Analysis of Fish Population Monitoring Data for Selected Waters of the Gila River Basin, Arizona, for the Five-year Period 1995-1999

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Introduction

The Central Arizona Project (CAP) canal and infrastructure was constructed by U.S. Bureau of Reclamation (Reclamation) to deliver Colorado River from Lake Havasu to users in the Gila River basin of central Arizona. The canal and its interconnected channels represent a potential conduit for the distribution within the system of nonindigenous fishes and other biota, and from the source to a suite of downstream sites. Because of this potential a U.S. Fish and Wildlife Service biological opinion (USFWS 1994) determined that the project would jeopardize four federally listed native fishes: loach minnow *Tiaroga cobitis,* spikedace *Meda fulgida*, razorback sucker *Xyrauchen texanus*, and Gila topminnow *Poeciliopsis occidentalis*, and adversely impact critical habitat of the first three species. A reasonable and prudent alternative of the biological opinion directed Reclamation to develop a long-term monitoring program for the CAP and interconnected regional canals, plus selected stream reaches in Arizona. The fundamental purpose of such monitoring is two-fold, to detect (1) new species and (2) long-term trends in the fish community relative to distribution and assemblage structure.

Standardized monitoring of fish communities in canals and streams began in 1995 under the auspices of a detailed plan (Clarkson 1996). The plan identifies six watercourses to be sampled: (1) the CAP aqueduct, (2) Salt River Project (SRP) canals, (3) Florence-Casa Grande (FCG) Canal, (4) Salt River between Stuart Mountain and Granite Reef dams, (5) Gila River between Coolidge and Ashurst-Hayden dams, and (6) perennial reaches of San Pedro River north of the U.S. and Mexico international boundary. Multiple reaches and stations within reaches are further defined within each stream. The plan specifies annual sampling and identifies parameters to be measured, repeatable methods, a standardized database, statistical methods for data analysis, and a schedule for data analysis and review. Procedural field manuals are offered as appendices to the plan.

Several investigators have discussed or attempted to evaluate the ability of the CAP monitoring plan to detect changes in fish community composition (Wilson 1996, Abarca and Allison 2000, Allison 2000). These assessments determined that only large-scale changes in community structure (species abundances) would be detected using the established protocol. This primarily was due to rarity of many species and extreme variability in catch data for others. Other factors include the broad geographical scope of the program, which makes it unrealistic to perform sampling adequate to produce the data required to detect statistical changes. Allison (2000: 12) concluded that trends of only two of 17 species examined, Sonora sucker *Catostomus insignis* and red shiner *Cyprinella lutrensis*, could be adequately described from data acquired under the standardized monitoring. Detection of new species would be serendipitous if rare, with the likelihood of an encounter increasing with increasing abundance and/or expanding spatial distribution.

This report documents fish distributions and assemblage structure, and presents results of a statistical analysis of fish community data derived from the CAP standardized monitoring program for the five-year period 1995 to 1999, as provided by Reclamation. The statistical analysis was appropriate despite constraints identified by earlier workers because the dataset was temporally expanded by an additional year (1999). For Gila, Salt and San Pedro river samples the analytical approach recommended by Allison (2000) was followed: analysis of co-variance (ANCOVA) that includes all reaches and a time-by-reach interaction term. Other statistical approaches were explored and recommendations are made to refine results and increase the ability to detect change. CAP, SRP Arizona, SRP South, and FCG canal data were not amenable to statistical analysis because of small sample sizes and extreme sample variation. Instead, these data were evaluated by inspection and graphical interpretation.

Methods

Sampling Reaches and Stations. Reclamation designated sample reaches and sample stations on major streams and canals (see Clarkson 1996 for complete descriptions, coordinate locations, and maps). One-to-four, fixed sample reaches were designated on three natural streams (Gila, Salt and San Pedro rivers) and four artificial watercourses (Central Arizona Project [CAP], Florence-Casa Grande [FGC], and Salt River Project

[SRP] Arizona and South canals (Clarkson 1996). Stream reaches were stratified to reflect variation in geomorphology (gradient and channel confinement) and/or hydrology (distribution of perennial surface flows), while canal reaches were based on established geopolitical divisions.

Stream reaches on San Pedro River were (1) Hereford to Fairbank, (2) Cascabel to Redington, (3) Aravaipa Creek to Gila River; on Gila River were (1) Coolidge Dam to Needles Eye, (2) Little Ash Creek to Hayden, (3) Hayden to Mineral Creek, and (4) Mineral Creek to Ashurst-Hayden Diversion Dam; and on Salt River was Stewart Mountain Dam to Granite Reef Diversion Dam. Canal reaches on CAP Canal were (1) Hayden Rhodes Aqueduct, (2) Fannin-McFarland Aqueduct, and (3) Tucson Aqueduct; on FGC Canal was Ashurst-Hayden Diversion Dam to Pima Lateral Feeder Canal; on SRP Arizona Canal were (1) Granite Reef Diversion Dam to electrical fish barrier and (2) electric fish barrier to Indian Bend Wash; and on SRP South Canal were Granite Reef Diversion Dam to electrical fish barrier and (2) electrical fish barrier to terminus.

Three, fixed sample stations (upper, middle, and lower) were designated within each stream reach (but not always available to sample) and on the FGC Canal. Fixed sample stations on the CAP Canal were immediately upstream and in the forebays of pumping plants at Bouse, Little Harquahala, and Hassayampa (Hayden Rhodes Aqueduct), Salt-Gila (Fannin-McFarland Aqueduct), and Brady, Red Rock and San Xavier (Tucson Aqueduct). Fixed stations were not designated on the SRP Arizona or South canals, where each reach was considered a station.

Fish Collection Methods. A suite of standard collection techniques was available to sample fishes in behalf of the CAP Monitoring Program, and these were applied as appropriate to the variety of habitats and situations represented by the various stream and canal reaches and stations (see Clarkson 1996). Backpack electrofishing was the standard for most stream sites, augmented by opportunistic seining. Deeper stream habitats were sampled with entrapment or entanglement gears, or by boat or barge-mounted electrofishers. CAP Canal reaches were sampled primarily with boat electrofishing, entanglement and entrapment devices (trammel and hoop nets, minnow traps), and angling (multiple-hook trot lines, rod and reel). FCG and SRP Arizona and South canals typically were sampled during drawdown periods when backpack electroshocker, seines, and dip nets were effective in shallow water. Deeper water was sampled with trammel or hoop nets at selected locations in all canals, and with boat-mounted electrofishing in accessible portions of the SRP Arizona Canal.

Stream Data Analysis. Each record in the comprehensive raw database file provided by Reclamation included an individual species catch (number) for a period of sampling. Station samples for each species were totaled so as to represent the complete sampling for that station for a given species and year (Table 1). Not all stations were sampled every year, and data that were non-quantitatively sampled or sampled with gear other than electrofishing were not included in the analysis because this lack of methodological standardization could lead to statistical results that were spurious, misleading, or incorrect. This left a total of 89 station samples from 1995 to 1999 that could be used in the analysis.

All species were coded using a 4-letter abbreviation for the species scientific name (Table 2). Species that were absent in the sample were not included in the original database, so additional zero data were added to reaches in which species were recorded for some but not all years. Only adult (age 1) data were included in the final analysis, except for five smaller species in which all ages were included: *Gambusia affinis*, *Agosia chrysogaster*, *Cyprinella lutrensis*, *Dorosoma petenense*, and *Pimephales promelas*. There were several reasons for exclusion of age 0 data from our analysis. First, age 0 data are highly variable from year to year. This is because of natural variation in recruitment, which results in large numbers of young in some but not all years, and because sampling does not always coincide with presence of young, which may be captured in abundance in some years but not encountered in others. Next, not all collections of young were quantitative, and there are several instances in the database where small fish were only described qualitatively (e.g., “they were abundant”). And, those recording quantitative data did not always discriminate between age 0 and older fish, making it impossible to correctly attribute age to those fish. Finally, the recommendation to exclude age 0 data was made by L. Allison (personal communication), another investigator with expertise in statistical analysis of these data sets.

Station counts for each year also were summed within reaches, and fourteen species were excluded from any statistical analysis because they contained fewer than 3 data points for a given reach or occurred in only one reach (Table 3). A species must have been represented by at least three data points for at least two reaches to establish a trend and make comparisons between reaches.

As recommended by Allison (2000), four Analysis of Covariance (ANCOVA) models were fitted for each species to detect trends in the data, as follow:

			Fixed factors	covariate	Interaction	
Model 1	count	=	reach	year	reach x year	+ error
Model 2	count	=	reach	year	-	+ error
Model 3	count	=	stream reach(stream)	year	stream x year	+ error
Model 4	count	=	stream reach(stream)	year	-	+ error

Stations within reaches were considered replicates. These models represent a hierarchy of tests to determine consistency in annual trends among rivers and reaches for each species.

Summed reach data were used to test for autocorrelation between years. Dummy coding was used to represent the eight reaches as regressors (seven dummy variables were created to represent all eight reaches; a dummy variable for each reach except reach one). Each reach was represented by one dummy variable being set to one and all other dummy variables set to zero. Setting all dummy variables to zero was used to represent reach one.

The dummy coded data were regressed in SPSS to test for first-order autocorrelation by generating the Durbin-Watson statistic for each species (Table 4). The Durbin-Watson statistic compares the sum of the error differences between data points that are next to each other, in this case one year to the next year for a given reach, with the sum of the errors. If the data are not auto-correlated this value should be near 2 (Durbin and Watson 1951). If the statistic is significantly greater than 2 then the data are negatively auto-correlated (e.g. a good year is followed by a bad year), and if the statistic is significantly less than 2 then the data are positively auto-correlated (e.g. a good year is followed by a good year). The calculated value is compared to a table that uses the number of regressors and sample size as entering variables. The Durbin-Watson statistic gives a rejection range, an acceptance range, and a questionable range for positive and negative autocorrelation. No provision or mechanism to correct for autocorrelation is provided by the Durbin-Watson statistic. Thus, an auto-regression coefficient and an estimate of its significance were calculated using the SPSS autocorrelation routine. This provides a value that can be used to correct for autocorrelation, and a test of whether this autoregression coefficient is significantly different from zero. If the autoregressor is significantly greater than zero, then the data are assumed to be significantly autocorrelated (Neter and Wasserman 1974).

Normality of the error terms and homogeneity of variance were tested within the ANCOVA model. The assumption of normality was not formally tested, but instead was assessed using Q-Q plots, which represent normally distributed data as a straight line, and assessment is based on the closeness of graphed data to a straight line (Sokal and Rohlf 1995). Transformation of the data was necessary and a log+1 transformation was used because it improved normality and homogeneity of variance for more species than square root or fourth root transformations. Allison (personal communication) recommended this transformation. Homogeneity of variance was tested using the Levene's Test, provided within the General Linear Model routine in SPSS.

Canal Data Analysis. As for streams above, each record for canals in the comprehensive raw database file provided by Reclamation included an individual species catch (number) for a period of sampling. Station samples for each species in each reach were totaled so as to represent the complete sampling for that reach for a given species and year. The CAP Canal was represented by three reaches (upper, middle and lower) and the FCG, SRP-Arizona and SRP-North canals each were represented by two reaches, one upstream of the electrical fish barrier and one downstream (Clarkson 1996). There are no electrical fish barriers on the CAP Canal. Not all stations were sampled every year on each canal, and the CAP Canal was not sampled during 1996; for all other years at least one station was sampled in each reach in each canal (Tables 5-8). All species were coded using a 4-letter abbreviation for the species scientific name (Table 2).

Canal data were not amenable to statistical analysis because of sporadic occurrence of many species among stations, reaches, and years (see zero data in Tables 5-8) and extreme temporal variance in abundance (catch), in some cases across three orders of magnitude and in many cases across two orders of magnitude. Instead, two bar graphs were constructed for each species in each canal. Sample year was the dependent variable in both graphs and the independent variables were total number of individuals captured and percentage of total catch. Data for CAP Canal reaches 1, 2 and 3 (Clarkson 1996) and for above and below the electrical fish barriers (FGC, SRP-Arizona, and SRP-South canals) were represented separately. These bar graphs accommodate interpretation of temporal changes in species abundance through the five-year sample period, and allow within-canal comparison of reaches (CAP Canal) and above/below electrical fish barriers (FCG, SRP-Arizona and SRP-South canals).

Results and Discussion

New Species Records. There were no species occurrences that documented new records for the Gila River basin during the five-year period 1995-1999. There were, however, a number of occurrences that were new to individuals sample stations within the CAP monitoring program. These are summarized below, along with corrections of erroneous information, alphabetically by Latin name.

Ameiurus melas black bullhead. AZ, Gila River at O'Carroll Canyon, station 2-2-3. 30 November 1999. N=1. Coll: AZGFD. Specimen was re-identified by W.L. Minckley (Arizona State University, Tempe) as *A. natalis* yellow bullhead.

Ameiurus melas black bullhead. AZ, CAP Canal at San Xavier Pump Plant, station 4-3-3. N=24. 07 November 1995. Coll R.W. Clarkson, USBR, Phoenix, AZ.

Carassius auratus goldfish. AZ, CAP Canal at San Xavier Pump Plant, station 4-3-3. N=1. 07 November 1995. Coll. R.W. Clarkson, USBR, Phoenix, AZ.

Dorosoma petenense threadfin shad. AZ, Gila River at Hayden, station 2-3-1. N=2. 10 November 1998. Coll: AZGFD.

Dorosoma petenense threadfin shad. AZ, Gila River below Coolidge Dam, station 2-1-1. N=1359. Coll: R.W. Clarkson, USBR, Phoenix, AZ.

Lepomis macrochirus bluegill. AZ, Gila River at Christmas, station 2-2-2. N=1. 30 November 1999. Coll: AZGFD.

Morone chrysops white bass. 09 November 1995. AZ, CAP Canal at Brady Pump Plant, station 4-3-1. N=1. Coll R.W. Clarkson, USBR, Phoenix, AZ.

Morone chrysops white bass. 10 November 1995. AZ, CAP Canal at Salt-Gila Pump Plant, station 4-2-1. N=1. Coll R.W. Clarkson, USBR, Phoenix, AZ.

Poecilia latipinna sailfin molly. AZ, Salt River 1 mile E of Blue Point Ranger Station, station 3-1-2. 10 November 1999. N=2. Coll: AZGFD.

Pomoxis nigromaculatus black crappie. October, November 1997; October, November 1998. AZ, Gila River below Coolidge Dam, stations 2-1-3 (Hook and Line Ranch), 2-2-1 (Dripping Spring), 2-2-2 (Deer Creek). N=13. Coll: AZGFD.

Pylodictus olivaris flathead catfish. AZ, San Pedro River at Charleston Bridge, near station 1-1-3. 20 November 1995. N=1. Coll: Angling by J.J. Swift, BLM. Reported by M. Fredlake, BLM, Sierra Vista, AZ via S. Stefferud, FWS, Phoenix, AZ per telecom record 22 November 1995.

Stream Data. Twenty-four fish taxa were encountered among the three natural streams sampled, including hybrid suckers, *Catostomus insignis x Pantosteus clarki*, and hybrid sunfishes, crosses of undetermined parentage among the several members of the genus *Lepomis* (Tables 1 and 4). Eleven taxa were taken from San Pedro River and 17 each from Gila and Salt rivers. Five taxa are native to the Gila River basin, *Agosia chrysogaster, Gila robusta, Catostomus insignis, Pantosteus clarki*, and the sucker hybrid; the remainder are species introduced from Africa, Asia, and eastern and northwestern United States. Although there was much variation among streams, reaches, and stations, native *Agosia chrysogaster* overall was the most abundant species, followed by non-native *Cyprinella lutrensis* and *Gambusia affinis.*

Three of 11 species collected in San Pedro River were found in all five sample years, four were found in four years, two in three years, and one each in two and one year. Five of the 11 species were taken from all three reaches, three were in two reaches, and three were from one reach. There was much variation in abundance among years. *Agosia chrysogaster* was the most abundant taxon in four of five years, and *Pantosteus clarki* was most abundant in the fifth, although the last species was generally less common and consistently exceeded in abundance by *Gambusia affinis* in other years. *Cyprinella lutrensis, Lepomis cyanellus,* and *Pimephales promelas* were common in most years, while other taxa generally were uncommon-to-rare and sporadic in occurrence.

Four of 17 species collected in Gila River were found in all five sample years, four were found in four years, three in two years, four in two years, and two in only one year. More than half the taxa (nine of 17) were taken from all four reaches, one was in three reaches, and four each were in two and one reach. There was substantial variation in abundance among years. *Cyprinella lutrensis* was the most abundant species in all five years, followed in two years by *Catostomus insignis* and in one year each by *Agosia chrysogaster, Pantosteus clarki*, or *Gambusia affinis*. *Ameiurus natalis, Cyprinus carpio, Dorosoma petenense,* and *Lepomis cyanellus* were common in some years, uncommon-to-rare in others. The remaining species generally were sporadic in occurrence and few in number.

Three of 17 species collected in Salt River were found in all five sample years, three were found in four years, one in three years, four species were found in two years, and six were taken only in one year each. There were no assemblage comparisons among reaches because there was only one reach. Total catch generally was small, likely a reflection of the gears deployed in this stream, which favored capture of large-bodied fishes. There was considerable variation among years in relative abundances, and no one species showed clear predominance among samples. *Catostomus insignis* was the most abundant taxon in three of five years and *Pantosteus clarki* and *Gambusia affinis* was predominant in one year each. And one of these three species was second in abundance each year except one, when *Micropterus salmoides* and *Tilapia aurea* shared that distinction. Other species were sporadic in occurrence and generally were uncommon-to-rare.

Two species, *Agosia chrysogaster* and *Pantosteus clarki*, had significant annual trends that were consistent among reaches and rivers (Table 4). This trend was negative for both species, resulting in decreasing abundance from 1995 to 1999 (Figure 1). Significant interaction terms for *Gambusia affinis* resulted in no consistent annual trend, and *Gambusia affinis* abundances in each stream appear to be moving in different directions (Figure 2). A significant interaction between reach and year but not stream and year for *Cyprinella lutrensis* indicates that reaches within streams are trending in different directions, but the Gila River is the only river in which the species occurred in more than one reach (Figure 3). Annual trends for other species (Appendix A, Figures. A1-A36) were not significantly different from zero. However, the significance of the results is affected by heteroscedasticity and autocorrelation, and the slope and direction of the trend is affected by the transformation of the data and the measure of abundance used.

The ANCOVA model proved to be an ill fit for the data with numerous assumption violations across all species. Three species, *Dorosoma petenense, Ameiurus melas*, and *Pantosteus clarki*, have a significant auto-correlation coefficient, and all other species except *Ameiurus natalis* are within the questionable bounds (between the lower and upper limits) of the Durbin-Watson statistic at a 5% significance level (Durbin and Watson 1951). In addition, significant results from the Levene's Test for all but three or four species (depending on the ANCOVA model) demonstrated that the assumption of homogeneity of variance was habitually violated. *Micropterus salmoides, Cyprinella lutrensis*, and *Gambusia affinis* never failed the assumption test and *Ameiurus natalis* failed only once. However, the test only provides proof of a significantly non-homogenous data set; data sets that pass the test can still be non-homogenous.

In general, ANCOVA is used to correct for a known covariate, not to test for the significance of the covariate (Sokal and Rohlf 1995). In fact, a significant result in the ANCOVA for the covariate (year) does not mean there is a good fit between year and log+1 counts. For example, *Pantosteus clarki* showed a significant result for a yearly trend with no interaction, and yet only 11% of the variation is explained by this relationship (r^2 from the ANCOVA). Although there may be a real trend in abundance over time (i.e. a relationship between year and abundance), the amount of background variation or noise is high relative to this variation. This is similar to the conclusions of Allison (2000).

A third problem arises from the use of actual catch data. Two species, *Agosia chrysogaster* and *Pantosteus clarki*, showed significant year trends in the ANCOVA results with no interaction between reaches or streams. However, there was a strong general decline in catch for all species in the San Pedro River (Figure 4), but not for the Gila River or Salt River. To examine how this may influence the trend analysis, raw counts were converted into relative abundances (proportions of total catch). Relative abundance trends were markedly different than the log+1 count data with a negligible decline for *Agosia chrysogaster* and a rise for *Pantosteus clarki* in the San Pedro River (Figure 5). Trends in the other two rivers remained similar.

Another problem arises from the log+1 transformation of the raw counts to improve normality. While this transformation did improve normality, it also created a fourth problem in interpreting the results of the ANCOVA. For example, log+1 transformed data for *Cyprinella lutrensis* show a decreasing trend in the Gila River, but the actual raw counts show an increasing trend (Figure 6). This difference is due to the number of zeros in the data and the log+1 transformation. If two stations had 20 fish in one year, but in the next year one station had 120 and the other had 0, the average change would be an increase, but the log+1 average results in a decrease (raw count average, 20 to 60 and log+1 average, 1.3 to 1.0). Station averages for each reach are what the ANCOVA model uses to assess trends, and so trends can be reversed by the log+1 transformation.

The use of relative abundance data is an alternative approach, which solves the last two problems, but the data are neither normally distributed nor homoscedastic, and thus are not amiable to standard statistical procedures. Graphically analyzing relative abundance changes over time for each species would be tedious and uninformative.

A fundamental problem with analyzing this data set is that no specific hypotheses have been developed. Statistically analyzing data and then looking for trends is problematic even with normal, homoscedastic data. If twenty species are run through any statistical procedure, one of those species is likely to have a significant result just by chance (if alpha = 0.05). This problem can be corrected by using an adjustment to the alpha value (e.g., Bonferroni's inequality; Feller 1950), just as all the other problems have adjustments or corrections, but power is lost with each correction. Given the number of adjustments required for the current data set, the amount of variability in the data, and the lack of replication, the ANCOVA model is an inadequate model to detect trends. All the current problems in the data set will remain as long as more specific hypotheses are not generated. Therefore, the best use of this data set is to develop hypotheses that will reduce the number of analyses that are required in the future, which will improve trend detection.

As an example of future directions we address the question as to whether stations are useful as replicates for estimating the abundance of species within a reach. One problem addressed in a previous report is that variation among replicates was high, and that this large variation could mask important trends in abundance (Allison 2000). This was true for single species, but by treating species abundances as variables a multivariate approach that characterizes each station by the abundance of all species may reduce the variation within a reach, which would increase our ability to detect trends. When the ANCOVA approach is used, a reach is characterized both by the average catch for all stations within the reach and by the variation among those stations for a single species. Using a multivariate approach, each station is characterized by the catch of all species that were caught at that station and their abundances. Thus, even though station abundances of a certain species may vary substantially within a reach, the composition and abundance should be similar for all species caught among all stations within a reach. Further, using 13 species to characterize a station improves the chances that stations within the same reach will be grouped together and the reach composition can be discriminated from other reaches, and also discriminated from the same reach from a different year if there is a change in composition over time. The operative concept here is that reaches in the same stream may have different compositions, but variability in the catch data is so high across samples that separation of reaches becomes impossible. Thus, if reaches cannot be statistically separated, it is difficult to envision any analytical approach that will be successful in detecting trends over time within or among reaches.

A simple example of this approach uses Non-metric Multi-Dimensional Scaling (Rencher 2002). This approach uses a measure of distance between two sites in multidimensional space. The number of dimensions is the number of variables used to characterize each site. In this case the same 13 species were used as in the ANCOVA approach. The Bray-Curtis Dissimilarity index for Log+1 abundances (Legendre and Legendre 1998) was selected among the many different measures of distance that can be used. The log+1 transformation reduces the influence of abundant species and the Bray-Curtis Dissimilarity is not influenced by zero abundances. The multivariate space is then compacted into two-dimensions, while an attempt is made to keep measures of distance between sites the same. Since this is a non-metric scaling, the process attempts to maintain the rankings of the distances between sites instead of the actual distances.

In a principal components analysis (PCA) the x and y-axes represent values of new variables or factors that are linear combinations of the original variables. These factors are orthogonal and independent, and it therefore is valid to display the scores of these new factors for each replicate in a bi-plot. However, with multidimensional scaling (MDS), the x and y-axes are not “real” in the sense that they may not be orthogonal or independent. The goal of MDS is to maintain a true representation of distance between points. Because it is impossible in this study to graph the stations in thirteen-dimensional space (the number of dimensions equals the number of variables, which is equal to the number of species used in the analysis), the MDS compacts the number of dimensions into a few as requested, in this case two, while attempting to maintain the distance measurements. Two dimensions was chosen for this example because this is most easily grasped. There are measured of “fit” for the two dimensional bi-plot that relate how well the bi-plot represents the reality of actual distances measurements, but for sake of clarity these are not included. Data from 1998 and 1999 were used to demonstrate the technique.

The data for 1998 and 1999 show that for some reaches - reach 1 in 1998 and 1999, reach 3 in 1998, reach 4 in 1998, reach 6 in 1998, and reach 7 in 1999 - the variability in species composition between stations is nearly as high as the variation among reaches within a river system (Figure 7). This suggests that stations make poor sampling units even on a multivariate scale and that habitat distribution or other environmental measures should be adopted to increase precision in estimates. This approach is likely impractical without substantial expansion of the monitoring program (Wilson 1996, Allison 2000) and it is uncertain what if any additional benefit might be derived. Further examination of the original data would result in further insights into the causes of the variation, and if environmental data were available, they may also be used to assess how future sampling should be conducted.

Canal Data. No statistical treatment was applied to canal data in attempts to ascertain temporal trends in species abundances. Instead, bar graphs were constructed and evaluated by objective graphical interpretation.

Ten of 15 species encountered in the CAP Canal were found in all years, three species were found in three years, one species was found in two years, and one was found only once (Table 5). Seven of the 15 species were taken from all three reaches, five were in two reaches, and three were from one reach. The most abundant taxon was *Lepomis macrochirus,* followed respectively by undetermined *Lepomis, L. cyanellus, Cyprinella* *lutrensis, Dorosoma petenense, L. microlophus, Cyprinus carpio,* and *Micropterus salmoides.* Generally, the most abundant taxa (cyprinids and centrarchids) were found in all years and in all reaches, while less abundant species were absent from one or more samples and from one or two reaches (Table 5). Catch varied among years but was consistently highest in the lowermost reach as a result of large catches of *Lepomis spp.* No consistent, monotone temporal trends in capture total or proportion of total catch could be identified for any species in any reach (Appendix B, Figures. B1-B15). Catch likely varied in response to vagaries of sampling and local differences in availability (or abundance), but do not necessarily reflect actual population abundances.

Two of 12 species encountered in the FGC Canal were found in all years, two species were found in four years, four species was found in three years, one species was found in two years, and three species were found only once each (Table 6). Ten species were found both above and below the electric fish barrier; two fishes, *Lepomis cyanellus* and *L. macrochirus,* each encountered only once, were only in the reach below the barrier. The most abundant species, *Cyprinella lutrensis,* was found during all years; the next most abundant fish, *Gambusia affinis*, was absent from samples during 1995. *Pantosteus clarki* and *Ictalurus punctatus* were the next two most abundant fishes, respectively, while other species were less common by an order of magnitude. No consistent, monotone temporal trends in capture total or proportion of total catch could be identified for any species in any reach (Appendix C, Figures. C1-C12). Catch likely varied in response to vagaries of sampling and local differences in availability (or abundance), but do not necessarily reflect actual population abundances.

Nearly half, 12 of 25 species, encountered in the SRP Arizona Canal were found in all years, two species were found in four years, four species were found in three years, four species were found in two years, and three species were found only once each (Table 7). Most species (18) were found both above and below the electric fish barrier. Three fishes, *Ictiobus cyprinellus, Micropterus dolomieui,* and *Stizostedion vitreum* were only in the reach above the barrier and four others, *Agosia chrysogaster, Carassius auratus, Gambusia affinis,* and *Lepomis microlophus* were found only below the barrier.

