISMP 2		0																	
	Mark pass 1						1													
	Recap 2						1													
3	ISMP 1	42	1	6						1										
288.67	ISMP 2		16	11	1		1			1		5					2	1		
	Depletion 1			3	1															
	Depletion 2		1	3	1					1										
	Depletion 3			6	1													1		
4	ISMP 1	1666					1			1						2				
1st	ISMP 2									1		1				1				
293.5	Mark pass 1					12	17													
	Recap 2					294	120	2		10		18		2						
	Recap 3				2	216	86	4	1	23		14		6		2				
4	ISMP 1	1580										6								
2nd	ISMP 2						1			7				1	1					
293.5	Depletion 1				8	171	94			199		66		55	12	4				
	Depletion 2				9	93	79	1		84		182		22	7	7				
	Depletion 3				1	37	29	3		17		40		113		3				
5	ISMP 1	233	1	17	9		1			2		85					1	3		
291.33	ISMP 2		2	45	17		1			1		70					1	2		
	Depletion 1		27	76	23					1		211				3	10	3	1	
	Depletion 2		7	9	2		1					32					2	2		
	Depletion 3		2	7	3							31				1	1	1		
6	ISMP 1	422	7	123	29					1						13	26	9	4	
290.12	ISMP 2		15	30	1		1					1						21		
	Depletion 1		199	369	28		9			3		44		1		21	30	93	35	
	Depletion 2		234	470	5	1	1			2		17				9	12	42	7	
	Depletion 3		157	488	4		4			2		31				1	2	25	2	
7	ISMP 1	137	17	34	12							20				1		1	1	
287.71	ISMP 2		10	39																
	Depletion 1		339	230	25	2						23			1	1		3	3	
	Depletion 2		27	144	13							39		1		1		1		
	Depletion 3		12	84	2							27		1		1		1	1	

Appendix II.-- continued.

Backwater		Surface	Non-natives													Natives				
(RK)	Sample	Area	RS	SS	FH	LM	GS	BG	BC	WS	BM	GA	PK	BB	CP	FM	BH	SD	CH	CS
8	ISMP 1	642	4	2	11					1						6	11	1		
286.9	ISMP 2			10			1					2					1		1	
	Depletion 1		13	38	24		2			7		5		1	2	22	10	13	2	
	Depletion 2		9	24	11		2			6		6		1	1	4	5	3		
	Depletion 3		1	16	2					1		2			1		1	4		
9	ISMP 1	50	1			1				3		11				2				
286.74	ISMP 2		52	9			1			1		10					1		1	
	Depletion 1		402	43	9	4	7			1		87				2	1	1		
	Depletion 2		54	4	2	2	1					13				1	2	2		
	Depletion 3		32	6								6				1	1	1		
10	ISMP 1	305		2								1				2				
286.82	ISMP 2									1		1								
	Depletion 1		8	16	2		11			3		25		2		1		1		
	Depletion 2		3	10		3	2					7								
	Depletion 3		9	3	1	1	2					3				1				
11	ISMP 1	311	4	1	3	1	6					1			2	2	1			
284.49	ISMP 2		8				3			1		2			2	1		1		
	Depletion 1		415	133	37	2	21			10		201	1		3	5	9	54	3	
	Depletion 2		128	36	4		8	1		4		63				1	5	18	1	
	Depletion 3		161	38	11	1	2					81			1	2	4	13		
12	ISMP 1	1252	1	1			8			2		1		1	1			1		
273.06	ISMP 2		3		1		7			10				11	2				1	
	Mark pass 1						122			1				4	3					
	Recap 2		13	2	22	56	97	4	4	37		76		34	15	8	2		2	
	Recap 3		8	2	8	30	53	2	2	22		51		3	3	1	2			
13	ISMP 1	221	5	1	5					1						1	1	1	2	
272.73	ISMP 2		30	34	21													1		
	Depletion 1		73	73	24		1			1								13	1	
	Depletion 2		74	68	19													16	2	
	Depletion 3		41	36	15													9		
14	ISMP 1	700		2	4		2													
274.51	ISMP 2		3	6	2											1		2		
	Depletion 1		283	491	683	1	24					2		1		10	12	19	11	
	Depletion 2		480	412	671		12			1							3	16	4	
	Depletion 3		240	356	752		6			2						2	6	10	2	
15	ISMP 1	314	13	352	74											1				
270.32	ISMP 2		2	42	22							15								
	Depletion 1		705	4710	937		1					118		1		4	2		5	
	Depletion 2		143	953	309		5					70				2		2	1	
	Depletion 3		61	408	79					1		38							1	