Undetermined *Tilapia* was the most abundant taxon, followed respectively by *Pantosteus clarki, Cyprinella lutrensis, Ictalurus punctatus, Catostomus insignis, Oncorhynchus mykiss, Micropterus salmoides, Gila robusta, Cyprinus carpio, Pylodictus olivaris, Tilapia zilli, Morone mississippiensis,* and *Ctenopharyngodon idella*. Species abundances varied greatly over the 5-year period and no consistent, monotone temporal trends in capture total or proportion of total catch could be identified for any species in any reach (Appendix D, Figures. D1-D25). Catch likely varied in response to vagaries of sampling and local differences in availability (or abundance), but do not necessarily reflect actual population abundances.

Ten of 25 species encountered in the SRP South Canal were found in all years, two species were found in four years, four species were found in three years, three species were found in two years, and six species were found only once each (Table 8). Most species (16) were found both above and below the electric fish barrier. Two taxa, "hybrids" and *Morone mississippiensis* were only in the reach above the barrier, while seven others, *Agosia chrysogaster, Ameiurus natalis, Gambusia affinis, Lepomis cyanellus, Morone saxatilis, Pomoxis nigromaculatus, and Tilapia zilli* were found only below the barrier. Undetermined *Tilapia* was the most abundant taxon, followed respectively by *Cyprinella lutrensis, Pantosteus clarki, Catostomus insignis, Ictalurus punctatus, Gila robusta, Micropterus salmoides,* and *Tilapia aurea* Species abundances varied greatly over the 5-year period and no consistent, monotone temporal trends in capture total or proportion of total catch could be identified for any species in any reach (Appendix E, Figures. E1-E25). Catch likely varied in response to vagaries of sampling and local differences in availability (or abundance), but do not necessarily reflect actual population abundances.

Conclusion and Recommendations

The above discussion of constraints and limitations notwithstanding, results of the monitoring program are important for reasons other than detecting trends in fish populations. Most significantly, standardized collections contribute to a storehouse of reliable baseline data against which to assess and measure future changes in the fish community. Such changes may accrue as a result of introduction and establishment of novel species, some other perturbation, or for other reasons, whether related or not to the Central Arizona Project. In fact, in the final analysis, it may not be possible to attribute a trend in fish abundance or a change in community composition, even if significant and dramatic, to the Central Arizona Project. Nonetheless, demonstration of change is critical if a prerequisite to a management response by resource agencies.

Finally, uncertainties and limitations that were evident in this and previous studies are results in part of inherent characteristics of the data and practicalities of sampling logistics. The Central Arizona Project standardized fish monitoring program acquires sample date from only a few, short stream (or canal) reaches (sites) of large systems over a broad geographic area. Habitat and other variations are great over the landscape, and sometimes even over relatively short distances, and acquiring representative samples is difficult, at best. Species richness (number of taxa) often is low, with some species collected only at some sites and only in some years. More importantly, individual sample sizes (number of fish) are highly variable in space and time, but often are small, even for species with large relative abundance. Stochastic unpredictability and high variation are recognized characteristics of stream environments and fish communities throughout the arid southwest, and long have been recognized as confounding factors when analyzing sample data (e.g., Meffe and Minckley 1987, Velasco 1997). Results of our analysis are consistent with this paradigm.

We offer two recommendations to improve the quality and utility of data acquired under the monitoring program, and provide justification for each suggestion.

First, ensure that a sample is acquired each year from each reach and each station, unless such sampling would result in a hazard to equipment or personal safety. This may require making collections during adverse conditions such as inclement weather or higher than anticipated discharge. The reason is to provide a more complete database for evaluation and analysis by avoiding zero or “no-data” entries, which weaken the overall design.

Next, an attempt should be made at each sample station to deploy at least one gear appropriate to collection of both of large- and small-bodied fishes, especially at natural stream sites. Boat electrofishing, trammel, gill, and hoop nets, or angling generally capture only larger individuals and are inadequate for collection of small-bodies fishes, while back-pack electroshocking, seines, and minnow traps sample small fishes but do not collect larger ones. This is because failure to use both kinds of gears can result in size-based, species bias such that some taxa and/or their relative abundance may not be represented.

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Table 1. Sampling scheme for detecting trends in species abundance.

Stations Sampled

	San Pedro River			Gila River				Salt River
Reach	upstream	middle	downstream	upstream	upper middle	lower middle	downstream	downstream
1995	1,2,3	1,2	1,2,3	1,3(nq)	1(ne),3(ne)	none	1,2(nq),3	1,3
1996	1,2,3	1,2	1,2,3	none	none	none	2	1,2
1997	1,2,3	1,2	1,2,3	1,3	1,2,3	1,2,3	1,2,3	1,2,3
1998	1,2,3	1,2	1,2,3	1,3	1,2,3	1,2,3	2,3	1,2,3
1999	1,2,3	1,2	1,2,3	1,3	1,2,3	1,2,3	1,2,3	1,2,3

nq = nonquantitative sample
ne = nonelectrofishing sample

# of Stations for Analysis

	San Pedro River			Gila River				Salt River
Reach	upstream	middle	downstream	upstream	upper middle	lower middle	downstream	downstream
1995	3	2	3	1	none	none	2	2
1996	3	2	3	none	none	none	1	2
1997	3	2	3	2	3	3	3	3
1998	3	2[c]	3[a]	2	3	3	2	3
1999	3	2	3	2	3	3[b]	3	3

[a] Only yoy taken quantitatively and others taken nonquantitatively for station 1
[b] Station 3 listed without any fish caught
[c] Station 2 listed without any fish caught

Table 2. Four-letter species codes used throughout this report and the scientific names they represent.

Code	Species
AGCH	*Agosia chrysogaster*
AMME	*Ameiurus melas*
AMNA	*Ameiurus natalis*
CAIN	*Catostomus insignis*
CYCA	*Cyprinus carpio*
CYLU	*Cyprinella lutrensis*
DOPE	*Dorosoma petenense*
GAAF	*Gambusia affinis*
GIRO	*Gila robusta*
HYBR	hybrid CAIN x PACL
ICPU	*Ictalurus punctatus*
LECY	*Lepomis cyanellus*
LEMA	*Lepomis macrochirus*
LEMI	*Lepomis microlophus*
LEPO	undet. *Lepomis*
MISA	*Micropterus salmoides*
ONMY	*Oncorhynchus mykiss*
PACL	*Pantosteus clarki*
PIPR	*Pimephales promelas*
PONI	*Pomoxis nigromaculatis*
PYOL	*Pylodictus olivaris*
RACA	*Rana catesbeiana*
RANA	undet. *Rana sp.*
RAYA	*Rana yavapaiensis*
STVI	*Stizostedion vitreum*
TILA	undet. *Tilapia*
TIZI	*Tilapia zilli*

Table 3. Total counts of species for all reaches sampled from 1995-1999. Reaches 1-3 are from the San Pedro River, reaches 4-7 are from the Gila River, and reach 8 is from the Salt River. Shaded columns indicate species that were not used in the trend analysis. Zero data were added for reaches in which a species had been sampled in other years within that reach, and x's are used to indicate reaches where a species was never detected and therefore the reach was excluded from analysis for that species. Reaches that were not sampled or non-quantitatively sampled are excluded from this table.

Year	Reach	AGCH	AMME	AMNA	CAIN	CYCA	CYLU	DOPE	GAAF	GIRO	HYBR	ICPU	LECY	LEMA	LEMI	LEPO	MISA	ONMY	PACL	PIPR	PONI	PYOL	STVI	TILA	TIZI	RACA	RANA	RAYA
95	1	216	15	0	x	x	x	x	212	x	x	x	13	x	x	x	0	x	18	94	x	x	x	x	x	1	0	x
	2	1734	x	x	x	x	x	x	609	x	x	x	0	x	x	x	x	x	0	0	x	x	x	x	x	x	x	0
	3	8202	1	0	1	0	0	x	677	x	x	x	0	x	x	x	x	x	1	1	x	x	x	x	x	0	x	x
	4	4	x	0	0	0	3	0	0	x	0	0	0	0	x	0	0	x	5	2	0	0	x	x	x	x	x	x
	7	64	x	1	3	0	76	0	0	x	x	0	0	x	x	x	x	x	16	x	x	x	x	x	x	x	x	x
	8	x	x	3	17	3	x	x	3	0	0	1	1	3	0	x	13	1	16	x	0	x	2	0	0	x	x	x
96	1	29	38	0	x	x	x	x	256	x	x	x	24	x	x	x	0	x	94	39	x	x	x	x	x	0	0	x
	2	148	x	x	x	x	x	x	22	x	x	x	0	x	x	x	x	x	0	0	x	x	x	x	x	x	x	1
	3	1839	0	3	18	0	99	x	30	x	x	x	1	x	x	x	x	x	247	0	x	x	x	x	x	0	x	x
	7	2	x	5	24	4	52	0	0	x	x	1	1	x	x	x	x	x	40	x	x	x	x	x	x	x	x	x
	8	x	x	0	3	0	x	x	0	0	x	0	0	0	0	x	1	0	31	x	0	x	0	0	0	x	x	x
97	1	70	1	2	x	x	x	x	133	x	x	x	5	x	x	x	7	x	9	39	x	x	x	x	x	4	6	x
	2	61	x	x	x	x	x	x	5	x	x	x	0	x	x	x	x	x	0	2	x	x	x	x	x	x	x	0
	3	10	0	0	0	0	52	x	23	x	x	x	0	x	x	x	x	x	0	3	x	x	x	x	x	1	x	x
	4	0	x	1	16	72	96	138	13	x	0	0	4	0	x	0	5	x	10	0	0	1	x	x	x	x	x	x
	5	6	0	5	122	88	94	x	0	x	x	3	7	x	x	x	9	x	48	x	0	x	x	x	x	x	x	x
	6	4	x	3	28	10	54	0	3	x	x	0	8	0	x	x	x	x	20	2	x	x	x	x	x	x	x	x
	7	0	x	3	8	1	59	0	50	x	x	1	0	x	x	x	x	x	51	x	x	x	x	x	x	x	x	x
	8	x	x	3	69	5	x	x	127	0	0	1	4	0	1	x	37	0	74	x	0	x	0	0	1	x	x	x
98	1	191	28	0	x	x	x	x	150	x	x	x	6	x	x	x	1	x	92	7	x	x	x	x	x	0	0	x
	2	624	x	x	x	x	x	x	0	x	x	x	1	x	x	x	x	x	1	6	x	x	x	x	x	x	x	0
	3	51	0	0	1	1	58	x	11	x	x	x	0	x	x	x	x	x	4	0	x	x	x	x	x	0	x	x
	4	0	x	1	24	9	47	3	9	x	0	9	74	0	x	3	5	x	0	0	0	7	x	x	x	x	x	x
	5	0	0	16	189	58	37	x	0	x	x	6	8	x	x	x	8	x	63	x	1	x	x	x	x	x	x	x
	6	10	x	21	8	16	105	2	64	x	x	2	3	2	x	x	x	x	11	0	x	x	x	x	x	x	x	x
	7	0	x	5	2	0	51	2	109	x	x	1	0	x	x	x	x	x	15	x	x	x	x	x	x	x	x	x
	8	x	x	4	41	23	x	x	37	0	0	0	6	0	3	x	27	0	32	x	1	x	0	4	0	x	x	x
99	1	29	0	15	x	x	x	x	66	x	x	x	0	x	x	x	0	x	20	0	x	x	x	x	x	0	0	x
	2	1177	x	x	x	x	x	x	0	x	x	x	0	x	x	x	x	x	0	0	x	x	x	x	x	x	x	0
	3	127	0	0	0	0	52	x	10	x	x	x	0	x	x	x	x	x	3	0	x	x	x	x	x	0	x	x
	4	0	x	4	0	7	226	18	258	x	1	1	23	1	x	0	8	x	0	0	1	3	x	x	x	x	x	x
	5	2	1	11	32	24	815	x	387	x	x	6	1	x	x	x	11	x	0	x	0	x	x	x	x	x	x	x
	6	0	x	2	0	0	27	0	57	x	x	0	0	0	x	x	x	x	0	0	x	x	x	x	x	x	x	x
	7	1	x	4	7	11	8	0	152	x	x	0	0	x	x	x	x	x	0	x	x	x	x	x	x	x	x	x
	8	x	x	3	54	3	x	x	0	1	1	0	12	5	0	x	31	0	3	x	0	x	0	31	0	x	x	x

Table 4. Results of assumption tests and ANCOVA results for log transformed count data on 13 species that were sampled from 8 reaches in the San Pedro, Gila, and Salt rivers. Significance level for all tests was 0.05. Species codes as in Table 2. See Myers (1990) for a description of the autoregressor statistic (rho).

Statistic	AGCH	AMME	AMNA	CAIN	CYCA	CYLU	DOPE	GAAF	ICPU	LECY	MISA	PACL	PIPR
n	30	13	28	25	24	20	12	35	20	35	16	35	22
k (no of regressors)	7	3	7	6	6	5	3	8	5	8	4	8	5
Durbin-Watson	1.727	3.254	2.084	2.320	2.565	2.030	3.093	2.116	2.592	1.661	2.466	2.686	1.119
Autoregressor (rho)	0.164	-0.681	-0.053	-0.185	-0.309	-0.468	-0.916	-0.093	-0.397	0.227	-0.243	-0.395	0.411
estimated prob	0.418	0.028	0.820	0.450	0.205	0.095	<0.001	0.656	0.163	0.286	0.450	0.042	0.132
homogeneity	0.005	<0.001	0.047	0.002	<0.001	0.233	0.001	0.993	0.043	<0.001	0.512	0.001	<0.001
reach*year	0.114	0.225	0.687	0.297	0.694	0.036	0.896	<0.001	0.367	<0.001	0.578	0.769	0.145
homogeneity	0.002	<0.001	0.173	<0.001	<0.001	Skip*	0.001	Skip*	0.007	Skip*	0.620	0.025	0.000
reach	<0.001	0.001	0.018	<0.001	0.001		0.002		0.015		<0.001	0.020	0.032
year	0.003	0.092	0.343	0.286	0.995		0.582		0.672		0.098	0.003	0.057
homogeneity	0.002	<0.001	0.134	0.001	<0.001	0.121	0.001	0.998	0.010	<0.001	0.512	0.003	<0.001
stream*year	0.692	0.362	0.909	0.214	0.821	0.303	NA	<0.001	0.241	0.051	0.378	0.218	0.818
homogeneity	0.002	<0.001	0.173	<0.001	<0.001	0.211	0.001	Skip*	0.007	<0.001	0.620	0.025	<0.001
Stream	<0.001	0.253	0.005	<0.001	0.006	0.418	NA		0.080	0.030	<0.001	0.219	0.294
Reach(Stream)	0.011	<0.001	0.361	0.006	0.004	0.383	0.002		0.018	<0.001	0.919	0.013	0.025
Year	0.003	0.092	0.343	0.286	0.995	0.311	0.582		0.672	0.641	0.098	0.003	0.057

(yellow) A significant result of the ANCOVA model.
(red) A significant violoation of an assumption of ANCOVA.
* statistical tests for main effects were skipped if the species had a significant interaction term.

Table 5. Reach totals for all species captured during surveys in the Central Arizona Project (CAP) Canal from 1995-1999. Totals include young of year and adult individuals.

		Species														
Year	**Reach**	AMME	AMNA	CAAU	CTID	CYCA	CYLU	DOPE	ICPU	LECY	LEMA	LEMI	LEPO	MISA	MOCH	MOSA
1995	1	0	0	0	0	1	0	126	16	0	1	1	0	8	0	20
	2	0	0	0	0	5	1	0	2	0	4	0	0	31	9	2
	3	16	5	6	16	10	26	2	0	386	340	100	8	33	1	5
1997	1	0	0	0	20	12	2	0	13	0	2	0	0	36	0	38
	2	0	0	0	0	7	0	0	3	0	6	0	0	0	0	7
	3	1	2	0	0	0	11	56	0	41	376	39	0	5	0	2
1998	1	0	0	0	2	10	0	0	3	1	4	1	38	6	0	6
	2	0	0	0	2	56	1	0	2	0	1	0	0	2	0	5
	3	0	0	1	7	36	10	1	1	0	246	20	0	9	0	2
1999	1	0	0	0	19	6	205	0	3	6	32	0	30	5	0	6
	2	0	0	0	9	6	0	0	2	0	0	0	0	2	0	2
	3	4	0	2	6	38	3	11	0	0	18	32	574	11	0	1
	Total	21	7	9	81	187	259	196	45	434	1030	193	650	148	10	96

Table 6. Reach totals, above and below the electrical fish barrier, for all species captured during surveys in the Florence-Casa Grande (FCG) Canal from 1995-1999. Totals include young of year and adult individuals.

		Species											
Year	**Reach**	AGCH	AMNA	CAIN	CYCA	CYLU	DOPE	GAAF	ICPU	LECY	LEMA	PACL	PIPR
1995	above	0	0	0	3	0	0	0	3	0	0	3	0
	below	0	0	27	5	6	0	0	3	0	0	220	0
1996	above	0	1	1	0	28	0	55	10	0	0	12	2
	below	5	1	1	1	251	13	34	0	2	1	3	19
1997	above	1	5	1	0	4	0	21	2	0	0	0	0
	below	0	9	0	0	235	0	30	42	0	0	24	0
1998	above	0	23	4	8	118	7	19	53	0	0	0	0
	below	2	1	4	1	412	2	48	6	0	0	0	0
1999	above	0	0	0	0	49	0	67	55	0	0	0	0
	below	0	0	0	0	138	0	56	8	0	0	0	0
	Total	8	40	38	18	1241	22	330	182	2	1	262	21

Table 7. Reach totals, above and below the electrical fish barrier, for all species captured during surveys in the SRP Arizona Canal from 1995-1999. Totals include young of year and adult individuals.

		Species																								
Year	**Reach**	AGCH	CAAU	CAIN	CTID	CYCA	CYLU	DOPE	GAAF	GIRO	ICCY	ICPU	LECY	LEMA	LEMI	MIDO	MISA	MOMI	ONMY	PACL	PONI	PYOL	STVI	TIAU	TILA	TIZI
1995	above	0	0	288	0	155	15	17	0	1	1	274	0	2	0	0	30	37	167	601	0	23	0	0	0	0
	below	0	1	24	5	1	1250	0	18	1	0	1	1	1	0	0	5	0	1	71	1	1	0	2	0	0
1996	above	0	0	147	1	8	9	0	0	31	0	232	1	7	0	1	84	0	46	474	4	15	2	45	0	0
	below	0	0	95	11	2	3	0	0	2	0	2	0	0	1	0	3	0	1	270	0	0	0	4	0	1
1997	above	0	0	193	0	12	0	0	0	10	0	334	0	14	0	0	133	37	62	189	2	10	17	0	300	0
	below	4	1	82	104	50	413	0	0	12	0	12	1	9	0	0	17	3	3	768	0	2	0	4	0	4
1998	above	0	0	302	2	38	392	2	0	244	2	398	2	4	0	0	41	2	60	418	0	110	0	0	3297	231
	below	0	0	126	12	0	500	0	0	0	0	0	0	0	0	0	0	0	0	111	0	0	0	0	0	0
1999	above	0	0	89	1	10	0	13	0	18	0	267	1	1	0	1	44	91	56	121	1	99	0	0	454	0
	below	0	0	34	1	8	13	1	0	0	0	1	1	0	0	0	4	0	1	3	0	0	0	0	1	0
	Total	4	2	1380	137	284	2595	33	18	319	3	1521	7	38	1	2	361	170	397	3026	8	260	19	55	4052	236

Table 8. Reach totals, above and below the electrical fish barrier, for all species captured during surveys in the SRP South Canal from 1995-1999. Totals include young of year and adult individuals.

		Species																							
Year	**Reach**	AGCH	AMNA	CAIN	CTID	CYCA	CYLU	DOPE	GAAF	GIRO	HYBR	ICPU	LECY	LEMA	MIDO	MISA	MOMI	MOSA	ONMY	PACL	PONI	PYOL	STVI	TIAU	TILA	TIZI
1995	above	0	0	150	2	327	0	0	0	22	0	155	0	8	1	3	10	0	0	276	0	4	17	0	16	0
	below	0	0	80	10	0	543	4	0	3	0	0	0	6	0	1	0	0	1	135	0	0	0	0	0	0
1996	above	0	0	94	0	12	32	0	0	7	0	177	0	9	1	21	4	0	0	479	0	3	4	174	0	0
	below	6	0	31	8	4	1078	22	49	6	0	7	0	1	1	12	0	0	0	131	1	1	1	3	0	0
1997	above	0	0	59	0	16	358	0	0	18	0	278	0	4	0	17	0	0	0	322	0	0	8	0	115	0
	below	0	0	36	5	3	105	0	0	4	0	6	0	0	0	12	0	0	2	242	0	6	0	0	0	4
1998	above	0	0	527	0	75	4	20	0	498	0	223	0	17	0	67	2	0	0	129	0	10	0	0	2979	0
	below	0	0	171	29	10	511	0	11	47	0	48	10	10	0	16	0	0	0	254	0	4	0	0	0	63
1999	above	0	0	62	0	27	0	0	0	20	1	64	0	2	1	15	0	0	8	18	0	5	0	0	920	0
	below	0	5	113	4	0	23	1	0	65	0	9	3	3	0	14	0	1	0	47	0	3	0	0	15	0
	Total	6	5	1323	58	474	2654	47	60	690	1	967	13	60	4	178	16	1	11	2033	1	36	30	177	4045	67

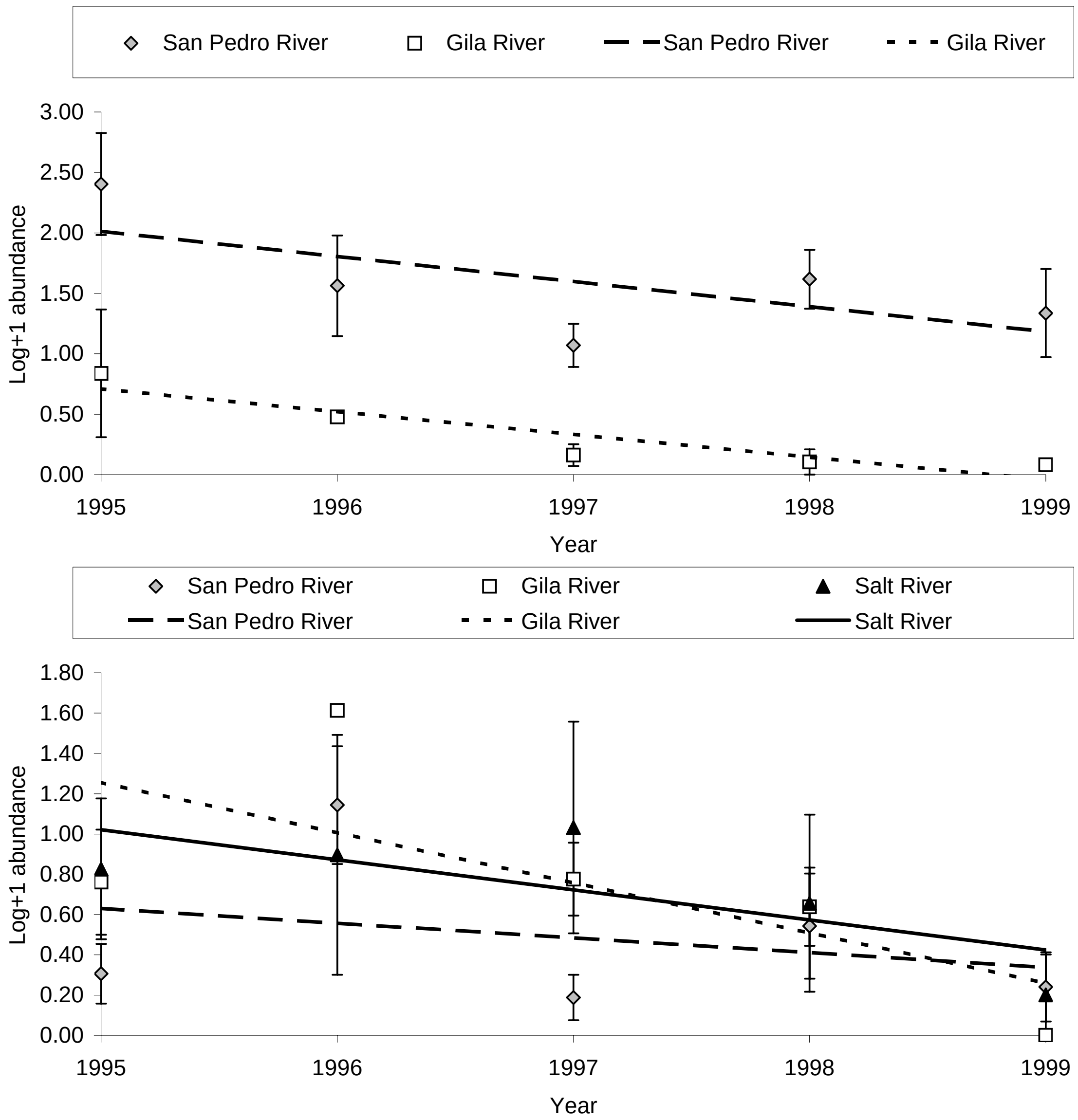


Figure 1. Catch trends for *Agosia chrysogaster* (top) and *Pantosteus clarki* (bottom). Each point represents the average of all stations within a stream for a given year with error bars representing one standard error. Trend lines are fitted to the point values.

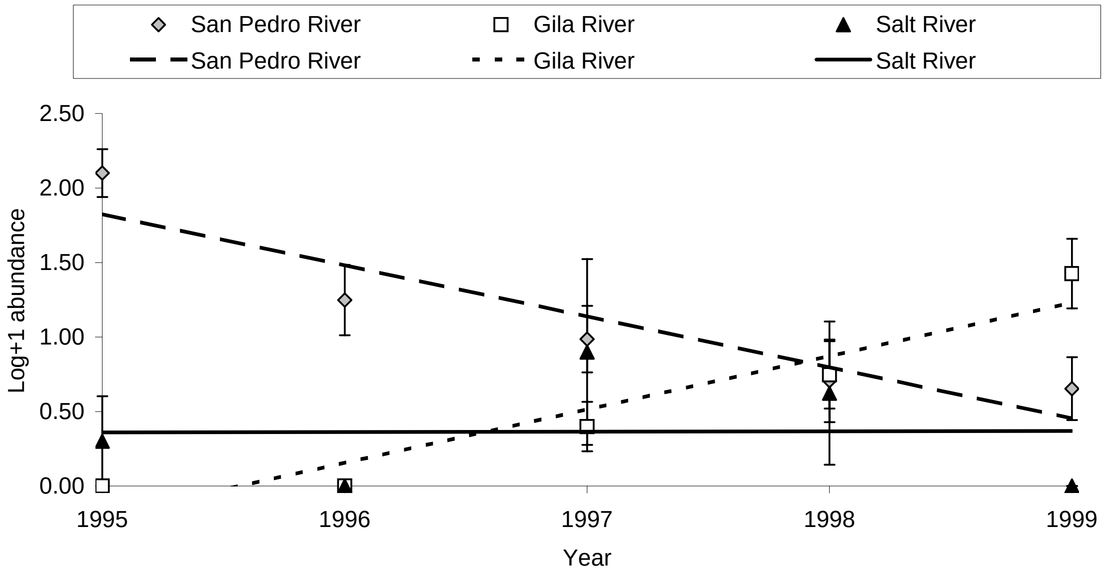


Figure 2. Log+1 abundance trends for *Gambusia affinis*. Each point represents the average of all stations within a stream for a given year with error bars representing one standard error. Trend lines are fitted to the point values.