Appendix II.-- continued.

Backwater		Surface	Non-natives													Natives				
(RK)	Sample	Area	RS	SS	FH	LM	GS	BG	BC	WS	BM	GA	PK	BB	CP	FM	BH	SD	CH	CS
16	ISMP 1	194																		
260.5	ISMP 2			1																
	Depletion 1		56	136	64							23						2		
	Depletion 2		24	55	63		1					15						6		
	Depletion 3		4	56	17		2					6						6		
17	ISMP 1	136		13												1				
260.48	ISMP 2		123	463	96													1		
	Depletion 1		510	1082	199		1		4			3				1		2	2	
	Depletion 2		149	327	79	1						2						1		
	Depletion 3		82	147	30							1								
18	ISMP 1	691	57	84	46														1	
262.11	ISMP 2		183	75	44		3												2	
	Depletion 1		1364	936	334	7	28							1	3		1	2	41	1
	Depletion 2		787	323	146	1	32			1		1		2		1		1	11	
	Depletion 3		383	253	125	1	16					1			1				3	
19	ISMP 1	228	6	44	1	1												1		
248.75	ISMP 2		2235	1752	416							18						10	1	
	Depletion 1		643	1194	687	4	21					70			2			3	1	
	Depletion 2		450	692	369		8					42						1	1	
	Depletion 3		256	373	206		7					32								
20	ISMP 1	1037			3															
255.67	ISMP 2			3	1															
	Depletion 1		901	1687	3405	3	3					35				1	2	11	24	
	Depletion 2		826	1767	1344		9			3		79					5	11	73	
	Depletion 3		814	1781	1053	2	5			3		37				4	1	7	20	
21	ISMP 1	228		3	1															
255.67	ISMP 2			1																
	Depletion 1		73	156	54		1											7	1	
	Depletion 2		48	57	27		2											5	1	
	Depletion 3		30	45	22											1		4		
22	ISMP 1	401	25	8	3								2							
246.65	ISMP 2		58	42	19															
	Depletion 1		760	629	159								1							
	Depletion 2		637	424	115								2						1	
	Depletion 3		349	255	66							1						1		
23	ISMP 1	2100	2	1	9		3					1								
248.42	ISMP 2					1	1			2		1								
	Depletion 1		13	34	81	213	381	3	1	95		14	2	43	29	11	2	2	3	
	Depletion 2		11	18	66	62	182	2		47		3		19	9	3	2	1		
	Depletion 3		2	12	25	31	148	3		15		11		32	5	2		1	2	

Appendix II.-- continued.

Backwater (RK)	Sample	Surface Area	Non-natives													Natives				
			RS	SS	FH	LM	GS	BG	BC	WS	BM	GA	PK	BB	CP	FM	BH	SD	CH	CS
24	ISMP 1	2042	282	56	18		1													
249.07	ISMP 2		760	73	32	4	1			6		1		1	2	2			2	
	Depletion 1		254	110	522	63	278			29		18		19	78	8	4	1	5	
	Depletion 2		153	79	314	32	101			24		5		8	48	4	4	1	42	
	Depletion 3		26	36	220	12	85			16		7		4	52	3	1		2	
Totals		**16229.19**	**18,307**	**28,971**	**14,655**	**1,366**	**2,176**	**25**	**12**	**718**	**3**	**2,294**	**8**	**390**	**286**	**246**	**214**	**560**	**410**	**1**
Total fish			**70,642**																	

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BB = black bullhead; *Ameiurus melas*
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CC = channel catfish; *Ictalurus punctatus*
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CH = roundtail chub; *Gila robusta*
CS = Colorado pikeminnow; *Ptychocheilus lucius*

Appendix III.-- ISMP and intensive fish densities for backwaters located in the Grand Valley reach of the Colorado River, 1997 and 1998. Density equals number of fish per 10 m^2.

Year	Backwater	RS		SS		FH		GS		LMB		BG		BC		YP	
		Intensive	ISMP	Intensive	ISMP	Intensive	ISMP	Intensive	ISMP	Intensive	ISMP	Intensive	ISMP	Intensive	ISMP	Intensive	ISMP
1997	1	0.531	0.819			0.027	0.181	5.011	0.102	0.163	0.102						
	2	1.121	15.572	2.510	1.122	0.449	0.246	0.345		0.086							
	3	8.655	28.004	9.512	6.374	32.465	1.826	0.601		0.408				0.007			
	4	2.775	1.595	4.265	1.660	0.438	0.217	0.088		0.029							
	5	19.839	20.342	2.523		1.019	0.470	2.847	0.947	0.139	0.140						
	6	0.269	0.459	0.253	0.115	0.163		0.106	0.115								
	7	2.795	1.231	0.587	0.257	0.242	0.365	0.449	0.770	0.932	0.690						
	8	1.050	1.043	14.511	4.180	0.573	0.744			0.048							
	9	50.935	9.135	16.315	9.358	14.896	14.037	0.156		0.087		0.017					
	10	18.802	10.997	67.795	77.368	19.933	17.273	0.702	0.589	0.078							
	11	4.974	2.811	16.990	18.047	5.119	2.766	0.036									
	12	3.767	2.192	6.085	6.602	19.052	25.629	0.290	0.185								
	13	0.310	0.536	0.050	0.084	0.216	0.084	1.744	0.153	0.709	0.077	0.033		0.033		0.001	
	14	1.845	1.516	0.146	0.083	5.658	4.896	0.898	0.174	0.923	0.340			0.073			
	15	1.240	1.412	23.905	7.136	18.301	17.537										
	16	5.293	9.902	40.999	39.447	12.984	7.003	0.882	0.113	0.250	0.452						
	17	0.017	0.168	0.014	1.731	0.059	0.084	6.412	0.732	0.641	0.132	0.007					
	18	2.852	1.560	13.166	15.872	3.956	2.337	0.041		0.033							
	19	0.742	2.548	4.034	7.415	0.148	0.069										
	20	58.513	68.737	290.133	440.809	58.919	83.750	2.028	1.471								
	21	74.374	29.076	48.463	38.633	20.762	10.952	0.119									
	mean	12.414	9.984	28.113	35.594	10.256	9.523	1.264	0.486	0.323	0.276	0.019		0.038		0.001	
1998	1	12.376	16.922	114.377	143.923	6.326	1.859	0.034									
	2		8.046		13.689		2.926	0.079		0.010							
	3	4.274	6.142	6.885	6.186	0.950	0.361		0.361								
	4.1					0.012		2.287	0.080	6.502		0.036		0.006			
	4.2					0.120		1.621	0.133	2.140		0.025					
	5	1.673	0.548	6.649	11.664	2.316	4.719	0.129	0.335								
	6	51.843	3.319	35.051	17.649	1.610	3.103	0.379	0.174	0.024							
	7	29.562	7.489	49.635	20.309	3.869	3.306			0.146							
	8	0.436	0.299	1.838	1.635	0.763	0.821	0.078	0.149								
	9	109.178	8.691	12.398	1.451	2.200		1.800	0.161	1.400	0.309						
	10	0.657		1.083	0.226	0.098		0.492		0.131							
	11	28.042	1.890	7.396	0.098	1.897	0.295	1.318	1.151	0.129	0.098	0.032					
	12	0.359	0.591	0.040	0.158	0.160	0.144	3.402	2.273	0.966		0.112		0.056			
	13	17.901	7.350	15.098	7.802	6.645	5.314	0.045									
	14	79.562	0.421	46.657	1.055	30.162	0.707	0.686	0.213	0.014							
	15	29.877	2.339	209.138	60.743	46.518	15.580	0.191									
	16	4.432		16.131	0.399	9.328		0.155									
	17	66.613	30.059	155.626	116.430	31.434	23.460	0.073		0.073				0.294			
	18	47.625	35.376	27.150	22.928	12.453	12.995	2.114	0.450	0.130							
	19	213.706	430.074	216.470	346.435	87.834	80.022	1.711		0.219	0.237						
	20	168.856		50.521	0.494	65.278	0.648	0.164		0.048							
	21	8.852		13.059	0.518	5.741	0.102	0.131									
	22	68.957	9.266	46.038	5.925	12.533	2.632										
	23	0.143	0.261	0.367	0.131	1.095	1.176	4.324	0.667	1.510	0.275	0.038					
	24	7.757	77.392	2.194	9.581	7.341	3.714	2.640	0.149	0.602	0.297						
	mean	43.304	34.025	46.991	34.323	14.028	8.194	1.084	0.484	0.878	0.243	0.049		0.119			