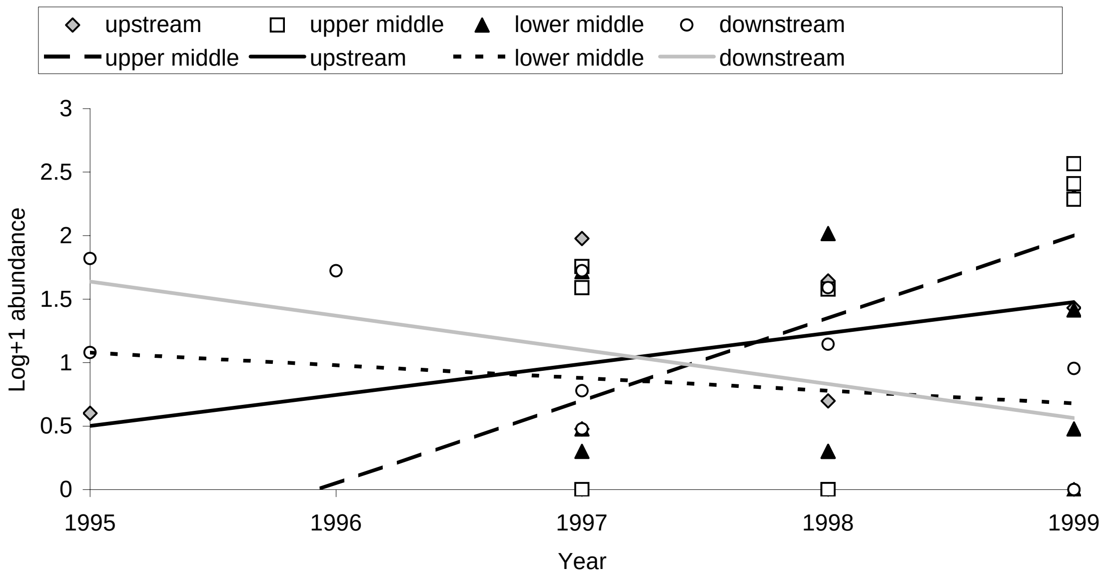


Figure 3. Log+1 abundance trends for reaches within the Gila River for *Cyprinella lutrensis*. Each point represents the value at a station within a given reach and year. The trend lines are fitted to all points for a given reach.

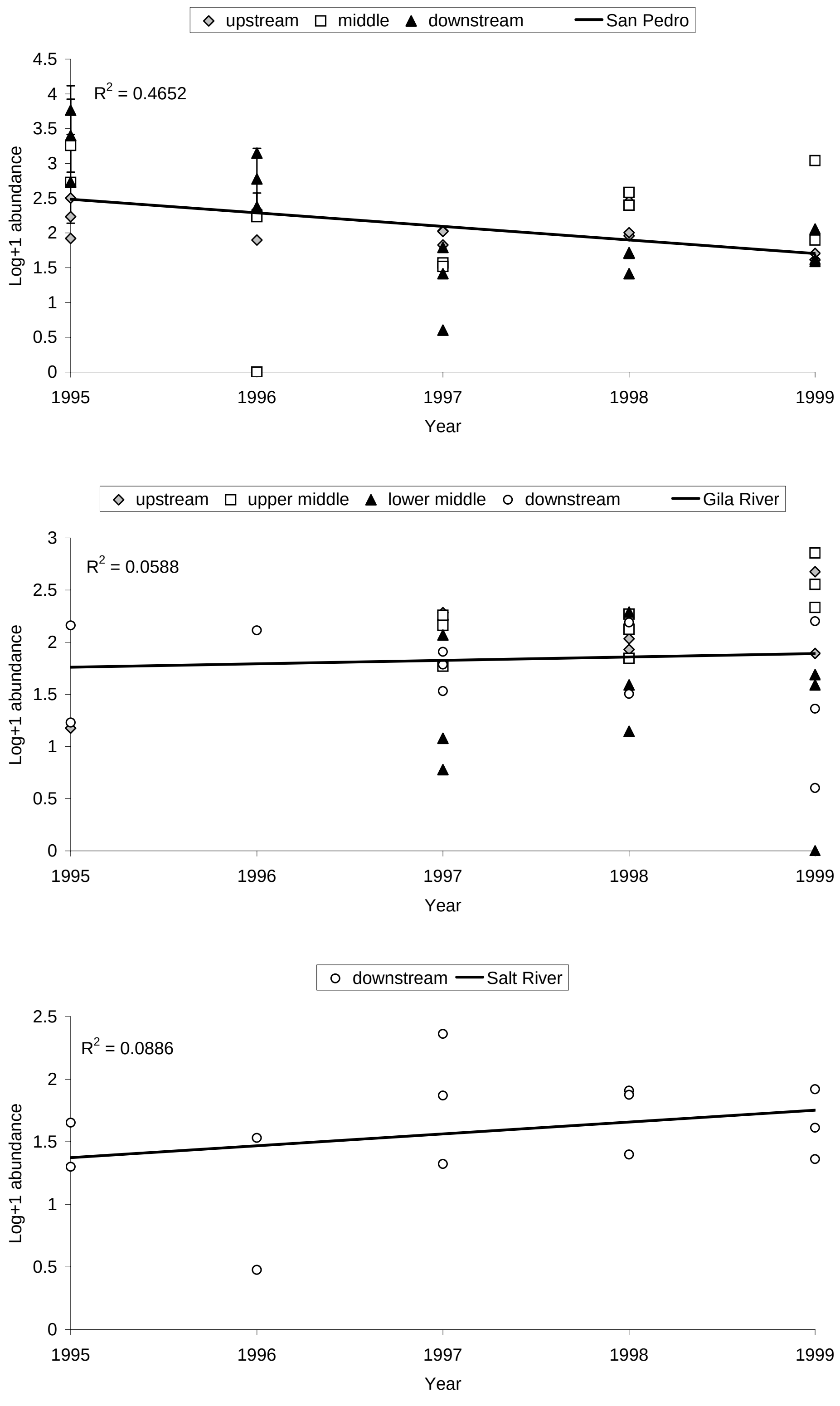


Figure 4. Log+1 transformed total catch reported from 1995 to 1999 for San Pedro River (top), Gila River (middle), and Salt River (bottom). Total catch for the San Pedro River trended downward over the course of the 5-year sampling period.

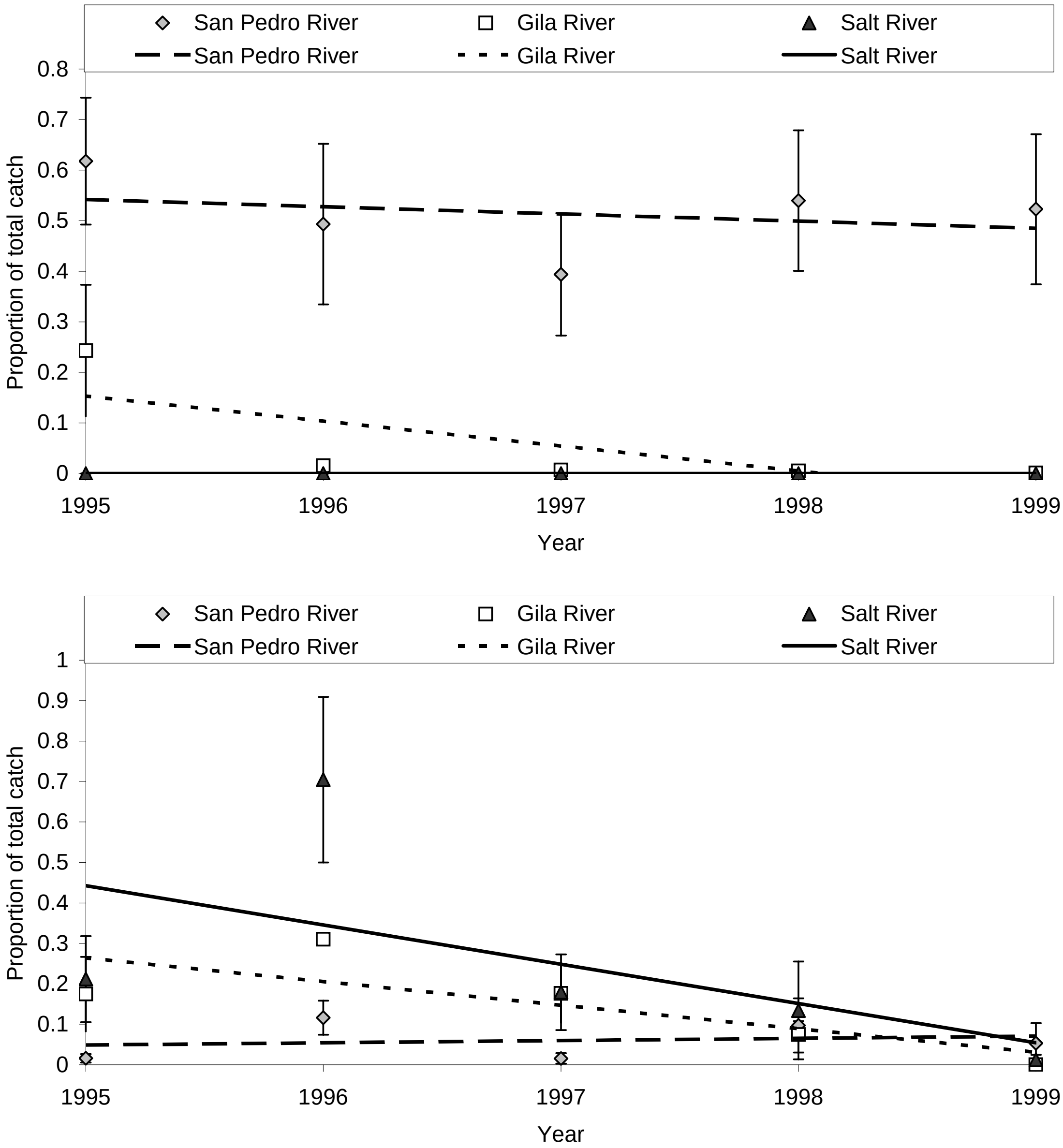


Figure 5. Relative abundance for *Agosia chrysogaster* (top) and *Pantosteus clarki* (bottom). Each point represents the average of all stations within a stream for a given year with error bars representing one standard error. Trend lines are fitted to the point values.

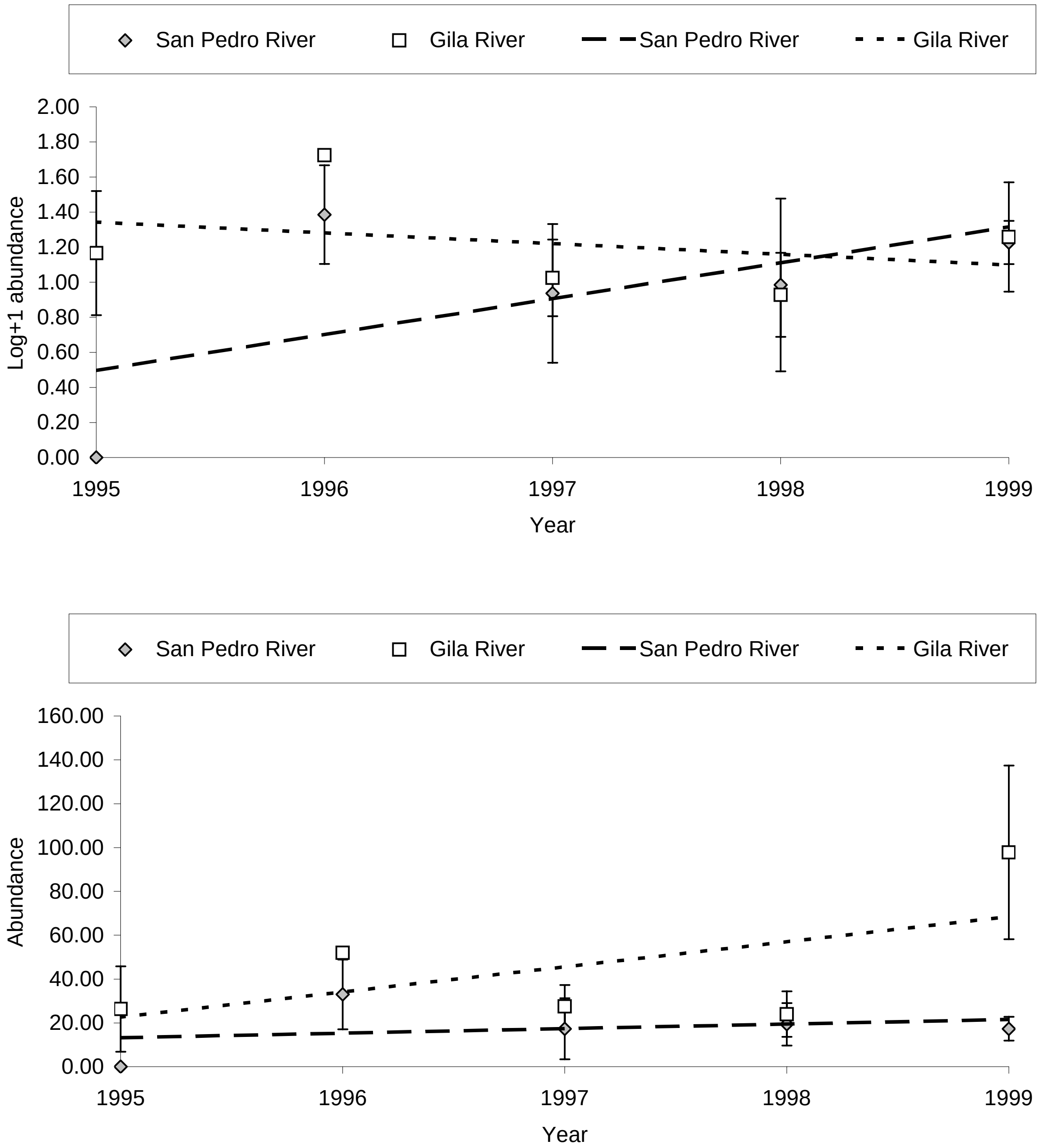
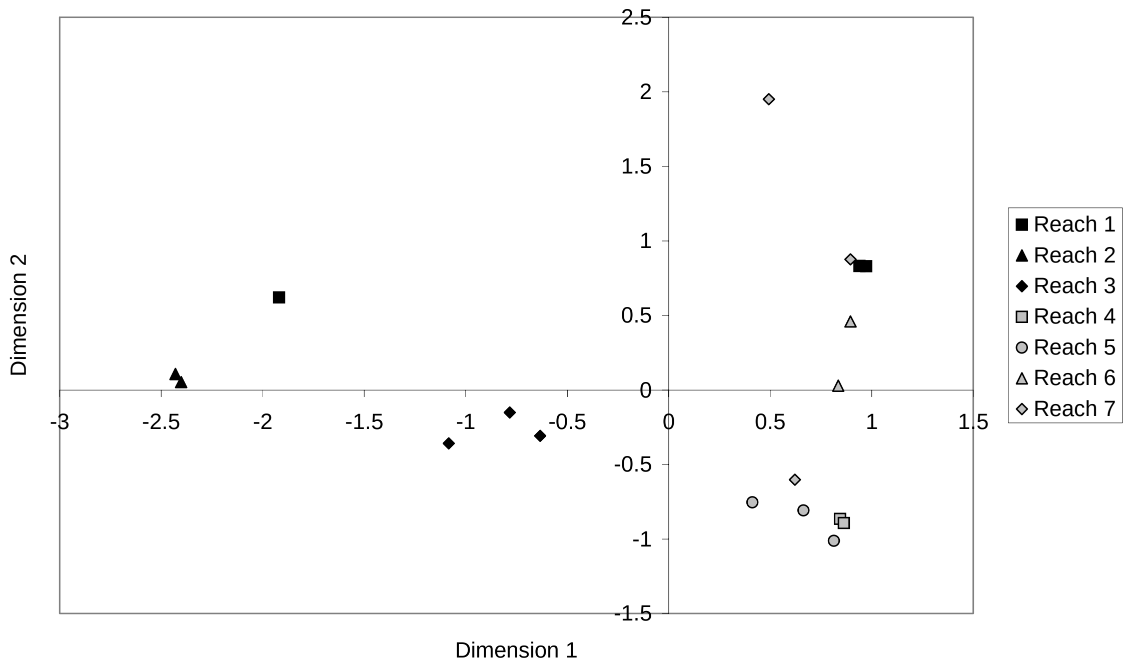


Figure 6. Trends in log+1 transformed (top) and raw (bottom) sample abundance of *Cyprinella lutrensis* in the San Pedro and Gila River from 1995 to 1999. Each point represents the average of all stations within a stream for a given year with error bars representing one standard error. Trend lines are fitted to the point values.



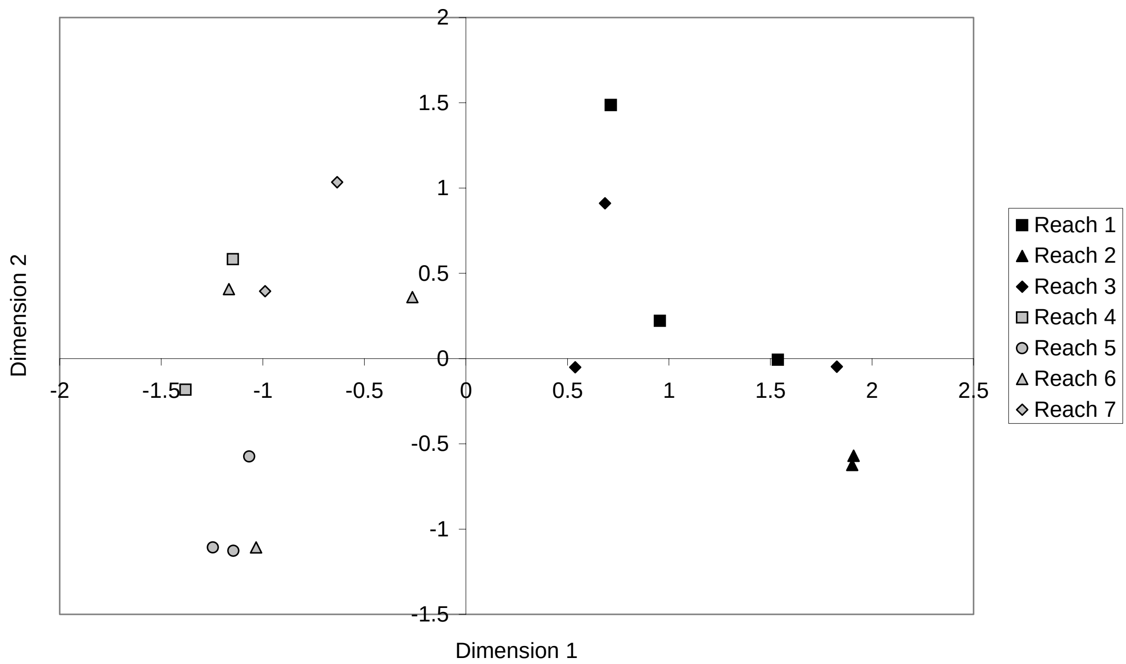


Figure 7. A bi-plot based on coordinates produced from NMDS using a Bray-Curtis Dissimilarity index on log+1 transformed abundance data. Data were collected from reaches in the Gila and San Pedro rivers for 1998 (top) and 1999 (bottom). Each point represents a station within a given reach.

APPENDIX A. Figures A1-A36. Bar graphs of fish capture total (number) and proportion of total catch (as percent) vs. year for Gila, Salt, and San Pedro rivers.

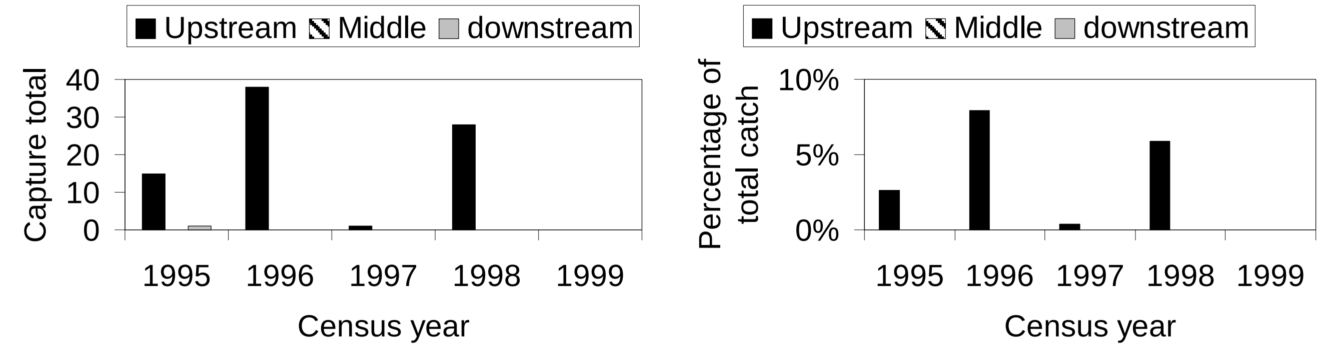


Figure A1. *Ameiurus melas* total catch (left) and proportion of catch (right) from annual sampling efforts in the San Pedro River.

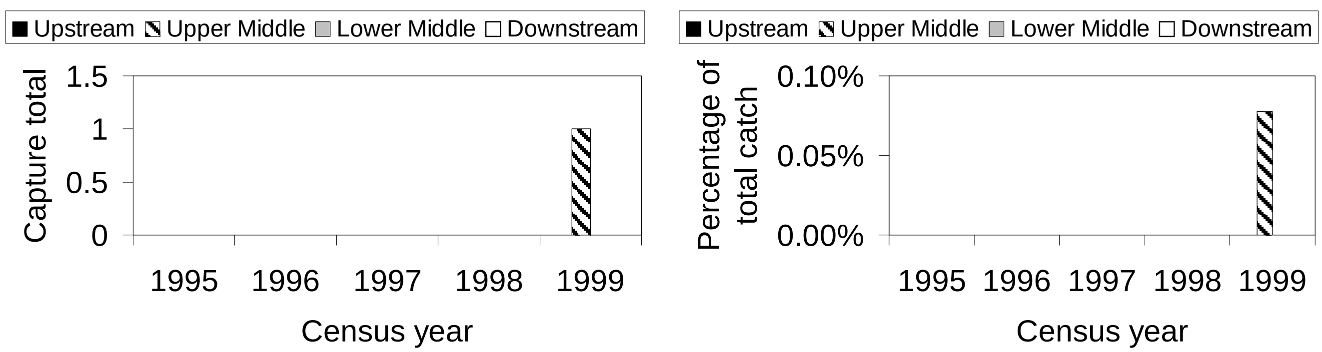


Figure A2. *Ameiurus melas* total catch (left) and proportion of catch (right) from annual sampling efforts in the Gila River.

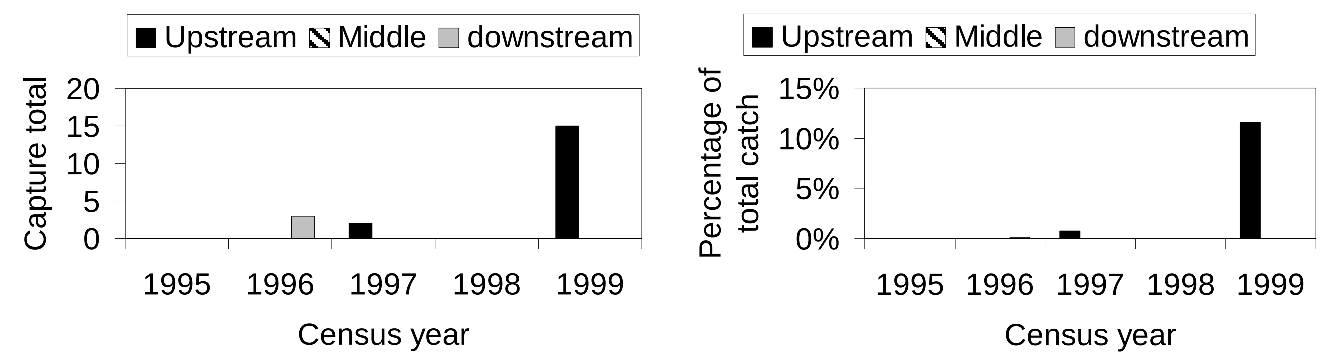


Figure A3. *Ameiurus natalis* total catch (left) and proportion of catch (right) from annual sampling efforts in the San Pedro River.

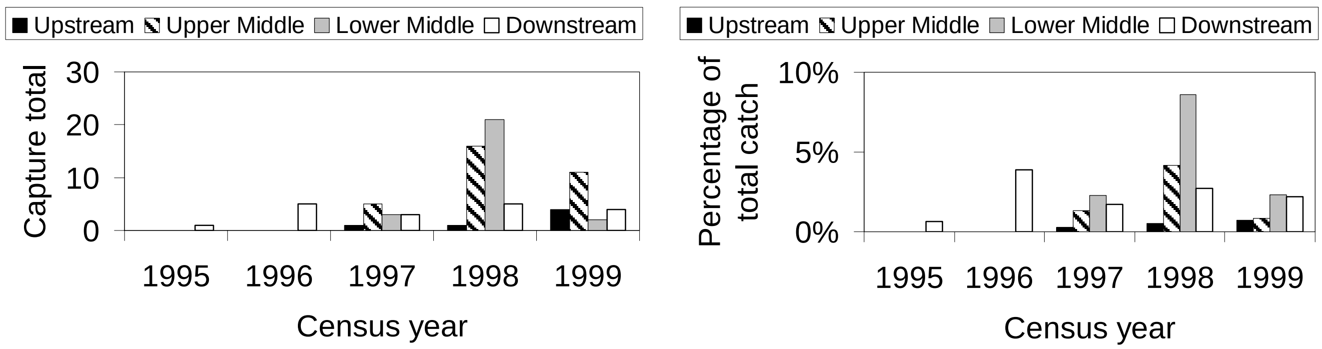


Figure A4. *Ameiurus natalis* total catch (left) and proportion of catch (right) from annual sampling efforts in the Gila River.

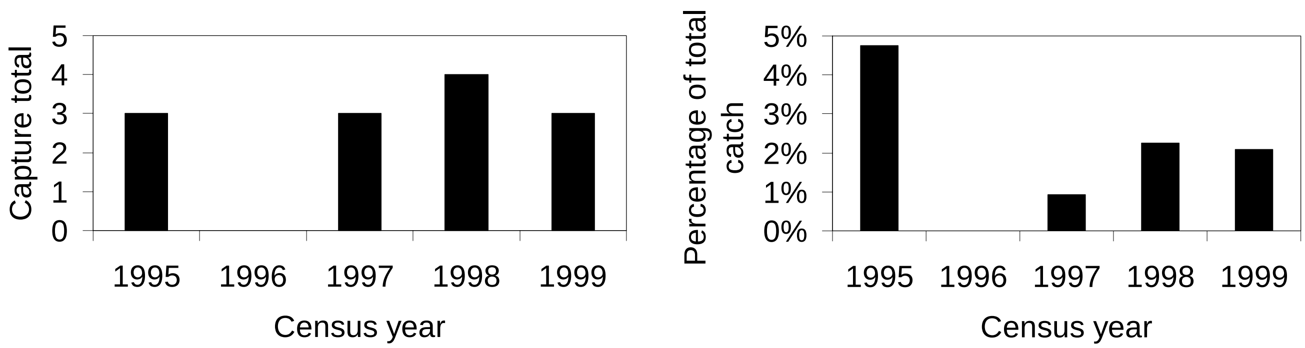


Figure A5. *Ameiurus natalis* total catch (left) and proportion of catch (right) from annual sampling efforts in the Salt River.