	Backwater	WS Intensive	WS ISMP	BM Intensive	BM ISMP	GA Intensive	GA ISMP	PK Intensive	PK ISMP	BB Intensive	BB ISMP	CP Intensive	CP ISMP	CC Intensive	CC ISMP	FM Intensive	FM ISMP
1997	1	0.436	0.102							0.463		0.014	0.102			0.027	
	2	0.069		0.129						0.026						0.216	0.947
	3	6.155	7.967	0.725	0.104	0.221				0.028		0.028		0.007		0.269	0.627
	4	0.467	0.710	0.321	0.275					0.088		0.088		0.029		1.081	0.435
	5									2.292		1.111	0.330			0.069	
	6	0.302	0.344	0.008							0.092					0.596	0.689
	7	0.138	0.108	0.035		0.690	1.337					0.311	0.108			0.173	0.514
	8	0.239		0.143	0.299											2.005	1.885
	9	0.709	0.891			0.433		0.002				0.104		0.017		0.952	3.788
	10	0.546	0.589			0.741										1.443	2.211
	11					0.036										0.363	0.894
	12	0.145		0.072		0.217										0.652	0.924
	13	0.044				0.150				0.310	0.077	0.044			0.160	0.039	
	14	0.024	0.257		0.174	0.461				0.170		0.097			0.257	0.049	0.174
	15																
	16					0.233				0.183						0.133	0.113
	17	0.031	0.066									0.003				0.031	0.132
	18		0.100			0.008				0.057	0.199			0.008		0.025	
	19	0.030															
	20	0.203				0.406										3.854	3.302
	21	0.015				1.940	1.565									0.030	
	mean	0.597	1.113	0.205	0.213	0.461	1.451	0.002		0.402	0.123	0.200	0.180	0.015	0.209	0.632	1.188
1998	1	0.069				0.206	0.605									0.997	1.732
	2		0.104														2.821
	3	0.712	0.730				1.804										
	4.1	0.198	0.201			0.114	0.121			0.048						0.012	0.281
	4.2	2.013	0.930			1.861	0.502			1.209	0.133	0.127	0.133			0.158	
	5	0.172	0.456			18.874	25.241									0.172	
	6	0.213	0.101			4.121	0.174			0.024						1.042	1.313
	7					7.956	5.510			0.146		0.073				0.292	0.275
	8	0.234	0.075			0.280	0.297			0.031		0.062				0.498	0.448
	9	1.000	1.089			25.595	5.013									1.200	0.618
	10	0.131	0.208			1.215	0.321			0.066						0.131	0.226
	11	0.482	0.187			13.796	0.472	0.032				0.257	0.571			0.354	0.384
	12	0.367	1.759			3.410	0.158			1.693	1.745	0.144	0.446			0.024	
	13	0.090	0.113														0.113
	14	0.043				0.029				0.014						0.186	0.140
	15	0.032				9.323	3.201			0.032						0.223	0.147
	16					2.577											
	17					0.441										0.147	0.253
	18	0.014				0.029				0.043		0.058				0.014	
	19					9.871	3.452					0.088					
	20	0.058				1.456										0.048	
	21															0.044	
	22					0.025		0.075	0.155								
	23	0.814	0.551			0.286	0.406	0.010		0.448		0.210				0.076	
	24	0.578	0.446			0.171	0.074			0.157	0.074	1.714	0.149			0.093	0.149
	mean	0.401	0.496			4.840	2.960	0.039	0.155	0.326	0.651	0.304	0.325			0.301	0.636