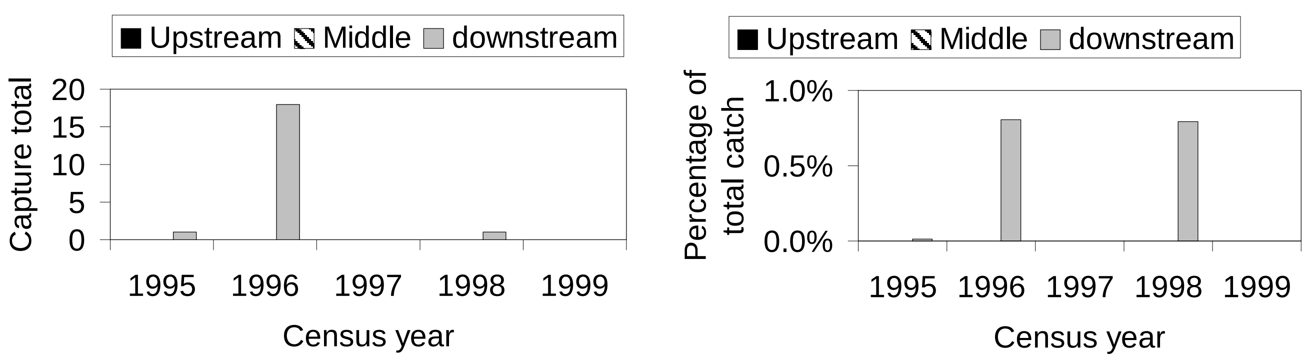
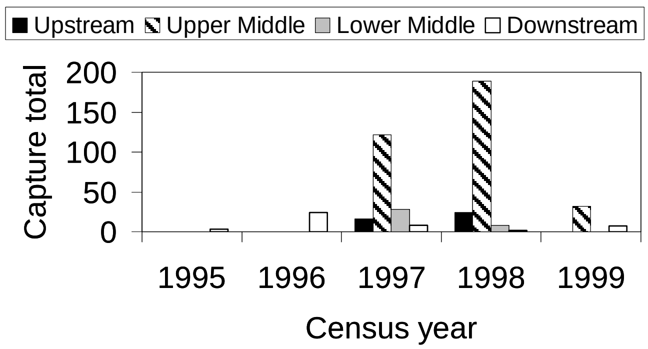


Figure A6. *Catostomus insignis* total catch (left) and proportion of catch (right) from annual sampling efforts in the San Pedro River.



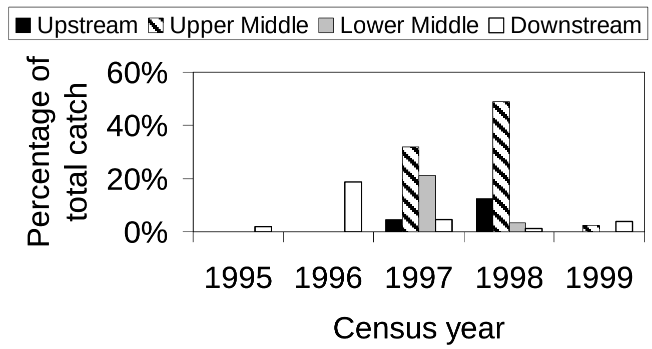
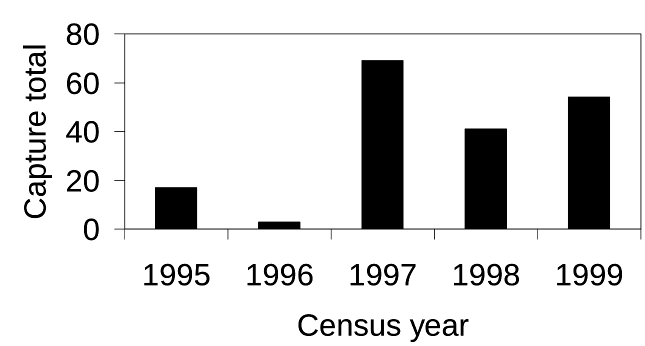


Figure A7. *Catostomus insignis* total catch (left) and proportion of catch (right) from annual sampling efforts in the Gila River.



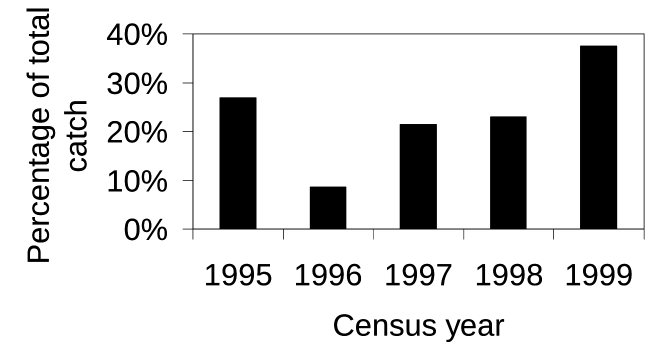
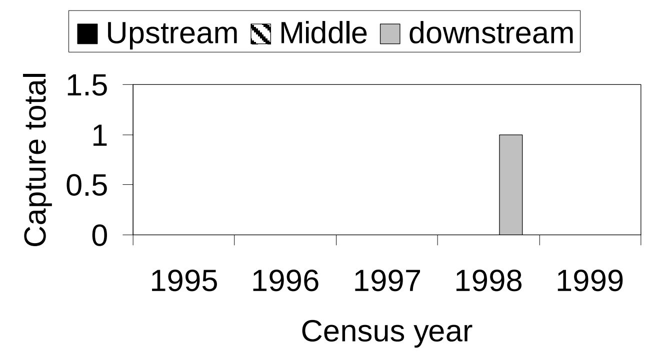


Figure A8. *Catostomus insignis* total catch (left) and proportion of catch (right) from annual sampling efforts in the Salt River.



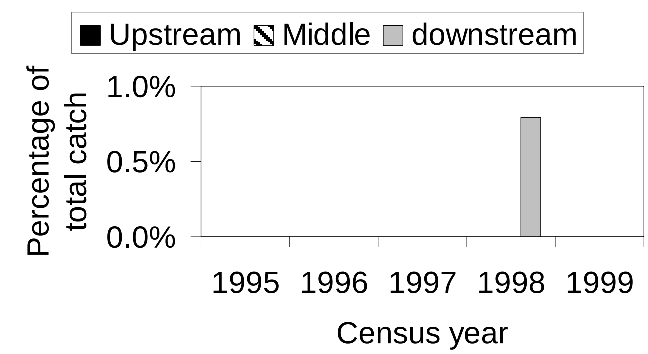


Figure A9. *Cyprinus carpio* total catch (left) and proportion of catch (right) from annual sampling efforts in the San Pedro River.

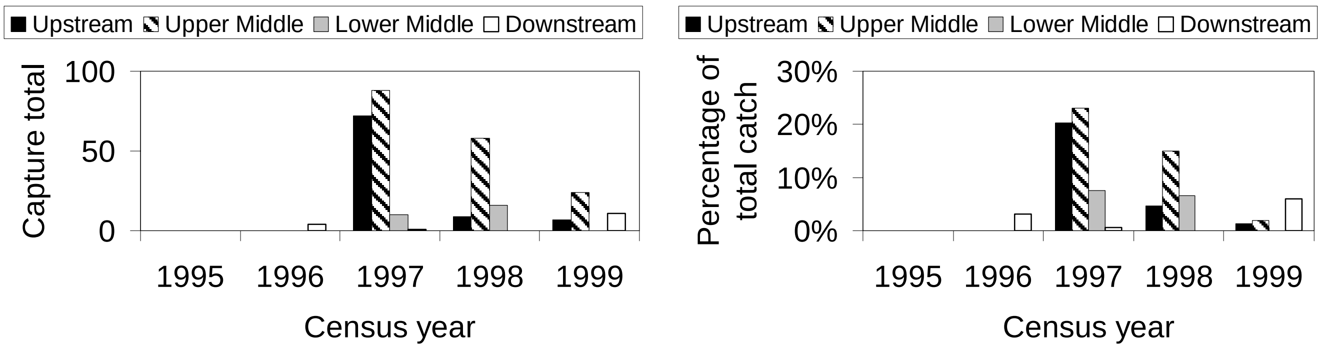


Figure A10. *Cyprinus carpio* total catch (left) and proportion of catch (right) from annual sampling efforts in the Gila River.

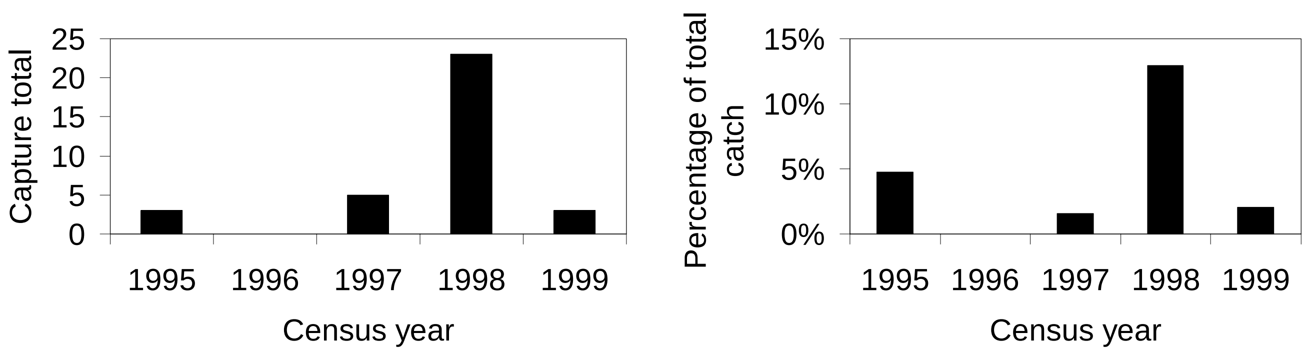


Figure A11. *Cyprinus carpio* total catch (left) and proportion of catch (right) from annual sampling efforts in the Salt River.

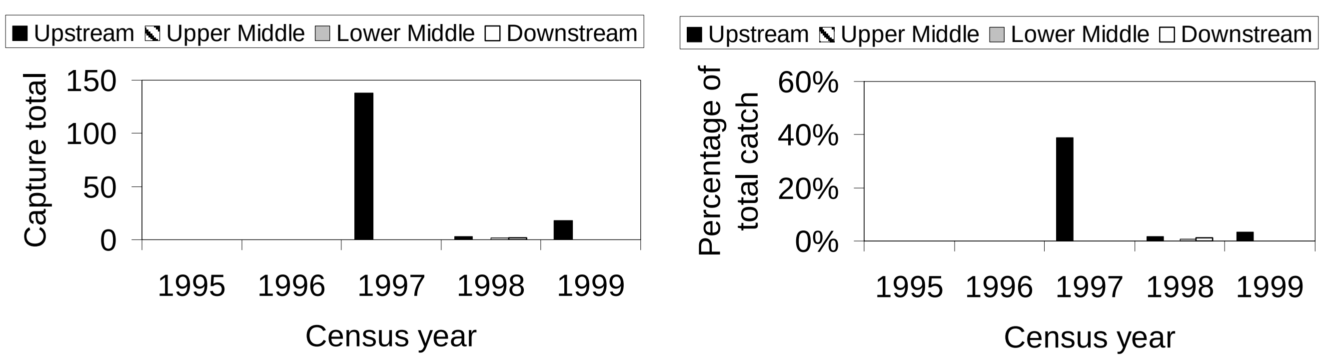


Figure A12. *Dorosoma petenense* total catch (left) and proportion of catch (right) from annual sampling efforts in the Gila River.

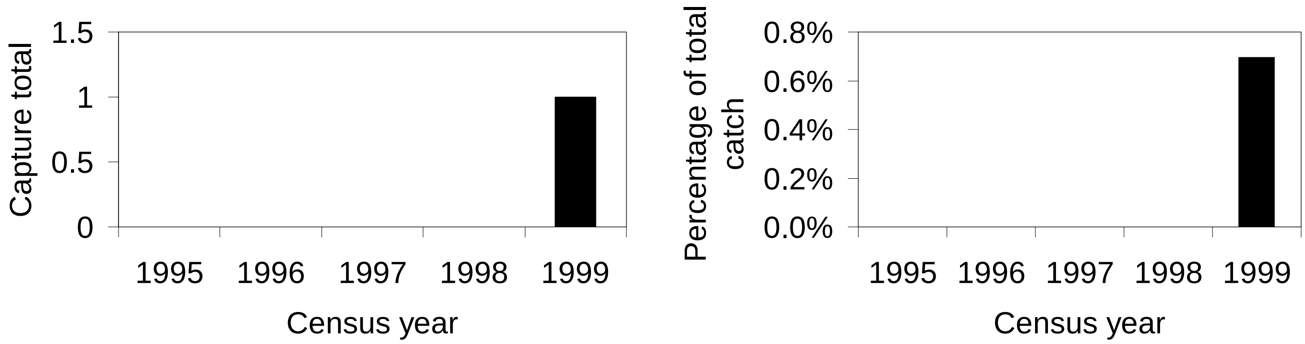


Figure A13. *Gila robusta* total catch (left) and proportion of catch (right) from annual sampling efforts in the Salt River.

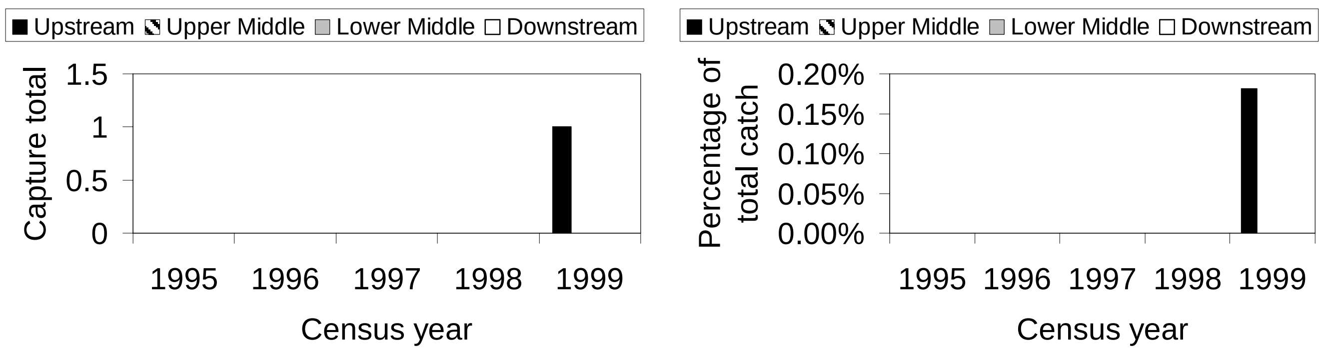


Figure A14. Hybrid *Catostomus insignis* × *Pantosteus clarki* total catch (left) and proportion of catch (right) from annual sampling efforts in the Gila River.

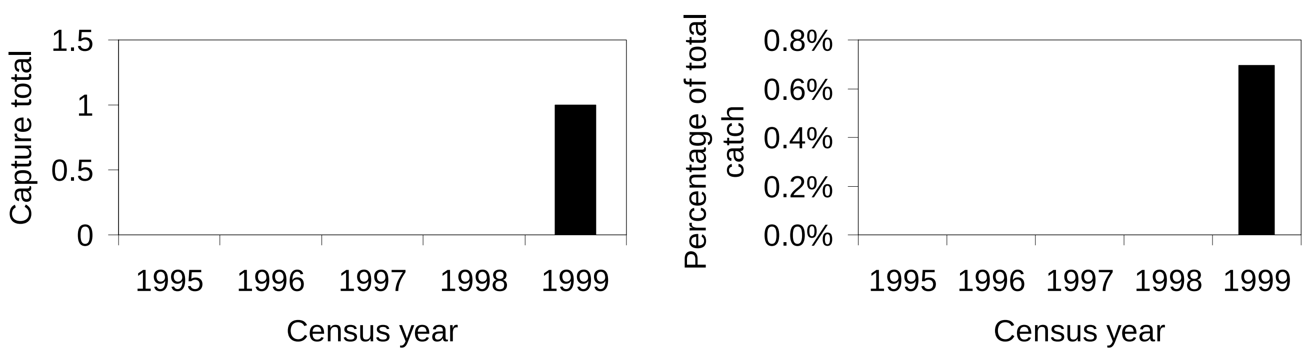


Figure A15. Hybrid *Catostomus insignis* × *Pantosteus clarki* total catch (left) and proportion of catch (right) from annual sampling efforts in the Salt River.

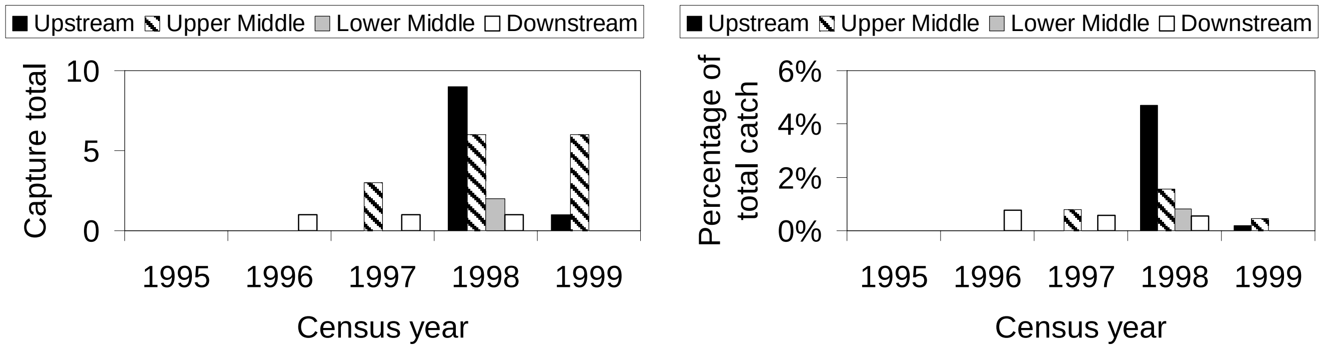


Figure A16. *Ictalurus punctatus* total catch (left) and proportion of catch (right) from annual sampling efforts in the Gila River.

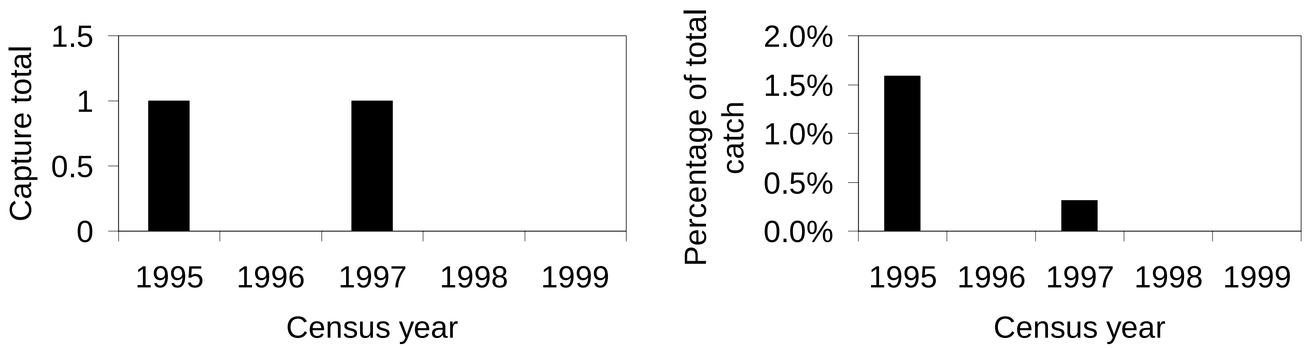


Figure A17. *Ictalurus punctatus* total catch (left) and proportion of catch (right) from annual sampling efforts in the Salt River.

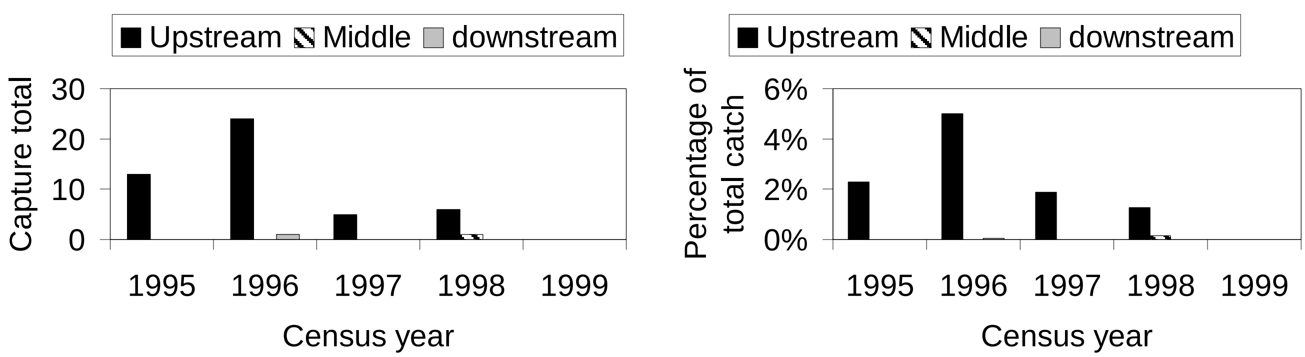


Figure A18. *Lepomis cyanellus* total catch (left) and proportion of catch (right) from annual sampling efforts in the San Pedro River.

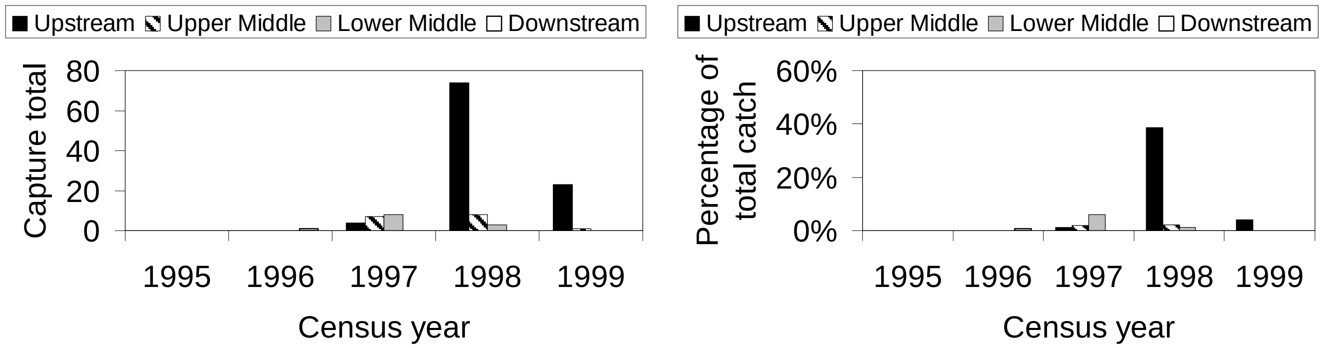


Figure A19. *Lepomis cyanellus* total catch (left) and proportion of catch (right) from annual sampling efforts in the Gila River.

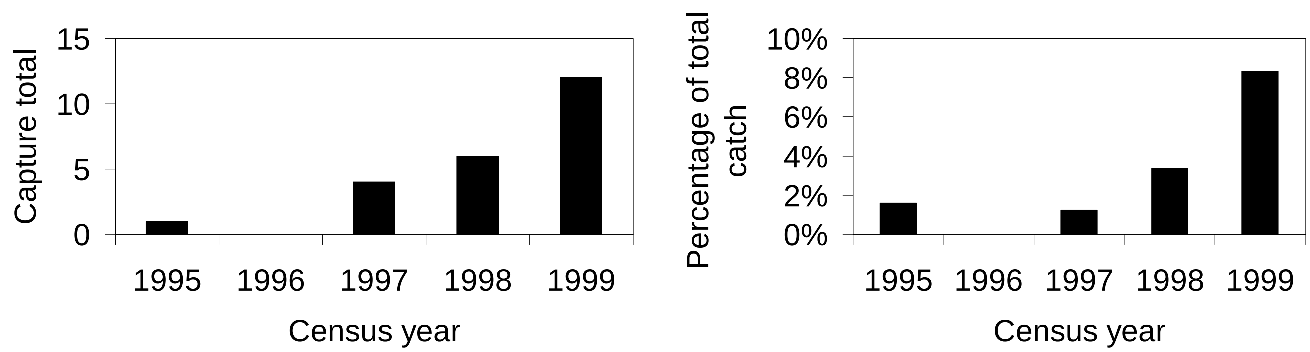


Figure A20. *Lepomis cyanellus* total catch (left) and proportion of catch (right) from annual sampling efforts in the Salt River.

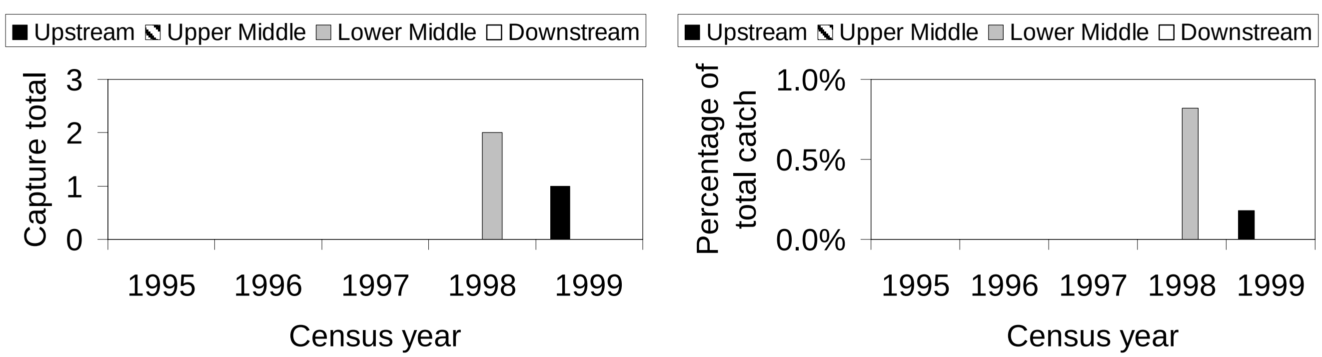


Figure A21. *Lepomis macrochirus* total catch (left) and proportion of catch (right) from annual sampling efforts in the Gila River.

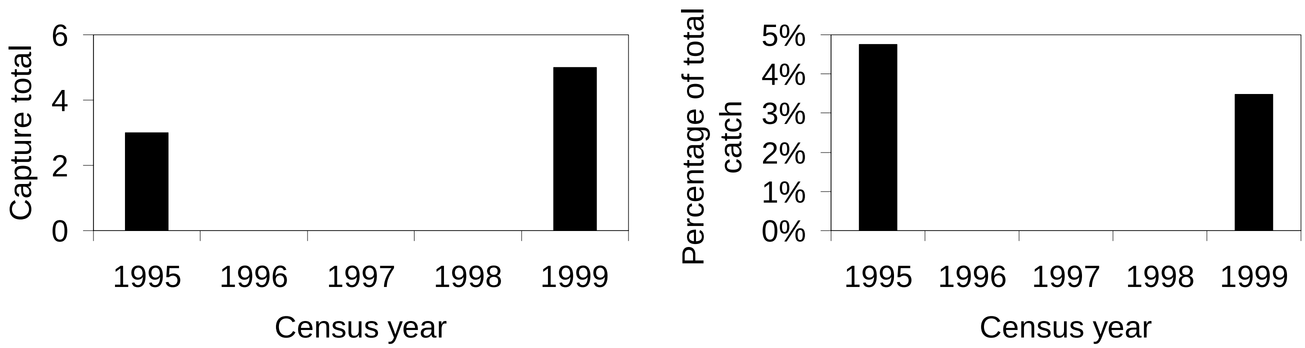


Figure A22. *Lepomis macrochirus* total catch (left) and proportion of catch (right) from annual sampling efforts in the Salt River.

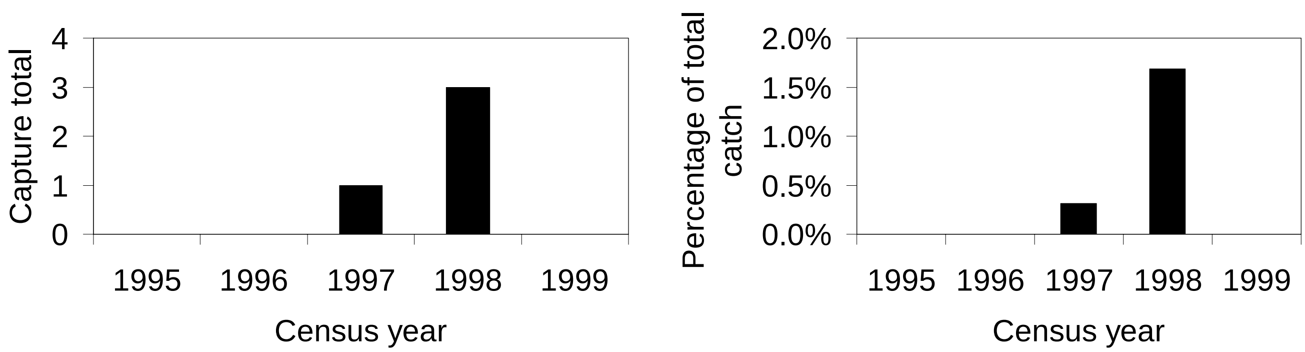


Figure A23. *Lepomis microlophus* total catch (left) and proportion of catch (right) from annual sampling efforts in the Salt River.

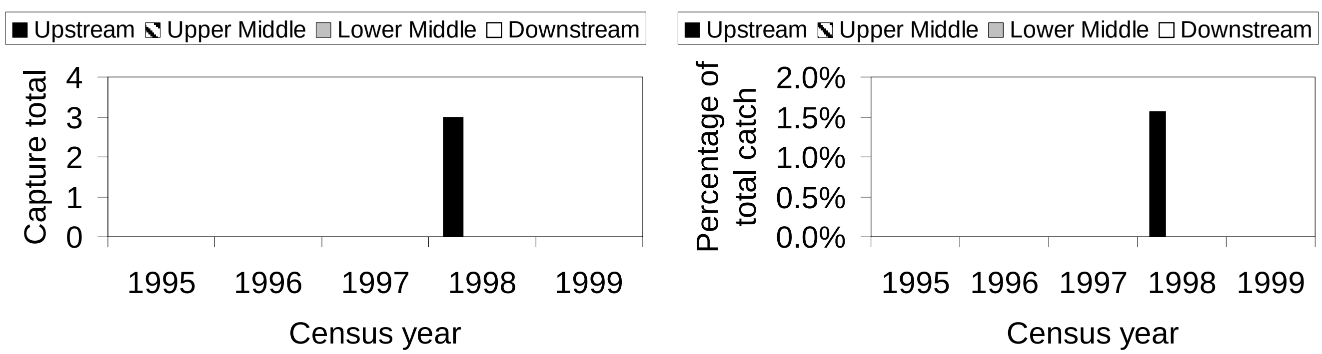


Figure A24. Undetermined *Lepomis* total catch (left) and proportion of catch (right) from annual sampling efforts in the Gila River.

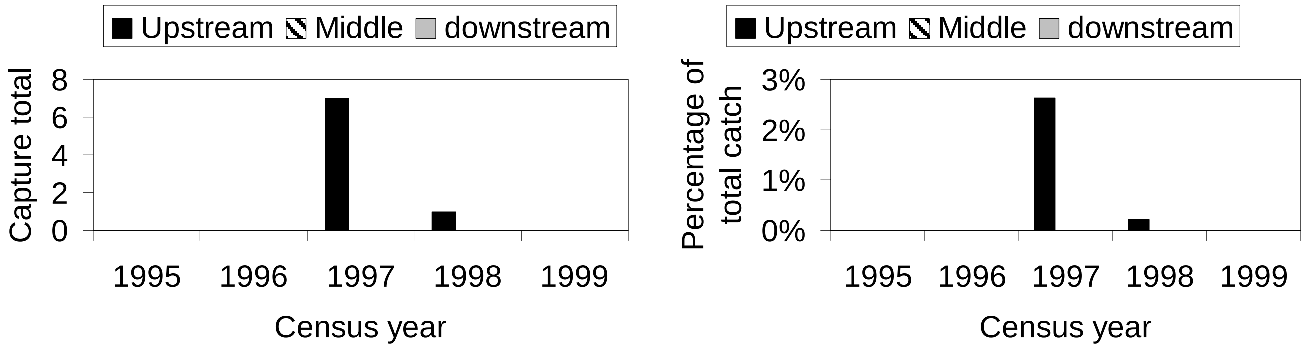


Figure A25. *Micropterus salmoides* total catch (left) and proportion of catch (right) from annual sampling efforts in the San Pedro River.

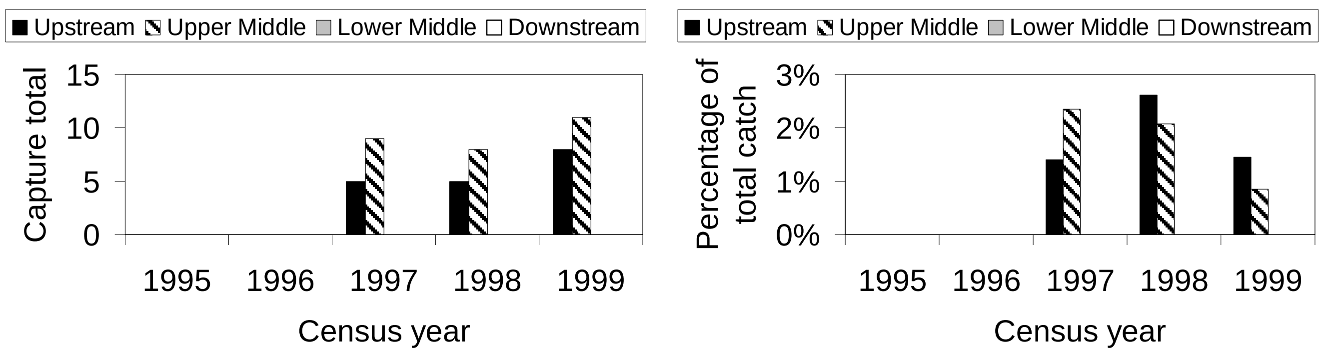


Figure A26. *Micropterus salmoides* total catch (left) and proportion of catch (right) from annual sampling efforts in the Gila River.

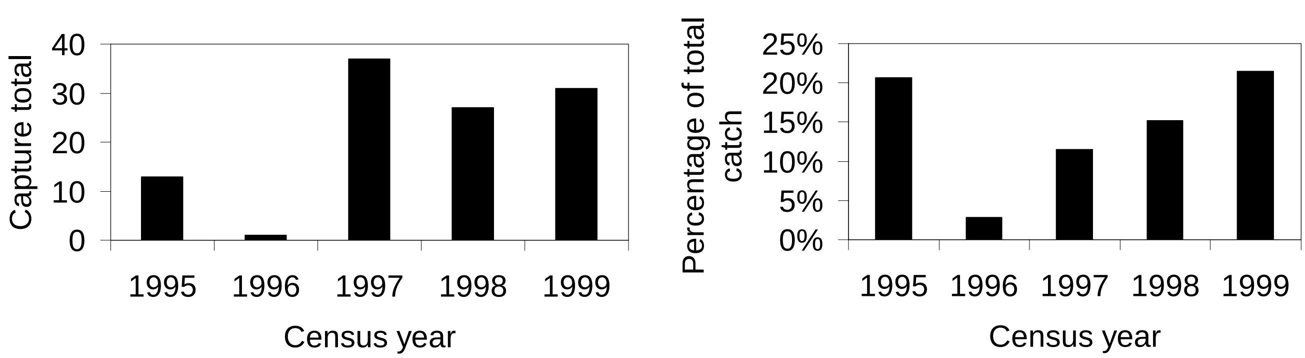


Figure A27. *Micropterus salmoides* total catch (left) and proportion of catch (right) from annual sampling efforts in the Salt River.

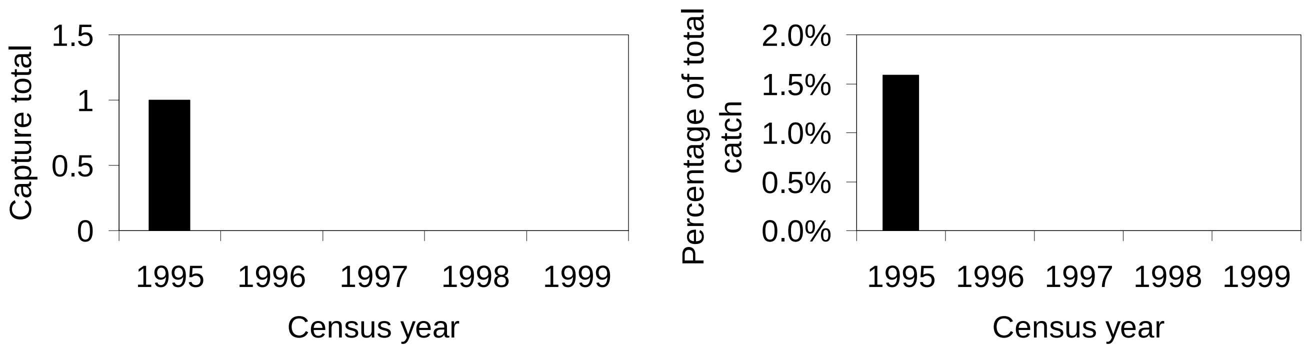


Figure A28. *Oncorhynchus mykiss* total catch (left) and proportion of catch (right) from annual sampling efforts in the Salt River.

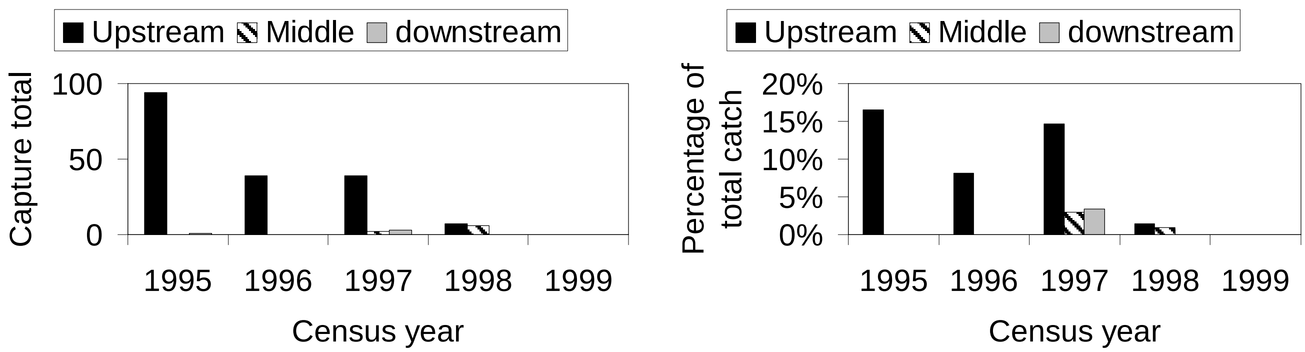


Figure A29. *Pimephales promelas* total catch (left) and proportion of catch (right) from annual sampling efforts in the San Pedro River.

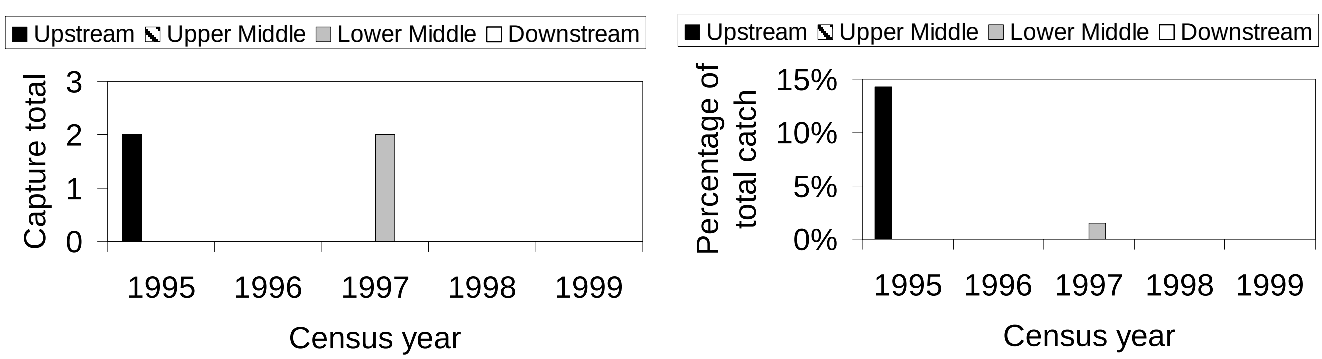


Figure A30. *Pimephales promelas* total catch (left) and proportion of catch (right) from annual sampling efforts in the Gila River.

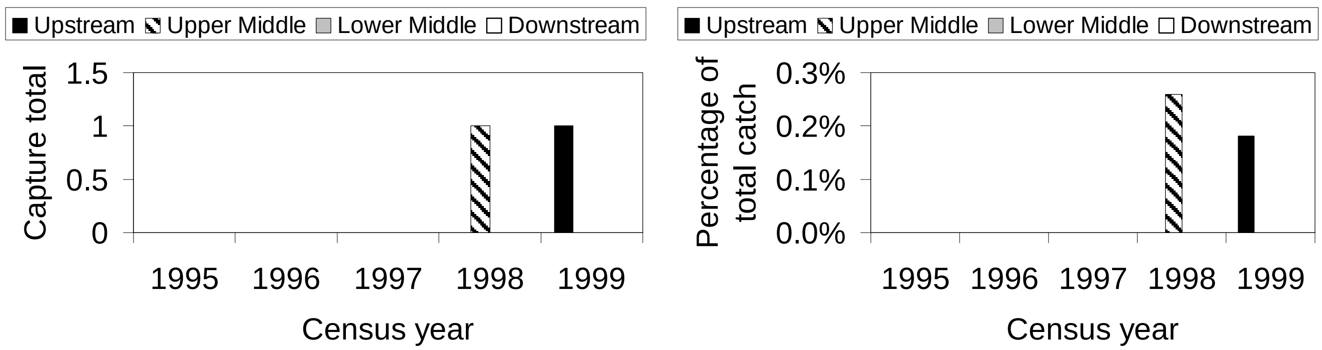


Figure A31. *Pomoxis nigromaculatus* total catch (left) and proportion of catch (right) from annual sampling efforts in the Gila River.

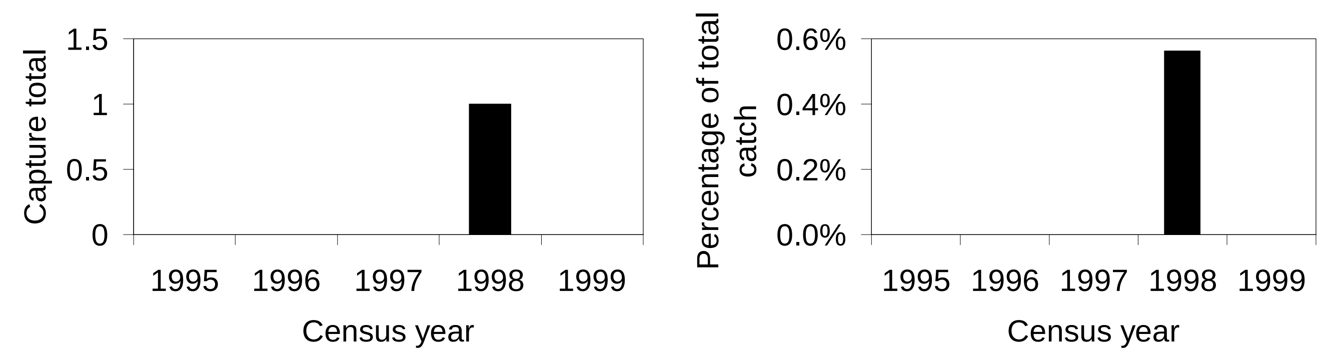


Figure A32. *Pomoxis nigromaculatus* total catch (left) and proportion of catch (right) from annual sampling efforts in the Salt River.

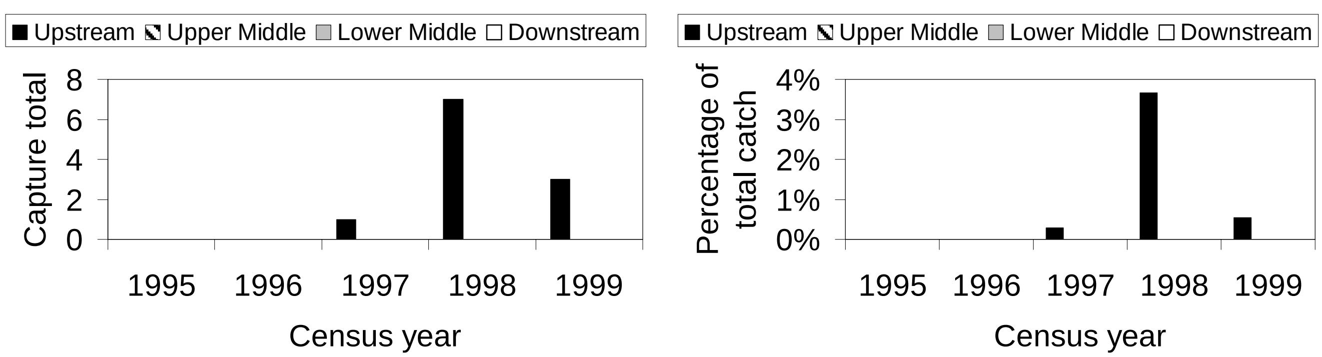


Figure A33. *Pylodictus olivaris* total catch (left) and proportion of catch (right) from annual sampling efforts in the Gila River.

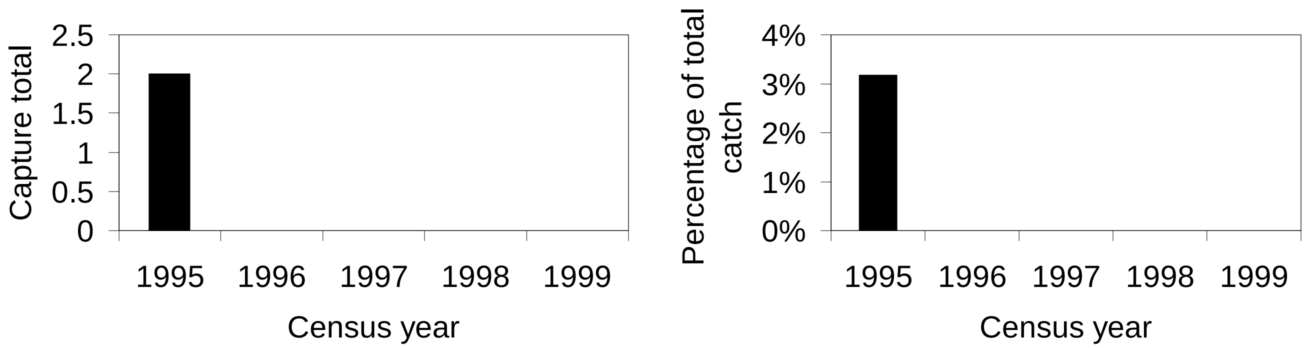


Figure A34. *Stizostedion vitreum* total catch (left) and proportion of catch (right) from annual sampling efforts in the Salt River.

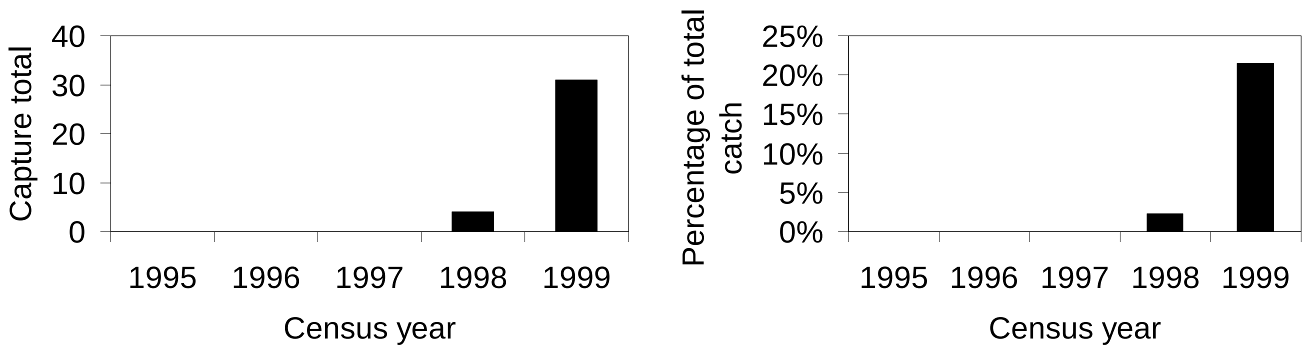


Figure A35. Undetermined *Tilapia* total catch (left) and proportion of catch (right) from annual sampling efforts in the Salt River.

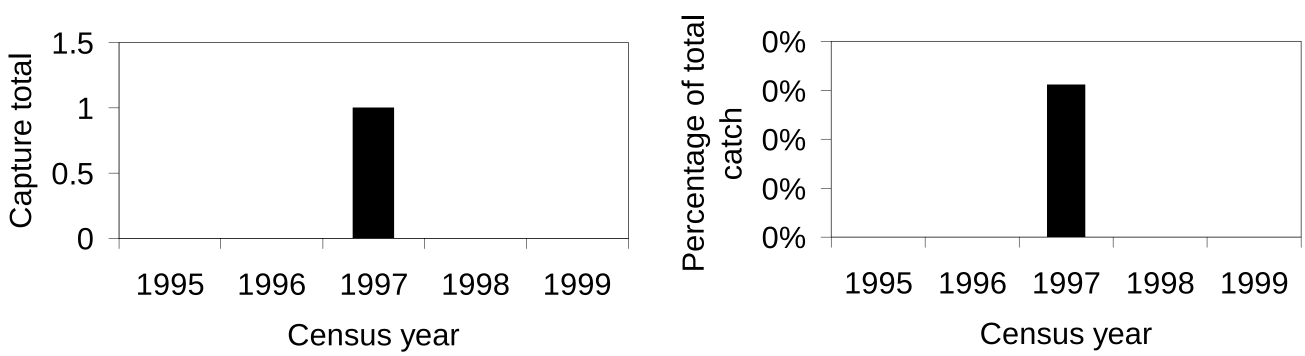


Figure A36. *Tilapia zilli* total catch (left) and proportion of catch (right) from annual sampling efforts in the Salt River.

APPENDIX B. Figures B1-B15. Bar graphs of fish capture total (number) and proportion of total catch (as percent) vs. year for the Central Arizona Project (CAP) Canal.

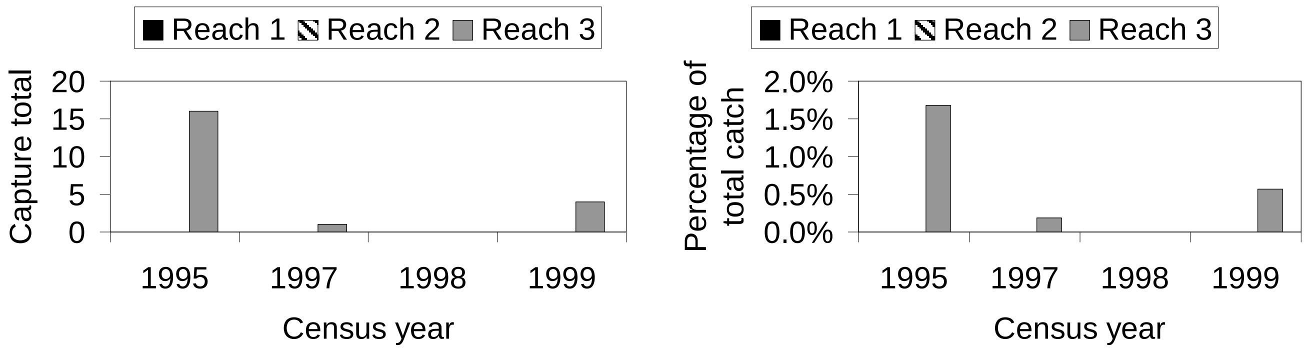


Figure B1. *Ameiurus melas* total catch (left) and proportion of catch (right) from annual sampling efforts in the CAP canal.

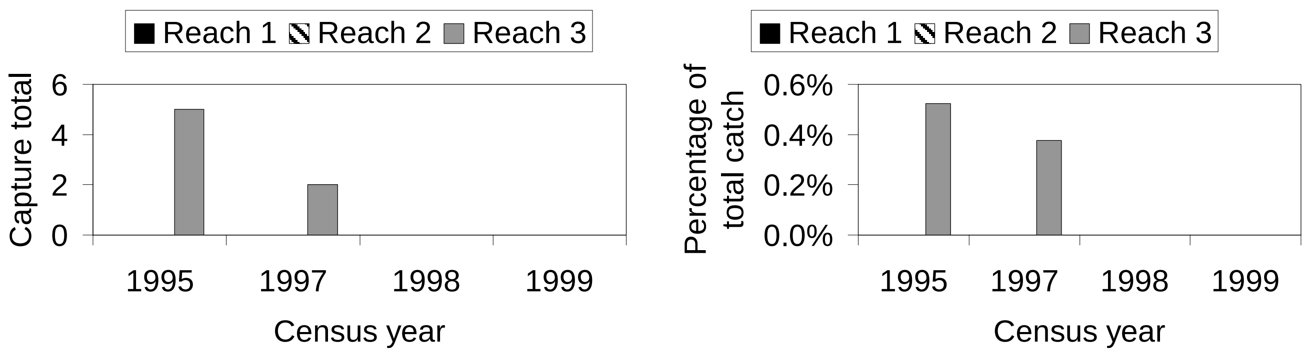


Figure B2. *Ameiurus natalis* total catch (left) and proportion of catch (right) from annual sampling efforts in the CAP canal.

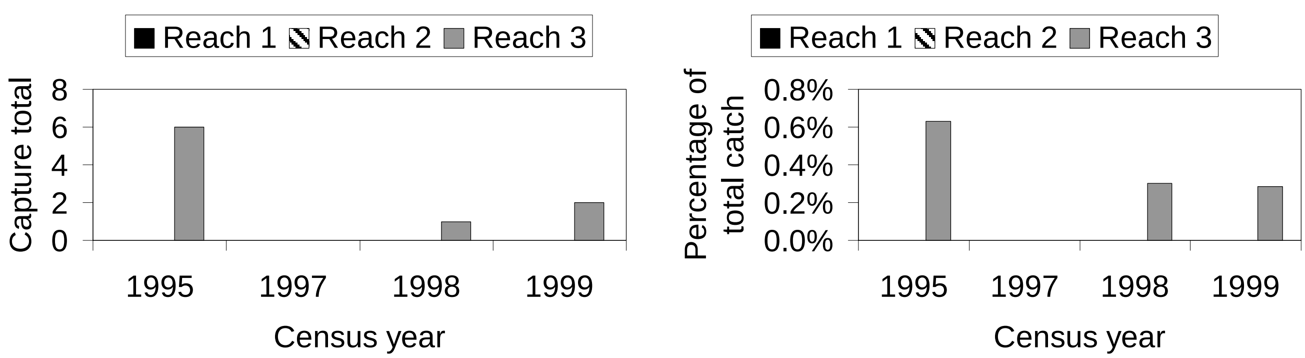


Figure B3. *Carassius auratus* total catch (left) and proportion of catch (right) from annual sampling efforts in the CAP canal.

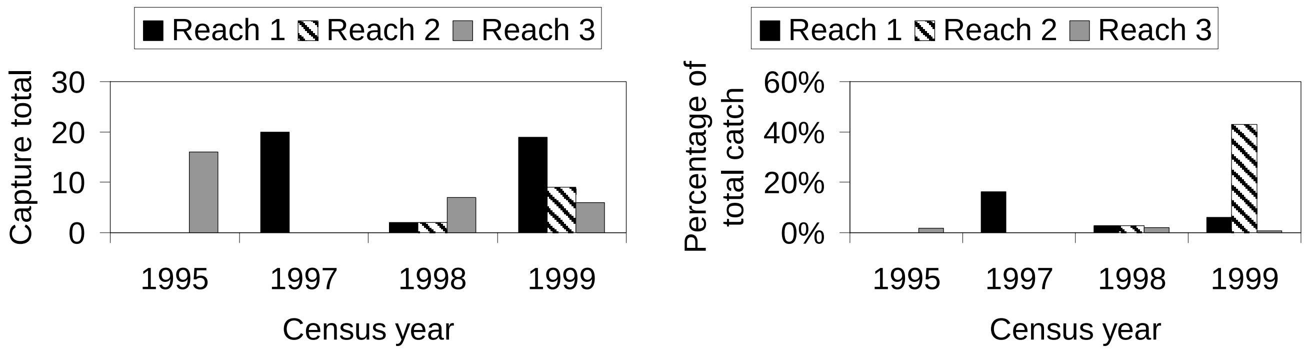


Figure B4. *Ctenopharyngodon idella* total catch (left) and proportion of catch (right) from annual sampling efforts in the CAP canal.