Appendix III.-- continued.

Backwater	(RK)	BH Intensive	BH ISMP	SD Intensive	SD ISMP	CH Intensive	CH ISMP	CS Intensive	CS ISMP
1997	1					0.068	0.102		
	2	0.173	0.666	0.009	0.140	0.069	0.281		
	3	0.249		0.076	0.104	2.445	4.284		
	4	0.204	0.138	0.497	0.080	0.555	0.080		
	5	0.046		0.046		0.023			
	6	0.196	0.459	0.024		0.620	0.092		
	7	0.138		0.104		0.207	0.108		
	8	1.384	1.952	5.203	3.004	1.575	1.569		
	9	3.253	2.228	0.709		3.218	4.679		
	10	3.355	1.866	4.642	2.410	0.936	0.589		
	11	0.762	1.994	4.320	9.326	1.597	1.389		
	12	2.753	4.055	0.507	0.779	0.507	0.594		
	13	0.044					0.084	0.07	
	14		0.083						
	15	0.068		0.237	0.642				
	16	0.017			0.113				
	17				0.066				
	18	0.016	0.100	0.327					
	19			0.148					
	20	0.101		0.811	1.110				
	21	0.030		1.388	0.466				
	mean	0.752	1.354	1.191	1.520	0.985	1.154	0.070	
1998	1	0.447	1.299	1.685	1.426	1.341	0.433		
	2		1.254		1.254		5.434		
	3		0.722	0.475	0.361				
	4.1								
	4.2								
	5	0.643	0.335	0.472	0.790	0.043			
	6	1.682	2.626	5.139	4.566	1.137	0.404		
	7			0.438	0.275	0.365	0.275		
	8	0.436	0.970	0.343	0.075	0.047	0.149		
	9	1.000	0.161	0.800			0.161		
	10			0.033					
	11	0.707	0.098	2.991	0.187	0.129			
	12				0.158	0.016	0.144		
	13		0.113	3.435	0.339	0.226	0.226		
	14	0.357		0.985	0.281	0.243			
	15	0.064		0.064		0.223			
	16			0.722					
	17			0.294	0.244	0.147			
	18	0.014		0.043		0.840	0.439	0.01	
	19			0.658	2.155	0.132	0.192		
	20	0.096		0.482		5.903			
	21			0.920		0.088			
	22			0.025		0.025			
	23	0.019		0.019		0.024			
	24	0.044		0.010		0.250	0.149		
	mean	0.459	0.842	0.954	0.932	0.621	0.728	0.010	

Appendix IV-- 1997 probability of capture by backwater for five abundant fishes in the Grand Valley reach of the Colorado River. Probabilities are for depletion backwaters only.