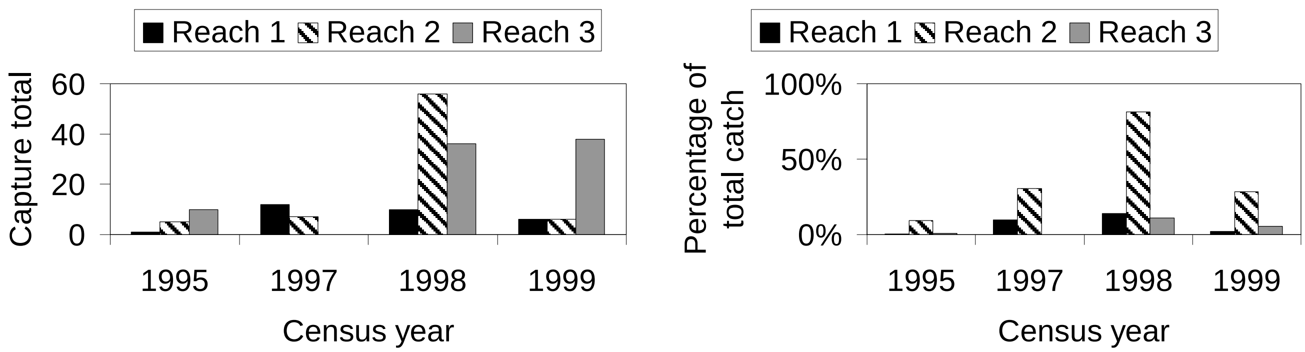


Figure B5. *Cyprinus carpio* total catch (left) and proportion of catch (right) from annual sampling efforts in the CAP canal.

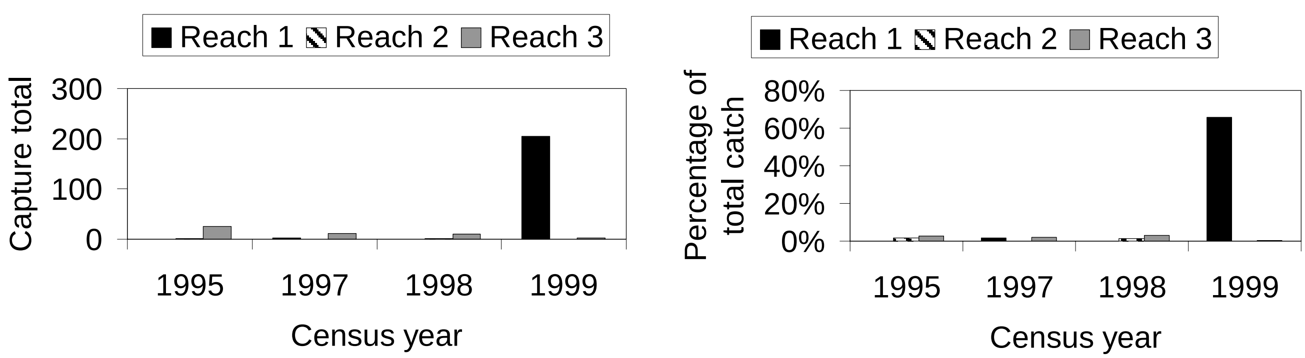


Figure B6. *Cyprinella lutrensis* total catch (left) and proportion of catch (right) from annual sampling efforts in the CAP canal.

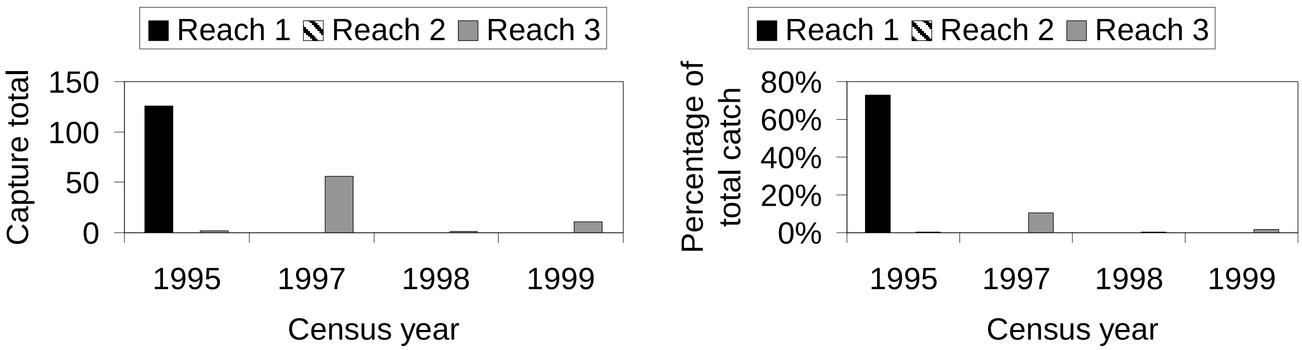


Figure B7. *Dorosoma petenense* total catch (left) and proportion of catch (right) from annual sampling efforts in the CAP canal.

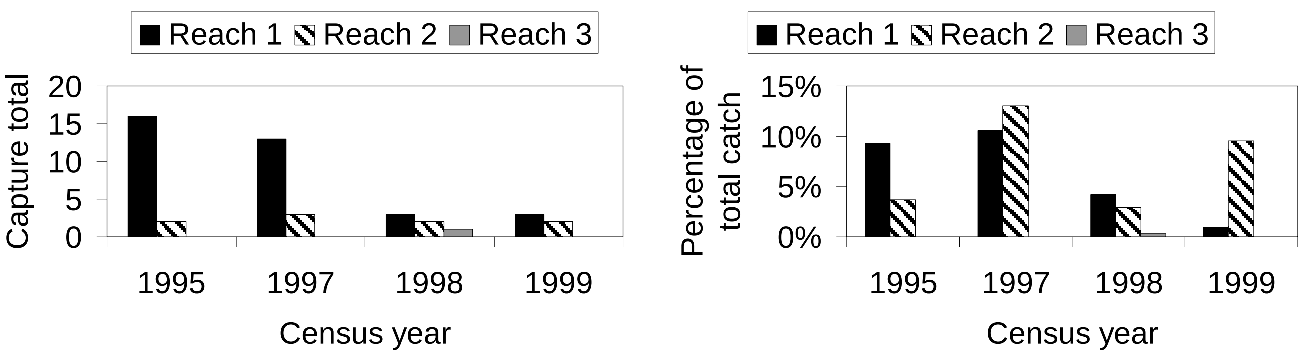


Figure B8. *Ictalurus punctatus* total catch (left) and proportion of catch (right) from annual sampling efforts in the CAP canal.

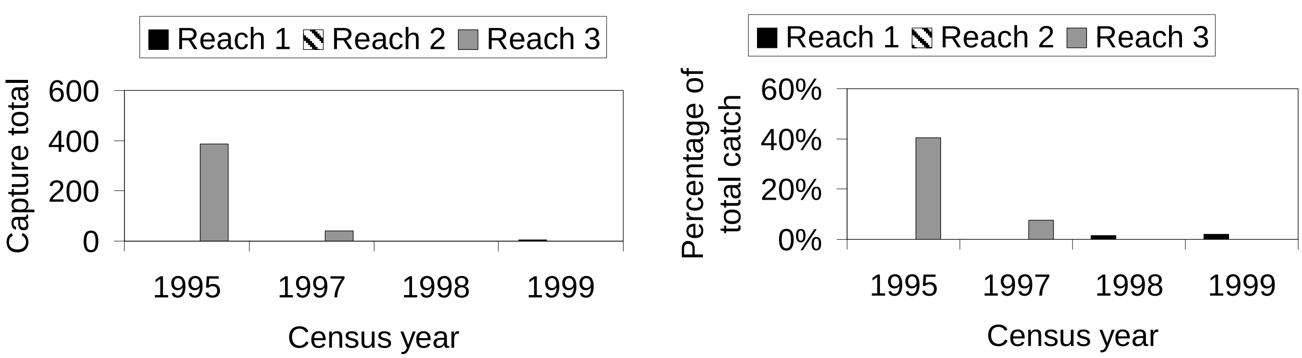


Figure B9. *Lepomis cyanellus* total catch (left) and proportion of catch (right) from annual sampling efforts in the CAP canal.

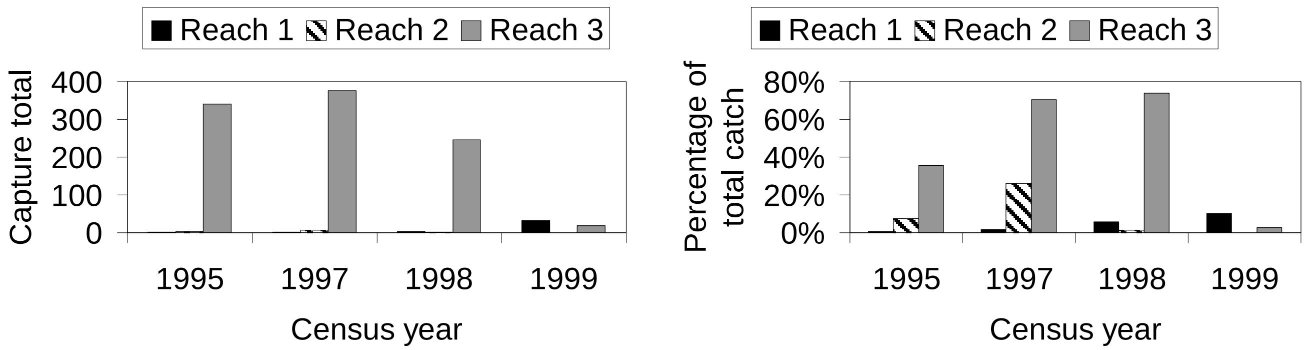


Figure B10. *Lepomis macrochirus* total catch (left) and proportion of catch (right) from annual sampling efforts in the CAP canal.

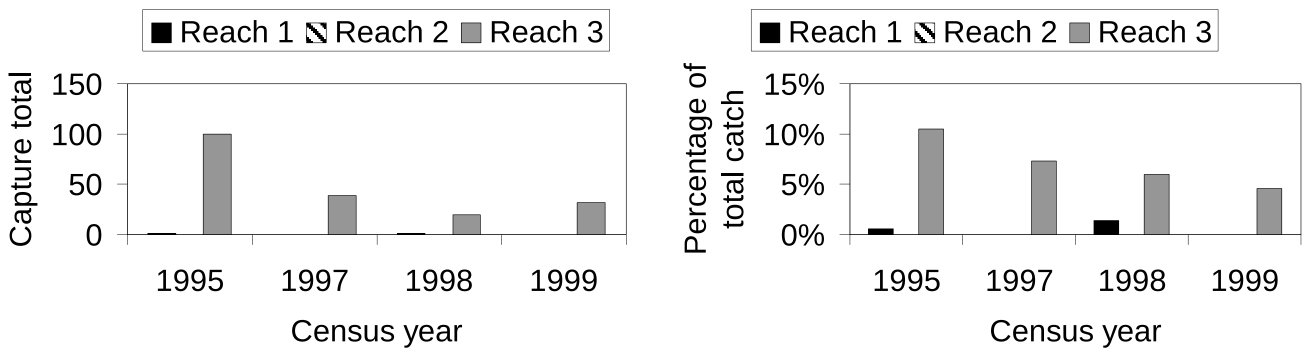


Figure B11. *Lepomis microlophus* total catch (left) and proportion of catch (right) from annual sampling efforts in the CAP canal.

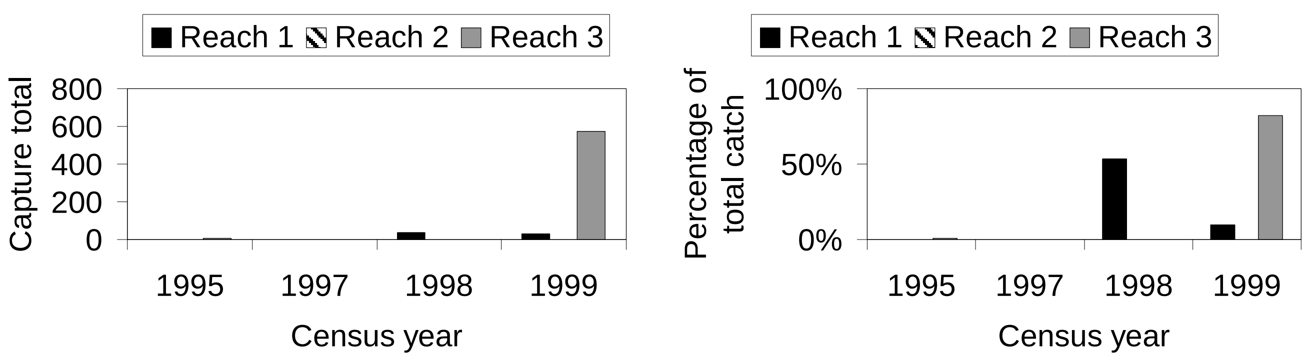


Figure B12. Undetermined *Lepomis* total catch (left) and proportion of catch (right) from annual sampling efforts in the CAP canal.

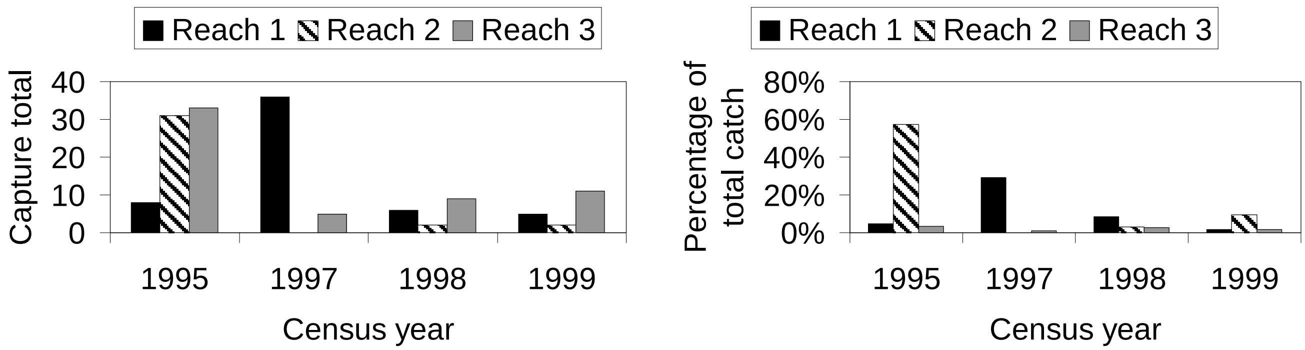


Figure B13. *Micropterus salmoides* total catch (left) and proportion of catch (right) from annual sampling efforts in the CAP canal.

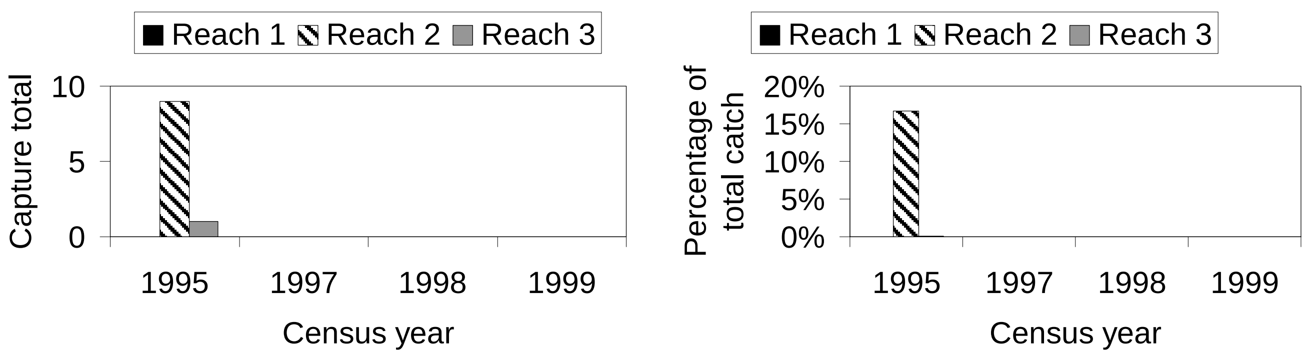


Figure B14. *Morone chrysops* total catch (left) and proportion of catch (right) from annual sampling efforts in the CAP canal.

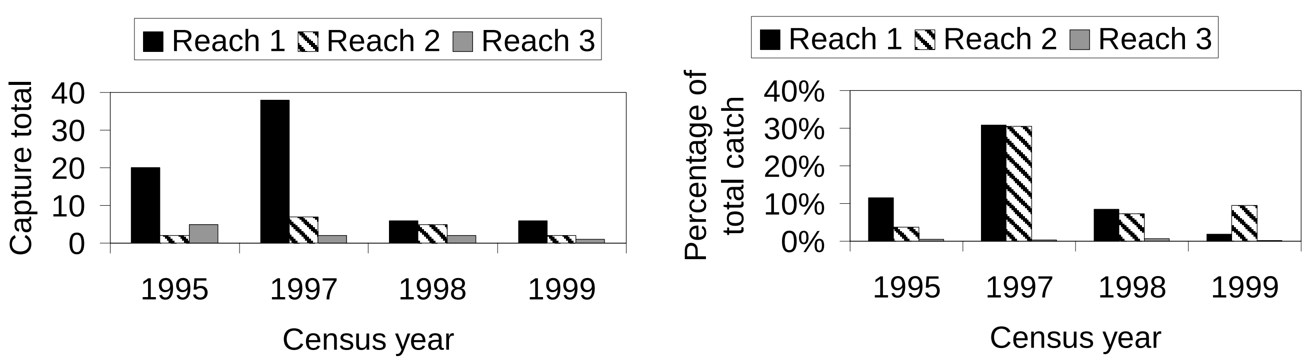


Figure B15. *Morone saxatilis* total catch (left) and proportion of catch (right) from annual sampling efforts in the CAP canal.

APPENDIX C. Figures C1-C12. Bar graphs of fish capture total (number) and proportion of total catch (as percent) vs. year for the Florence-Casa Grande Canal.

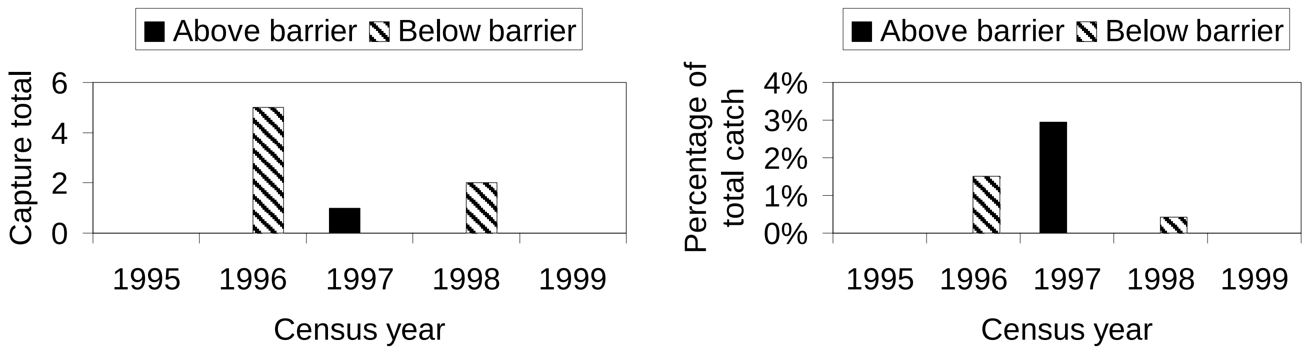


Figure C1. *Agosia chrysogaster* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the Florence-Casa Grande Canal.

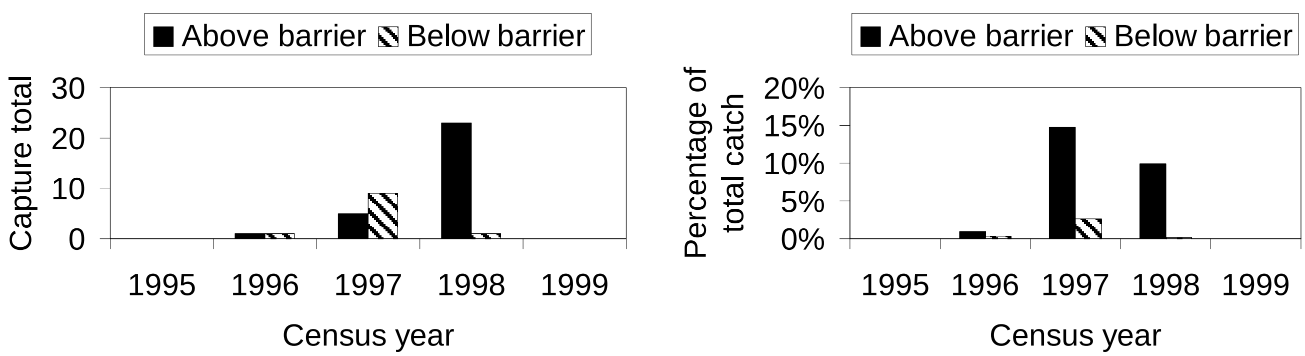


Figure C2. *Ameiurus natalis* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the Florence-Casa Grande Canal.

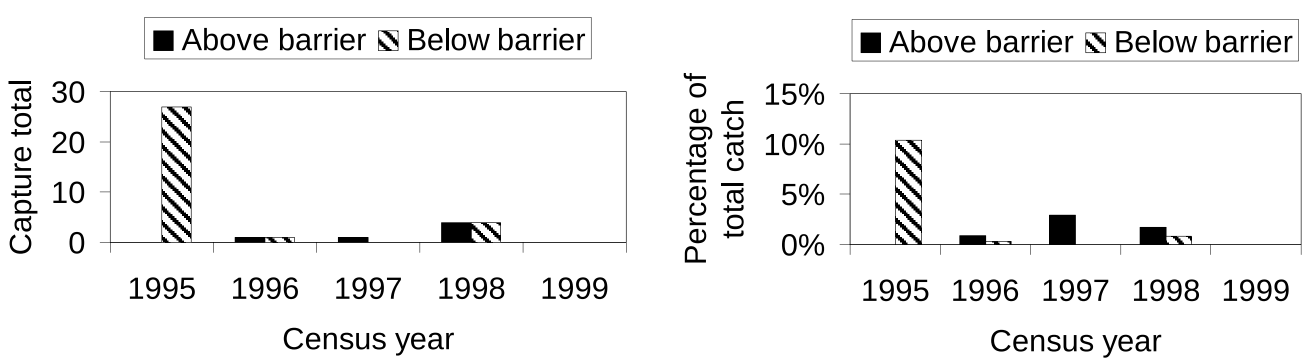


Figure C3. *Catostomus insignis* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the Florence-Casa Grande Canal.

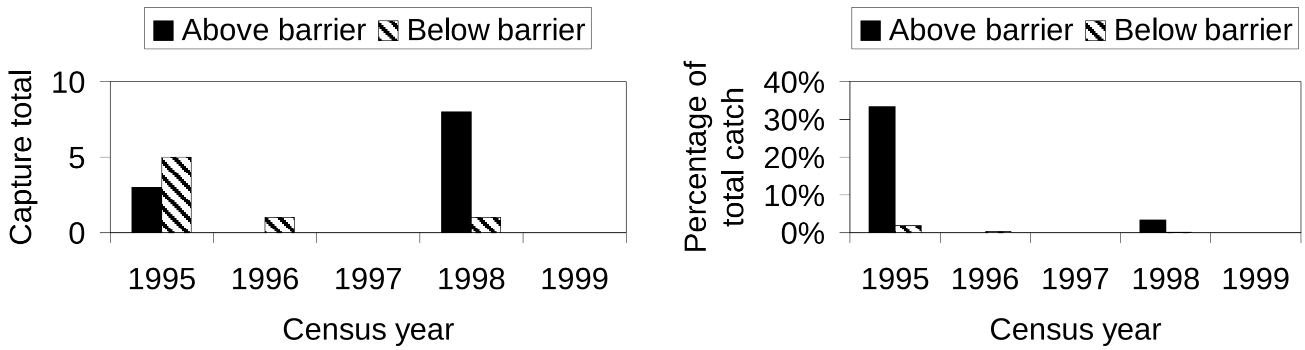


Figure C4. *Cyprinus carpio* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the Florence-Casa Grande Canal.

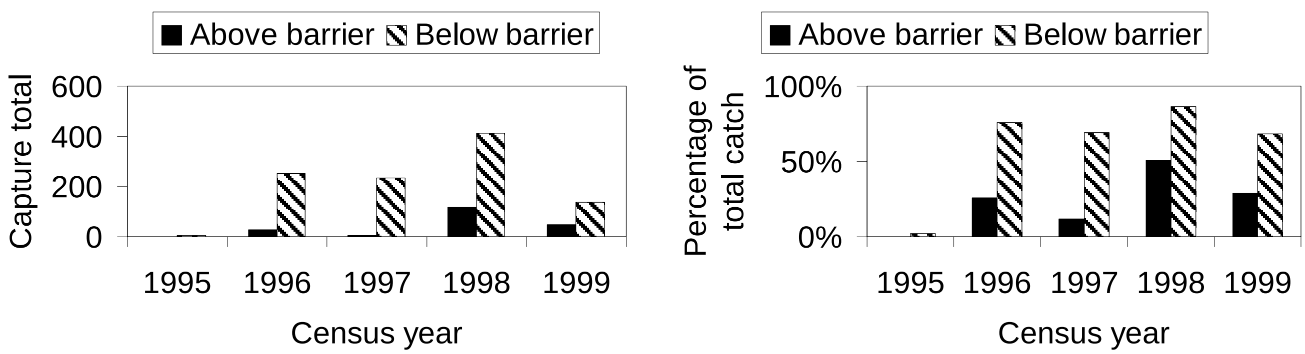


Figure C5. *Cyprinella lutrensis* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the Florence-Casa Grande Canal.

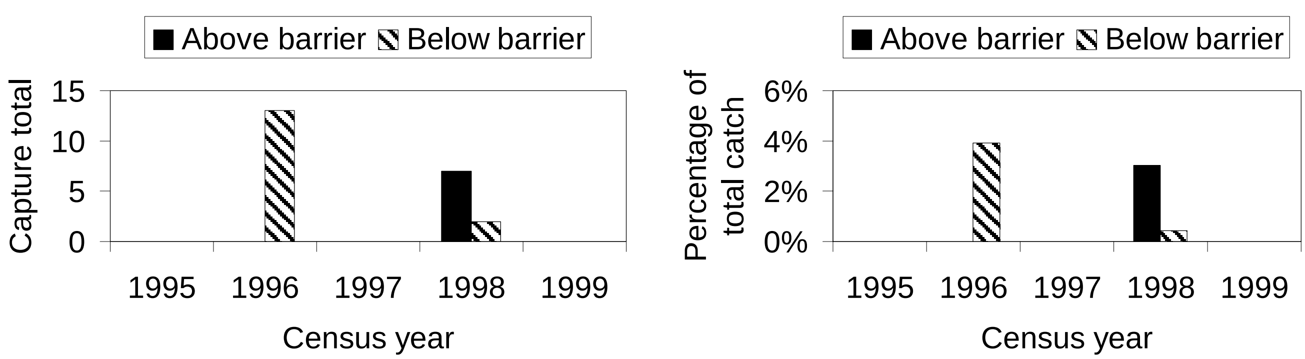


Figure C6. *Dorosoma petenense* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the Florence-Casa Grande Canal.