		Backwater															
Species	Pass	3	4	5	7	8	9	10	11	12	15	16	18	19	20	21	Mean
RS	1	0.79	0.62	0.62	0.43	0.95	0.08	0.56	0.78	0.56	0.74	0.66	0.64	0.48	0.79	0.41	0.61
	2	0.14	0.25	0.21	0.25	0.00	0.10	0.27	0.10	0.12	0.15	0.21	0.21	0.36	0.16	0.21	0.18
	3	0.06	0.08	0.11	0.15	0.05	0.07	0.10	0.10	0.21	0.09	0.09	0.10	0.08	0.05	0.16	0.10
	total	0.99	0.96	0.94	0.83	1.00	0.25	0.92	0.99	0.88	0.98	0.96	0.95	0.92	0.99	0.78	0.89
SS	1	0.25	0.50	0.53	0.65	0.73	0.49	0.43	0.63	0.89	0.86	0.78	0.42	0.70	0.85	0.41	0.61
	2	0.05	0.29	0.21	0.24	0.14	0.23	0.28	0.19	0.07	0.06	0.13	0.23	0.21	0.11	0.22	0.18
	3	0.18	0.10	0.15	0.12	0.10	0.14	0.12	0.12	0.04	0.07	0.08	0.15	0.07	0.03	0.16	0.11
	total	0.49	0.90	0.89	1.00	0.97	0.86	0.83	0.94	1.00	0.99	0.98	0.80	0.98	1.00	0.78	0.89
FH	1	0.10	0.80	0.48	0.57	0.50	0.47	0.59	0.65	0.80	0.43	0.64	0.40	0.60	0.66	0.50	0.55
	2	0.06	0.13	0.16	0.29	0.50	0.15	0.24	0.20	0.10	0.15	0.16	0.20	0.40	0.15	0.24	0.21
	3	0.09	0.07	0.20	0.14	0.00	0.19	0.10	0.11	0.09	0.19	0.14	0.16	0.00	0.14	0.13	0.12
	total	0.25	1.00	0.84	1.00	1.00	0.80	0.93	0.96	0.99	0.78	0.94	0.76	1.00	0.94	0.87	0.87
GS	1	0.26	0.33	0.53	0.46		0.44	0.72	0.00	1.00		0.21	0.40		0.50	0.88	0.48
	2	0.24	0.67	0.28	0.31		0.56	0.06	1.00	0.00		0.17	0.20		0.10	0.13	0.31
	3	0.14	0.00	0.11	0.15		0.00	0.22	0.00	0.00		0.15	0.40		0.25	0.00	0.12
	total	0.64	1.00	0.91	0.92		1.00	1.00	1.00	1.00	0.00	0.53	1.00		0.85	1.00	0.90
LMB	1	0.44	1.00	0.71	0.48	1.00	0.60	0.00				0.67	0.25				0.57
	2	0.19	0.00	0.29	0.33	0.00	0.40	0.00				0.20	0.50				0.21
	3	0.19	0.00	0.00	0.11	0.00	0.00	1.00				0.13	0.25				0.19
	total	0.81	1.00	1.00	0.93	1.00	1.00	1.00				1.00	1.00				0.97

Overall capture probability by pass		
	1	0.56
	2	0.22
	3	0.13
	total	0.91

Appendix V-- 1998 probability of capture by backwater for five abundant fishes in the Grand Valley reach of the Colorado River. Probabilities are for depletion backwaters only.