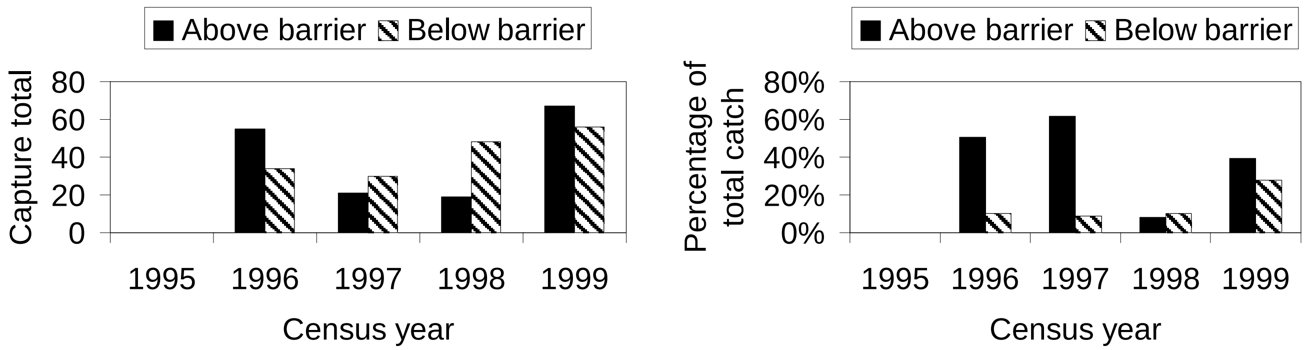


Figure C7. *Gambusia affinis* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the Florence-Casa Grande Canal.

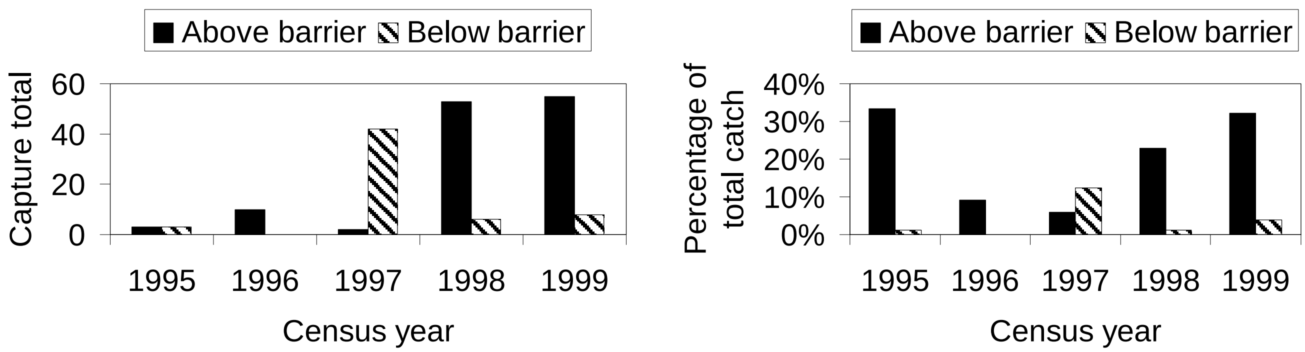


Figure C8. *Ictalurus punctatus* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the Florence-Casa Grande Canal.

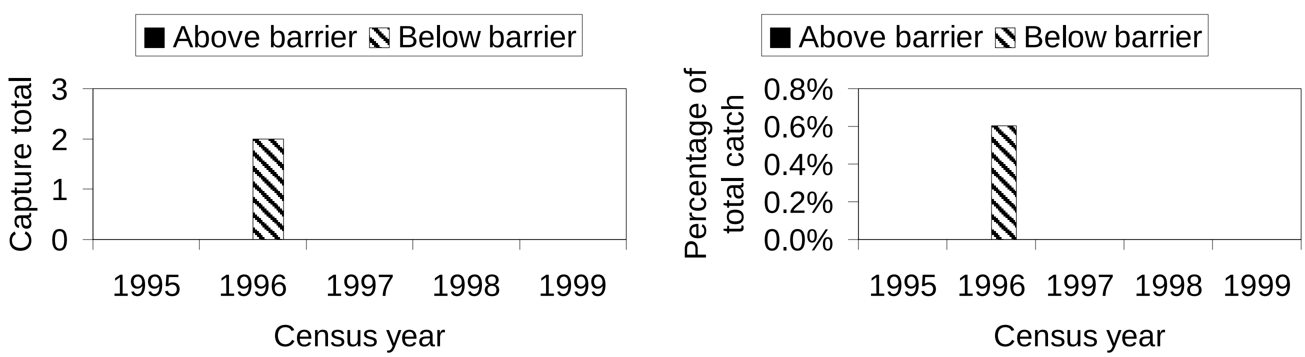


Figure C9. *Lepomis cyanellus* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the Florence-Casa Grande Canal.

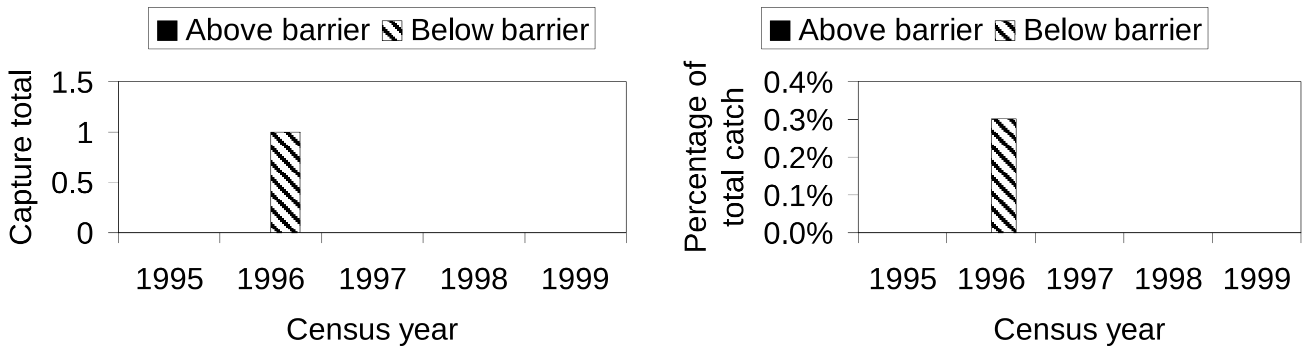


Figure C10. *Lepomis macrochirus* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the Florence-Casa Grande Canal.

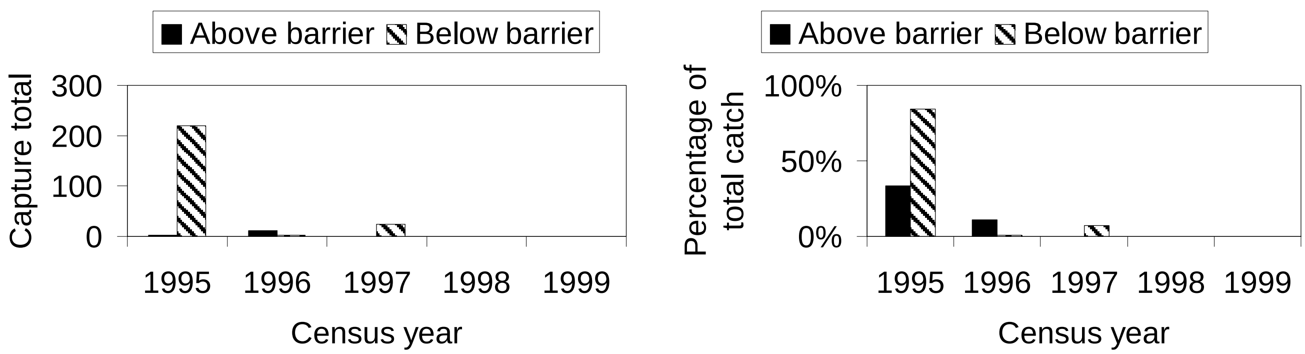


Figure C11. *Pantosteus clarki* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the Florence-Casa Grande Canal.

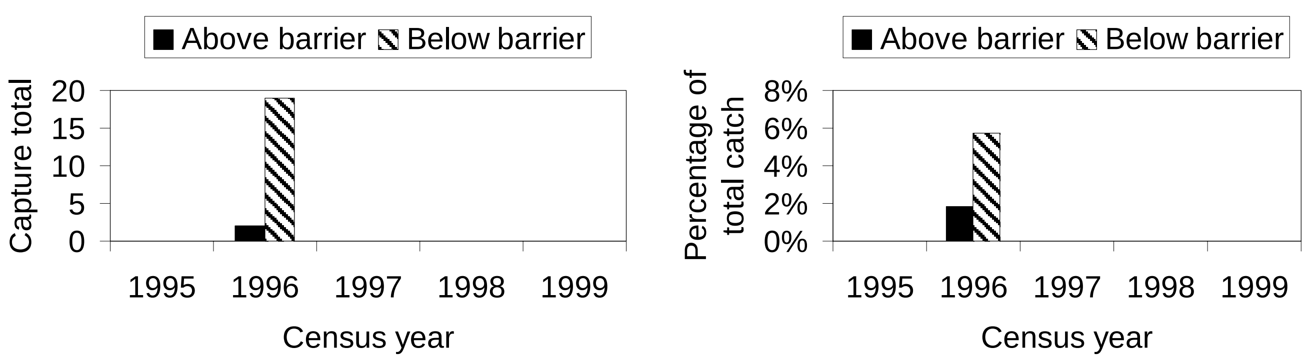


Figure C12. *Pimephales promelas* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the Florence-Casa Grande Canal.

APPENDIX D. Figures D1-D25. Bar graphs of fish capture total (number) and proportion of total catch (as percent) vs. year for the Salt River Project (SRP) Arizona (North) Canal.

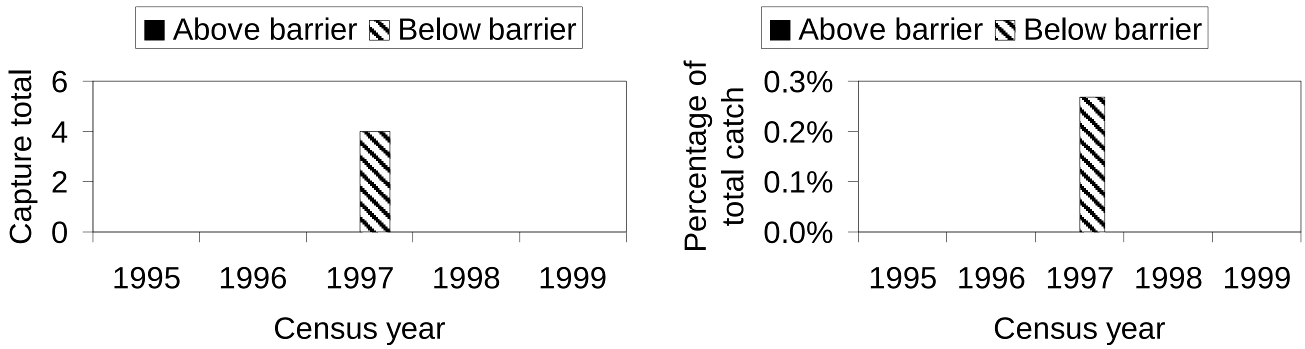


Figure D1. *Agosia chrysogaster* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the SRP Arizona Canal.

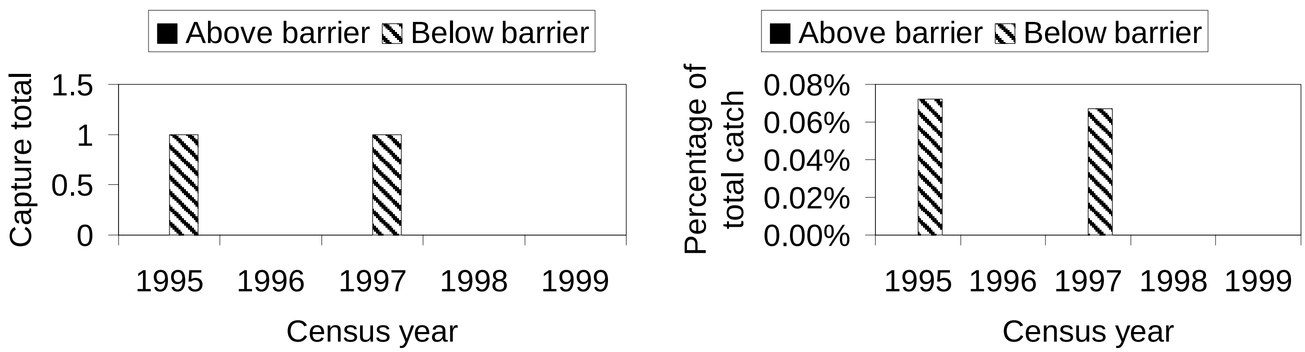


Figure D2. *Carassius auratus* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the SRP Arizona Canal.

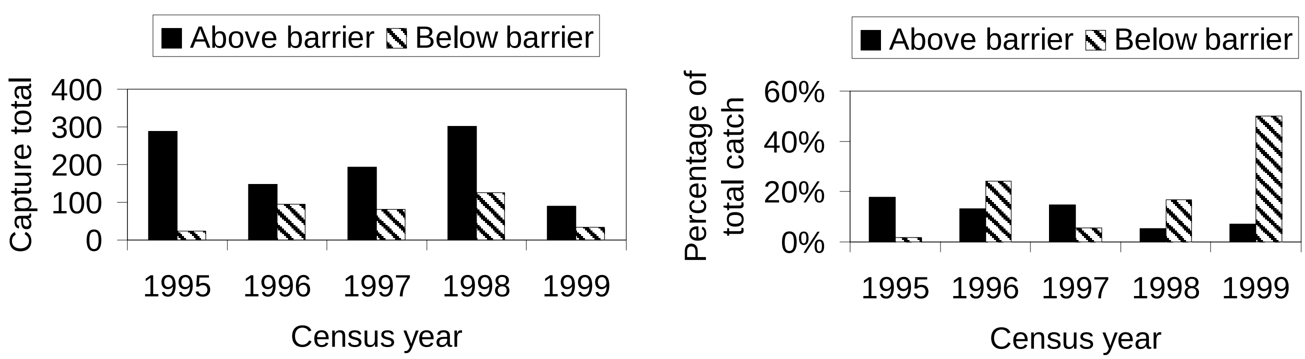


Figure D3. *Catostomus insignis* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the SRP Arizona Canal.

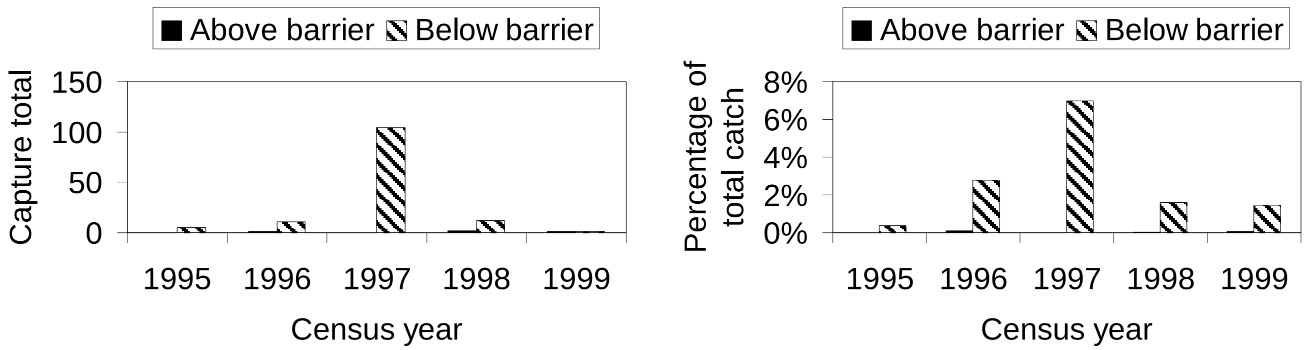


Figure D4. *Ctenopharyngodon idella* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the SRP Arizona Canal.

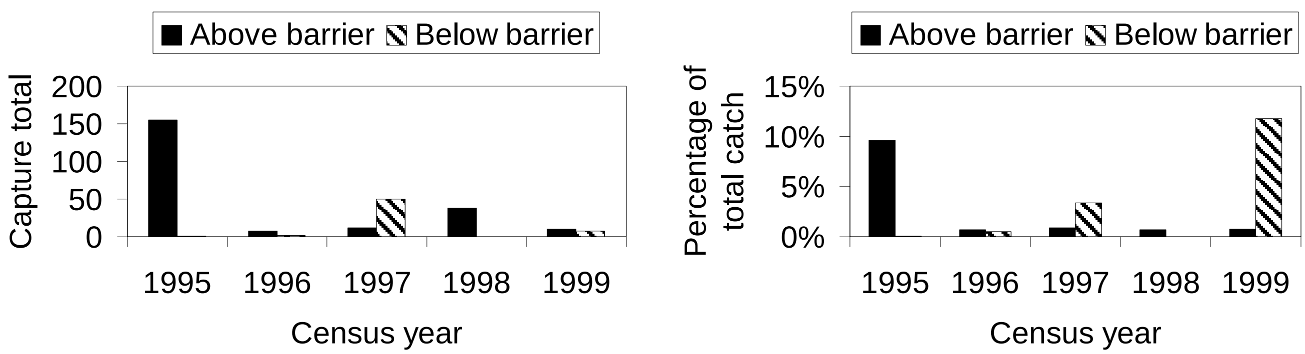


Figure D5. *Cyprinus carpio* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the SRP Arizona Canal.

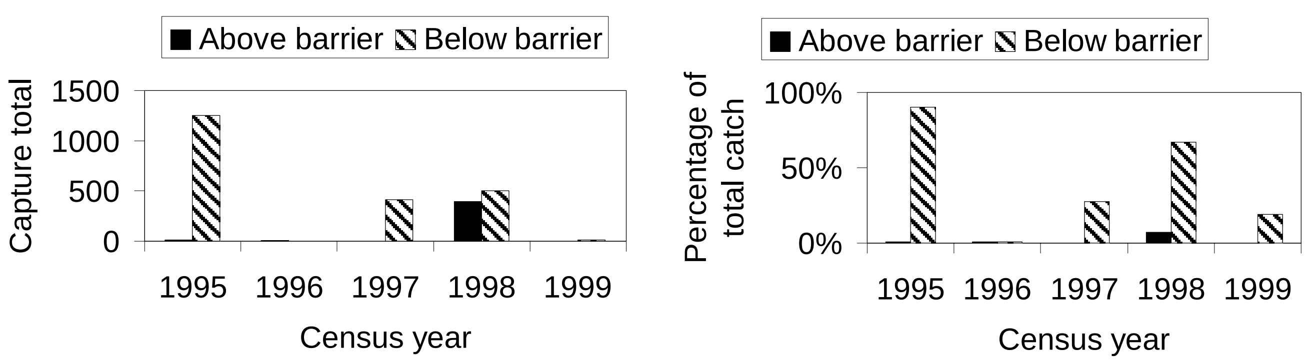


Figure D6. *Cyprinella lutrensis* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the SRP Arizona Canal.

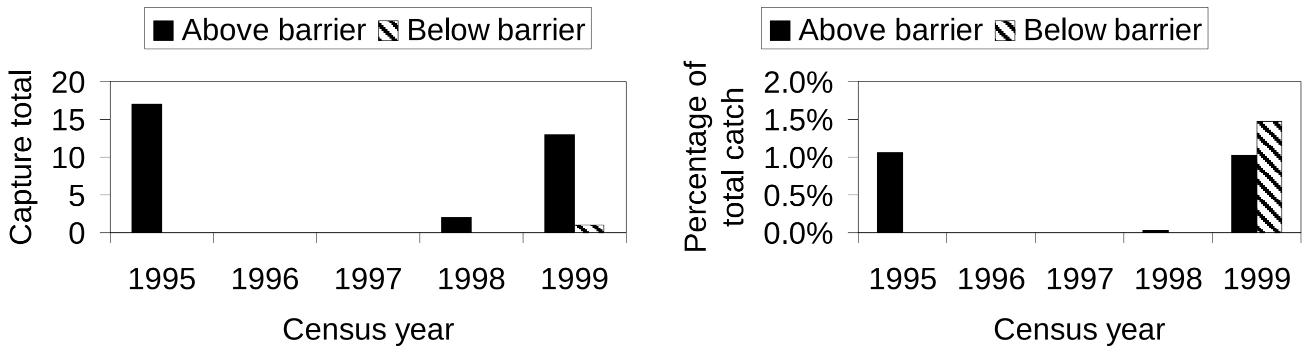


Figure D7. *Dorosoma petenense* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the SRP Arizona Canal.

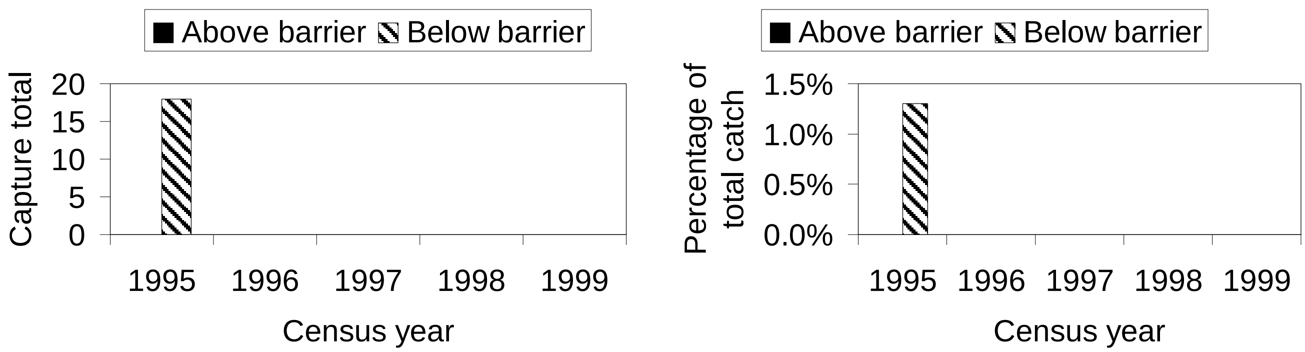


Figure D8. *Gambusia affinis* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the SRP Arizona Canal.

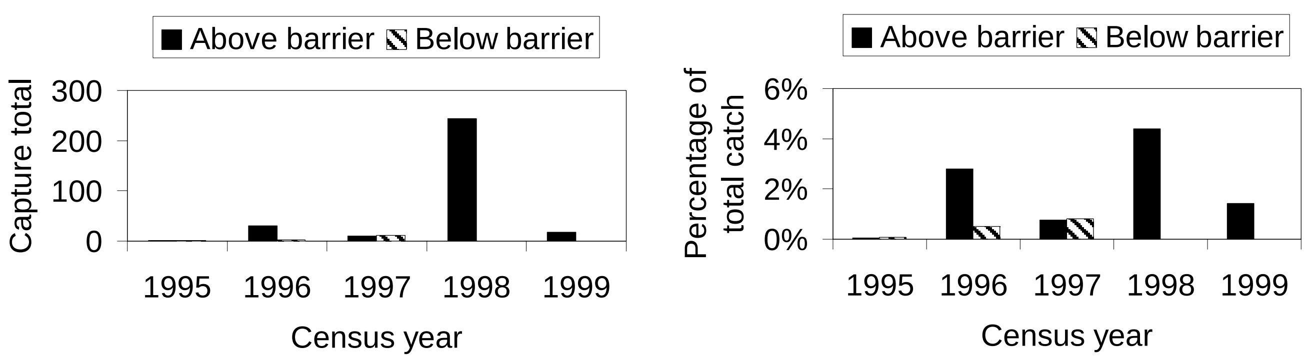


Figure D9. *Gila robusta* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the SRP Arizona Canal.

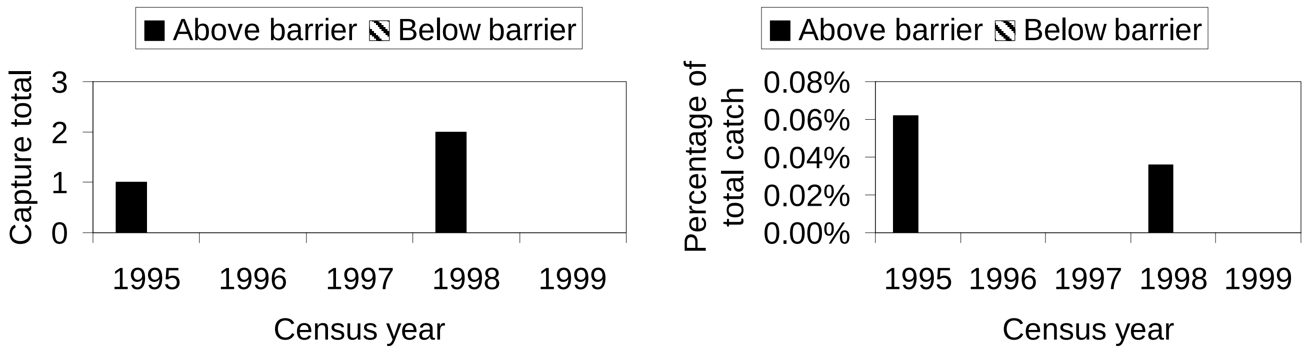


Figure D10. *Ictiobus cyprinellus* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the SRP Arizona Canal.

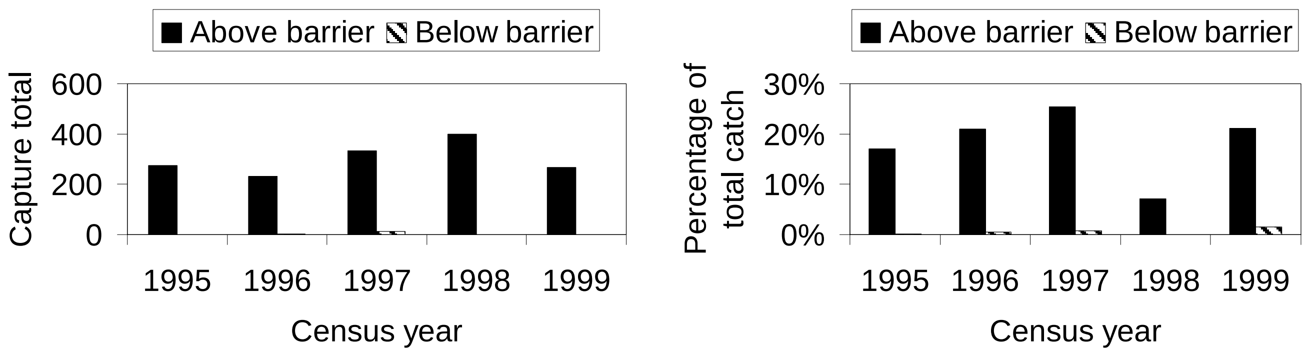


Figure D11. *Ictalurus punctatus* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the SRP Arizona Canal.

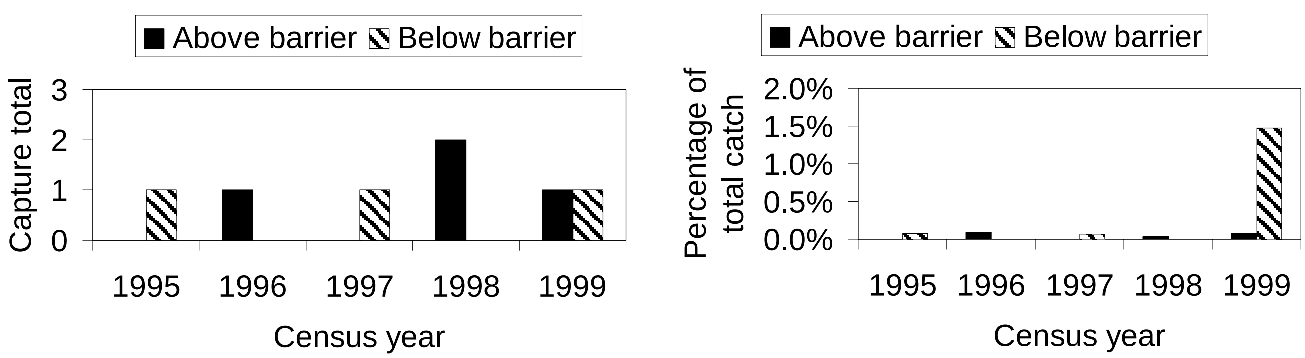


Figure D12. *Lepomis cyanellus* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the SRP Arizona Canal.