		Backwater																						
Species	Pass	1	3	4.2	5	6	7	8	9	10	11	13	14	15	16	17	18	19	20	21	22	23	24	Mean
RS	1	0.66	0.00		0.74	0.09	0.90	0.54	0.82	0.40	0.48	0.22	0.05	0.76	0.65	0.66	0.45	0.35	0.05	0.36	0.29	0.47	0.55	0.45
	2	0.11	1.00		0.21	0.11	0.07	0.39	0.11	0.15	0.15	0.22	0.09	0.15	0.28	0.19	0.26	0.25	0.05	0.24	0.24	0.40	0.33	0.24
	3	0.16	0.00		0.05	0.07	0.03	0.04	0.06	0.45	0.19	0.12	0.04	0.07	0.05	0.10	0.13	0.14	0.05	0.15	0.13	0.07	0.06	0.10
	total	0.94	1.00		1.00	0.28	1.00	0.96	0.99	1.00	0.82	0.56	0.18	0.98	0.98	0.95	0.84	0.74	0.15	0.75	0.66	0.93	0.93	0.79
SS	1	0.57	0.24		0.82	0.28	0.39	0.37	0.81	0.52	0.58	0.26	0.15	0.76	0.44	0.67	0.55	0.43	0.32	0.53	0.35	0.45	0.39	0.47
	2	0.20	0.24		0.10	0.35	0.25	0.24	0.08	0.33	0.16	0.24	0.13	0.15	0.18	0.20	0.19	0.25	0.34	0.19	0.24	0.23	0.28	0.22
	3	0.14	0.52		0.08	0.37	0.14	0.15	0.11	0.09	0.17	0.13	0.11	0.07	0.18	0.09	0.15	0.14	0.34	0.15	0.14	0.16	0.13	0.17
	total	0.91	1.00		0.99	1.00	0.78	0.76	1.00	0.94	0.90	0.63	0.39	0.98	0.79	0.96	0.89	0.82	1.00	0.88	0.74	0.84	0.79	0.86
FH	1	0.91	0.50	0.42	0.81	0.75	0.62	0.63	0.82	0.67	0.66	0.24	0.32	0.69	0.35	0.61	0.45	0.46	0.50	0.42	0.34	0.37	0.36	0.54
	2	0.03	0.25	0.47	0.07	0.13	0.32	0.29	0.18	0.00	0.07	0.19	0.32	0.23	0.35	0.24	0.20	0.25	0.20	0.21	0.24	0.30	0.22	0.22
	3	0.06	0.25	0.05	0.11	0.10	0.04	0.06	0.00	0.33	0.20	0.14	0.36	0.06	0.09	0.09	0.17	0.14	0.16	0.17	0.14	0.12	0.15	0.14
	total	1.00	1.00	0.95	1.00	0.99	0.98	0.98	1.00	1.00	0.93	0.57	1.00	0.97	0.80	0.94	0.81	0.84	0.86	0.79	0.72	0.79	0.74	0.89
GS	1	1.00		0.37	0.00	0.63		0.60	0.89	0.73	0.66	1.00	0.52	0.17	0.00	1.00	0.20	0.44	0.18	0.33		0.43	0.52	0.51
	2	0.00		0.31	1.00	0.06		0.40	0.11	0.13	0.24	0.00	0.27	0.83	0.33	0.00	0.23	0.21	0.53	0.67		0.20	0.19	0.30
	3	0.00		0.11	0.00	0.25		0.00	0.00	0.13	0.07	0.00	0.13	0.00	0.67	0.00	0.12	0.18	0.29	0.00		0.16	0.16	0.12
	total	1.00		0.79	1.00	0.94		1.00	1.00	1.00	0.98	1.00	0.92	1.00	1.00	1.00	0.54	0.82	1.00	1.00		0.79	0.87	0.93
LMB	1			0.51		0.00	1.00		0.71	0.00	0.75		1.00			0.00	0.78	1.00	0.60			0.67	0.54	0.58
	2			0.28		1.00	0.00		0.29	0.75	0.00		0.00			1.00	0.11	0.00	0.00			0.20	0.27	0.30
	3			0.11		0.00	0.00		0.00	0.25	0.25		0.00			0.00	0.11	0.00	0.40			0.10	0.11	0.10
	total			0.89		1.00	1.00		1.00	1.00	1.00		1.00			1.00	1.00	1.00	1.00			0.96	0.92	0.98

Overall capture probability by pass		
	1	0.51
	2	0.25
	3	0.13
	total	0.89