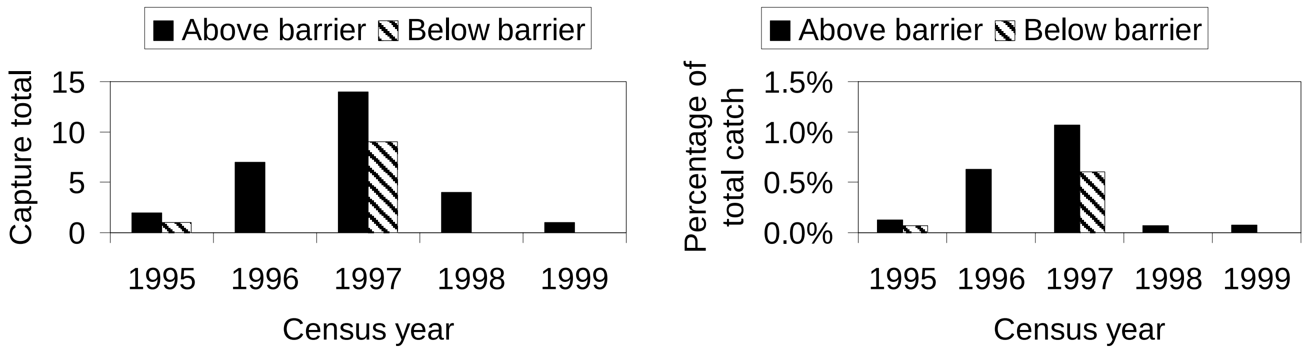


Figure D13. *Lepomis macrochirus* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the SRP Arizona Canal.

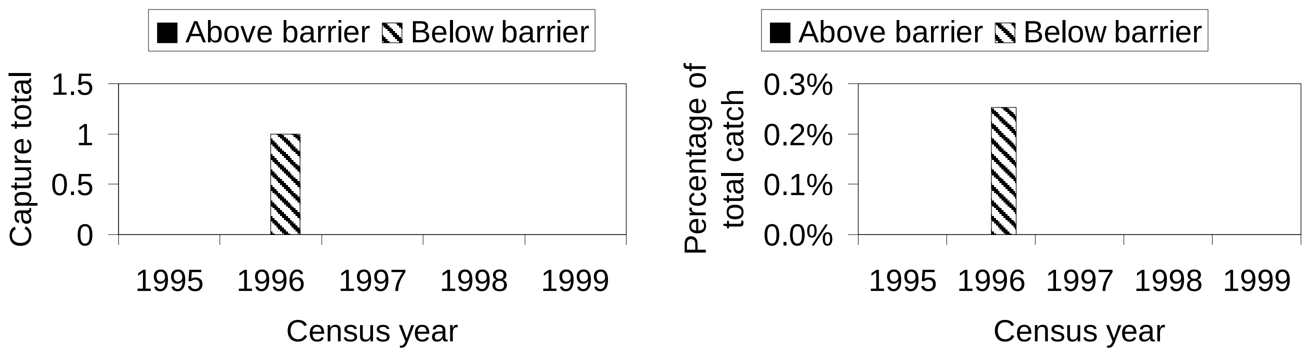


Figure D14. *Lepomis microlophus* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the SRP Arizona Canal.

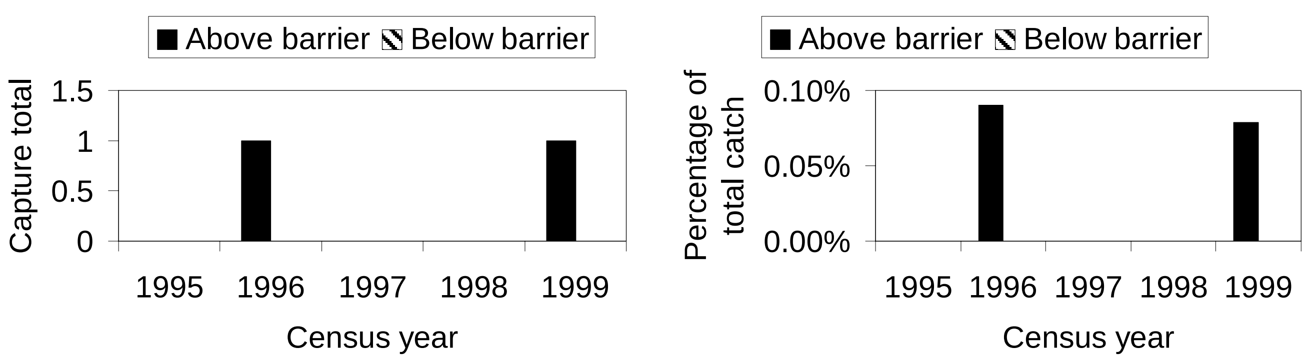


Figure D15. *Micropterus dolomieu* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the SRP Arizona Canal.

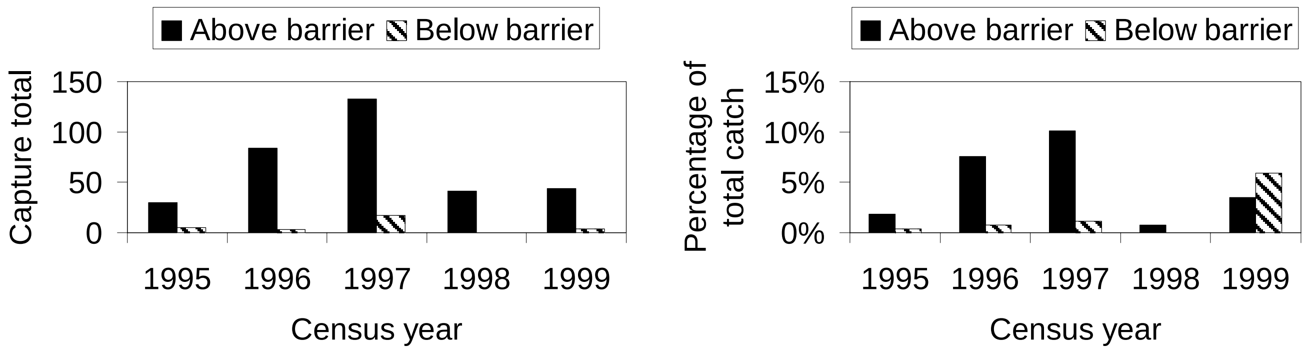


Figure D16. *Micropterus salmoides* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the SRP Arizona Canal.

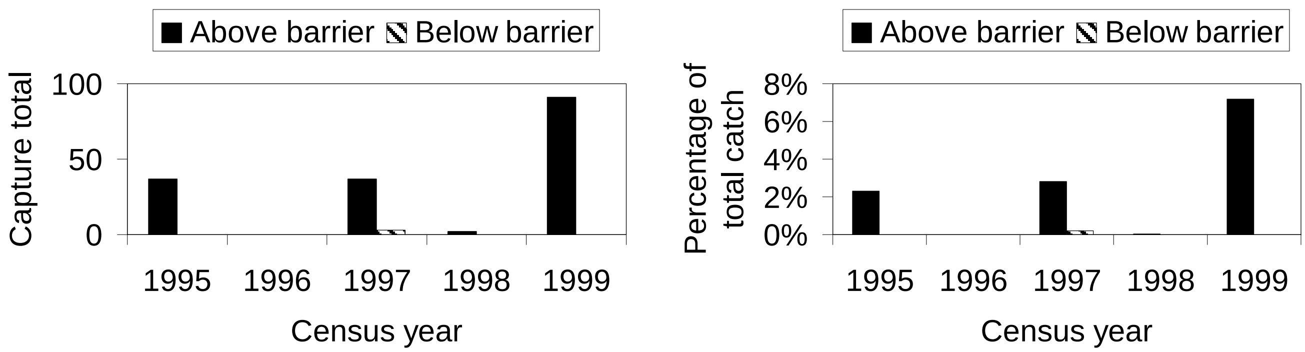


Figure D17. *Morone mississippiensis* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the SRP Arizona Canal.

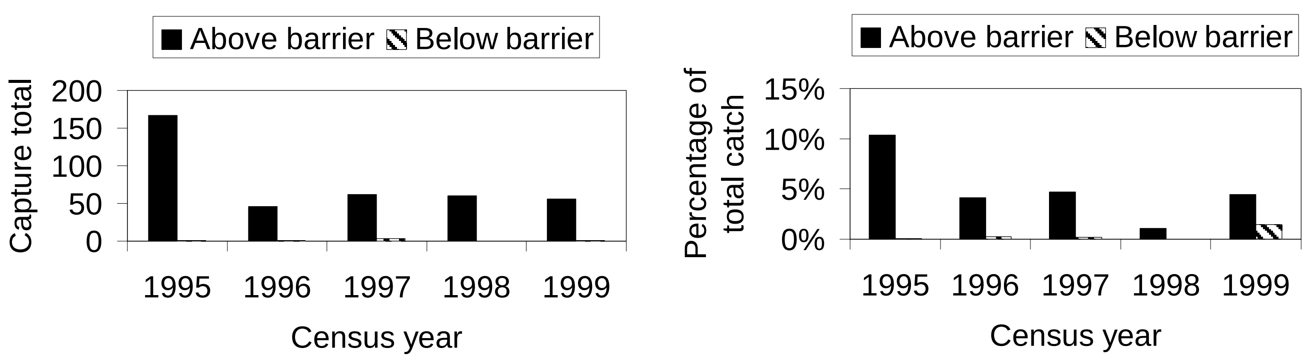


Figure D18. *Oncorhynchus mykiss* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the SRP Arizona Canal.

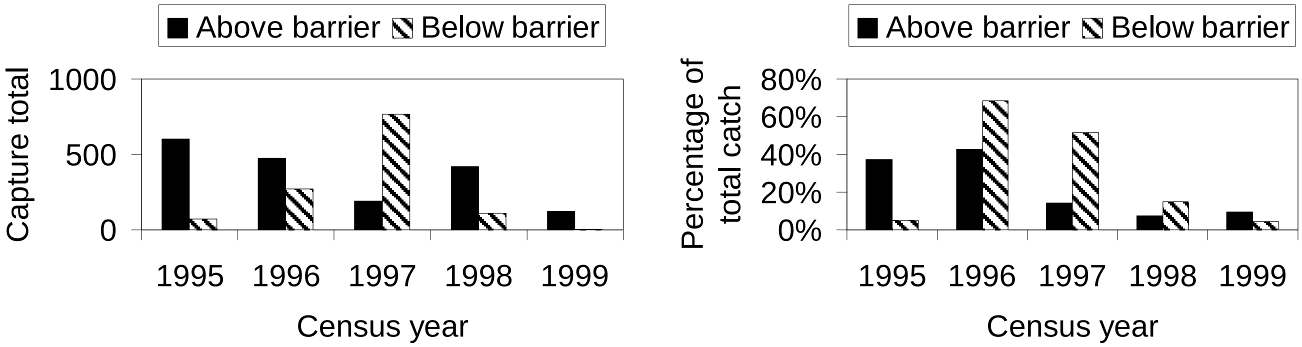


Figure D19. *Pantosteus clarki* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the SRP Arizona Canal.

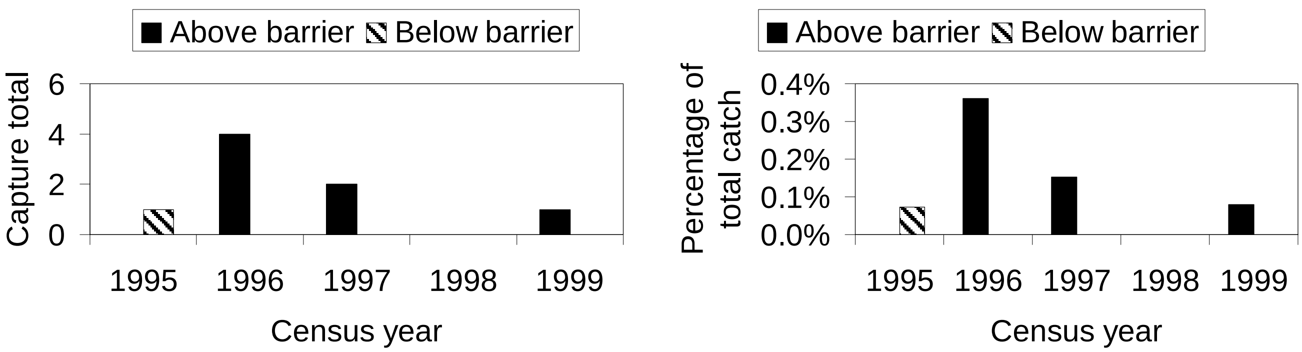


Figure D20. *Pomoxis nigromaculatus* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the SRP Arizona Canal.

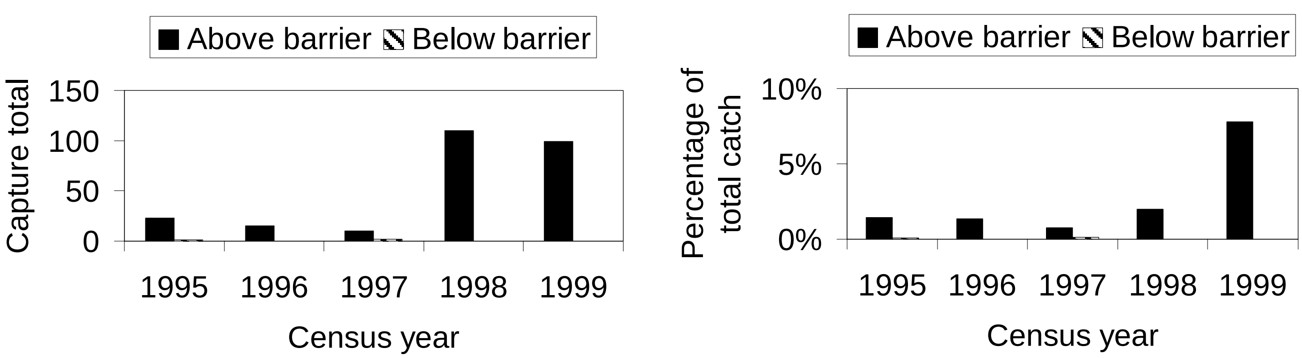


Figure D21. *Pylodictus olivaris* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the SRP Arizona Canal.

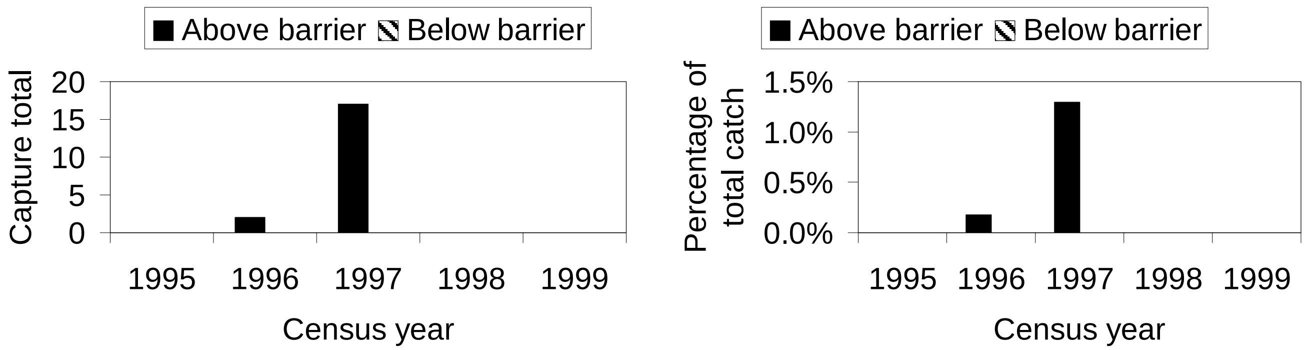


Figure D22. *Stizostedion vitreum* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the SRP Arizona Canal.

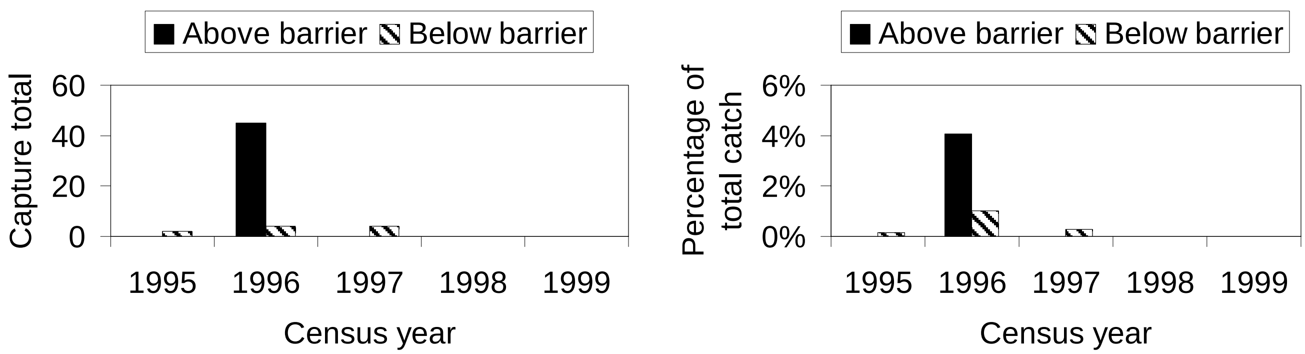


Figure D23. *Tilapia aurea* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the SRP Arizona Canal.

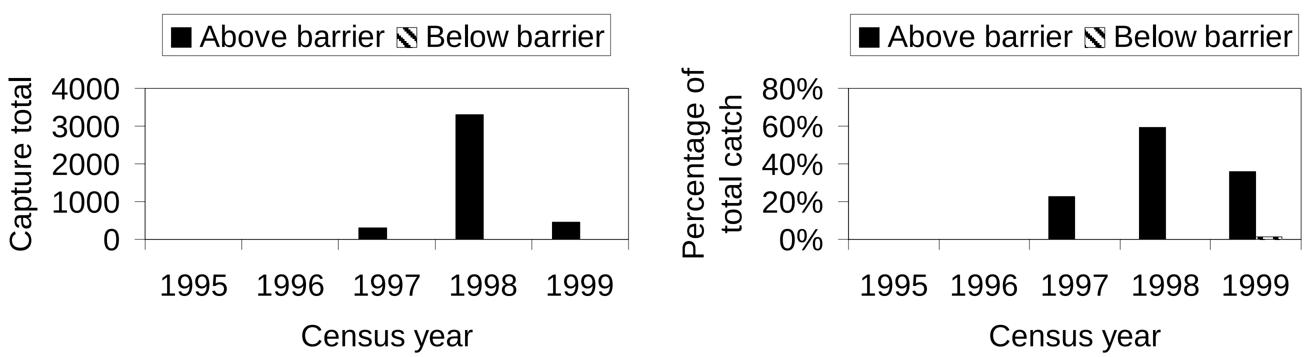
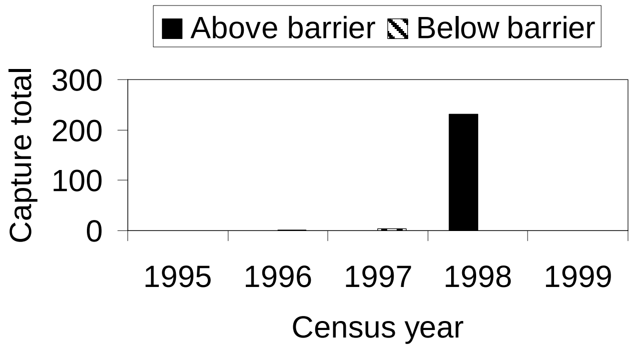


Figure D24. Undetermined *Tilapia* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the SRP Arizona Canal.



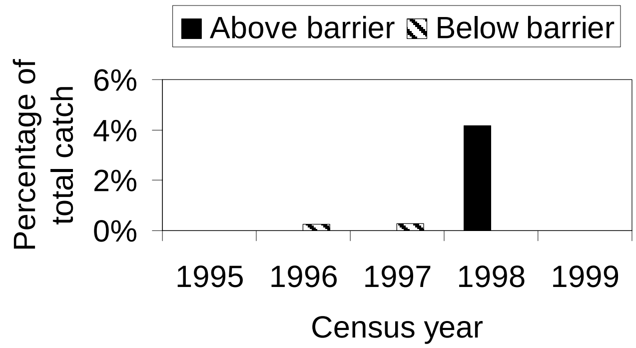


Figure D25. *Tilapia zilli* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the SRP Arizona Canal.

APPENDIX E. Figures E1-E25. Bar graphs of fish capture total (number) and proportion of total catch (as percent) vs. year for the Salt River Project (SRP) South Canal.

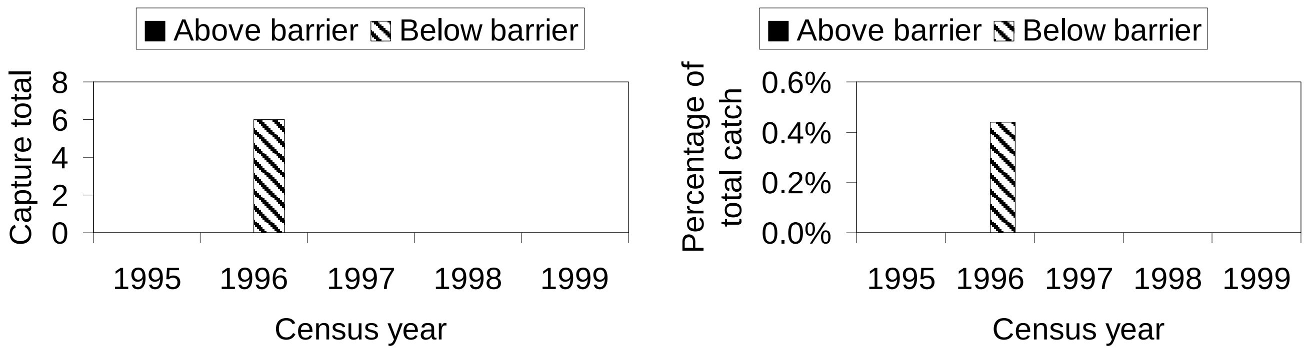


Figure E1. *Agosia chrysogaster* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the SRP South Canal.

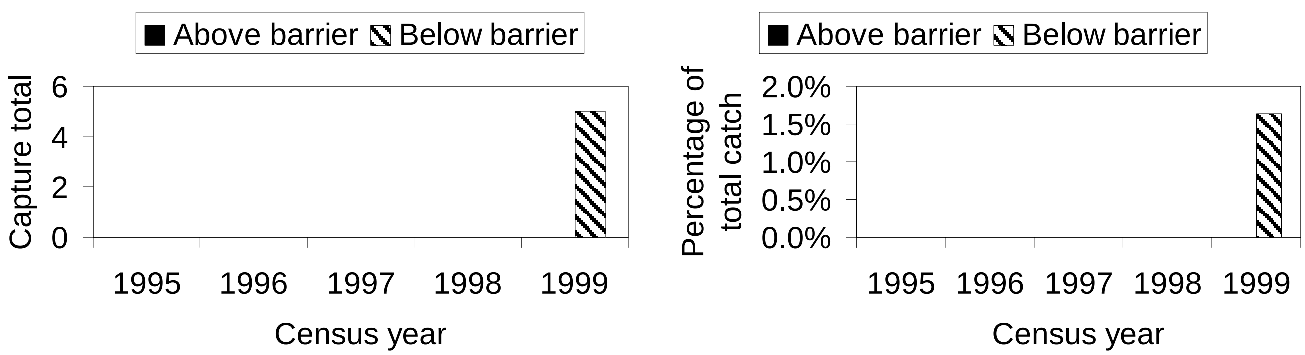


Figure E2. *Ameiurus natalis* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the SRP South Canal.

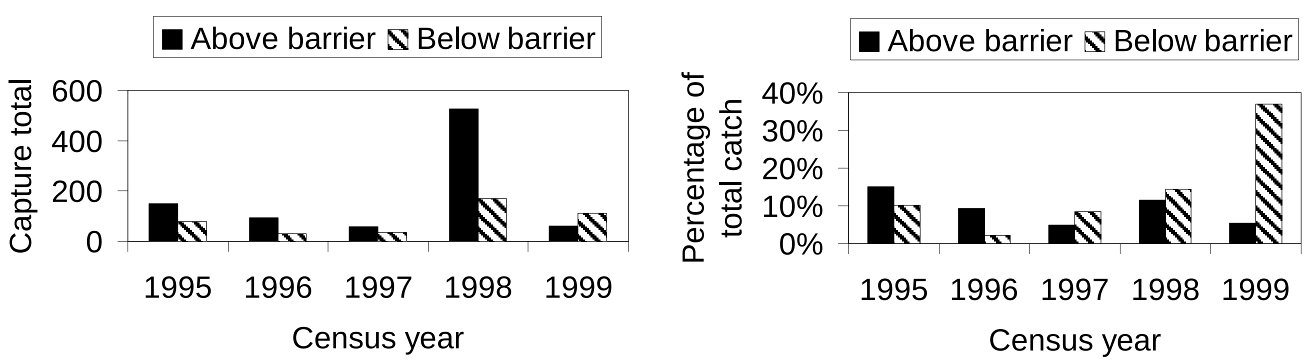


Figure E3. *Catostomus insignis* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the SRP South Canal.

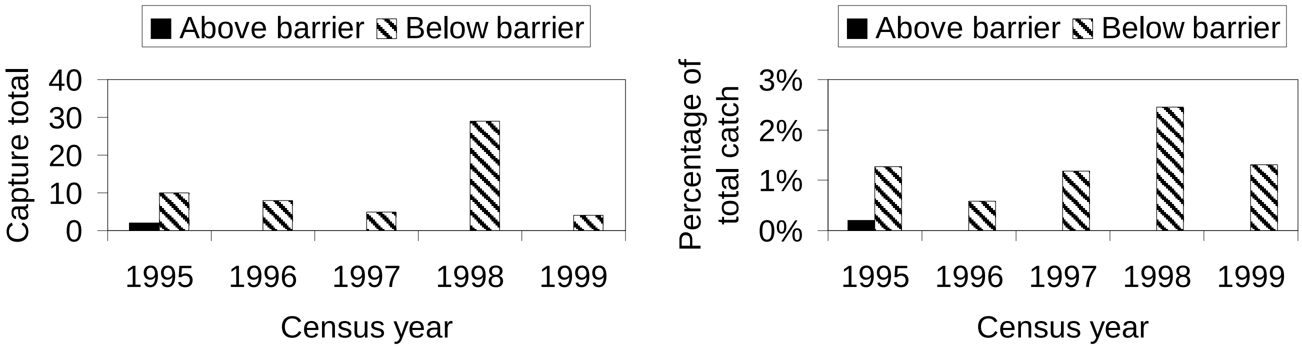


Figure E4. *Ctenopharyngodon idella* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the SRP South Canal.

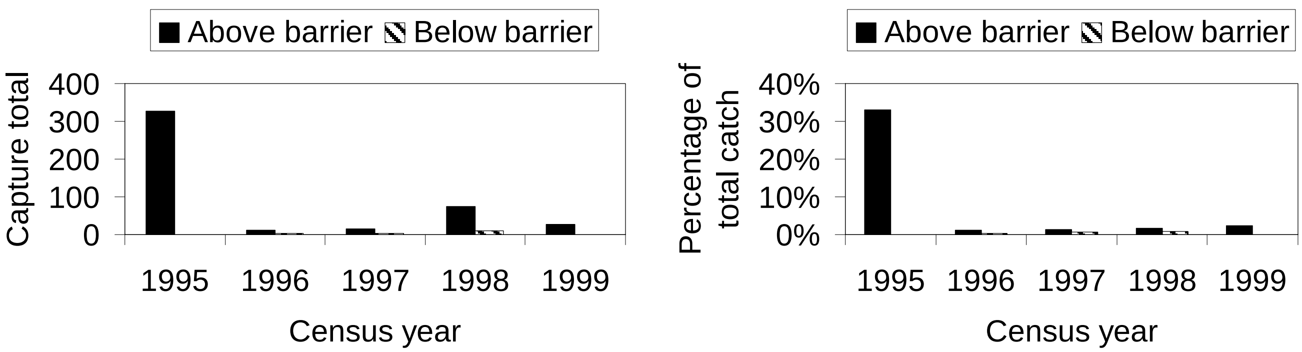


Figure E5. *Cyprinus carpio* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the SRP South Canal.

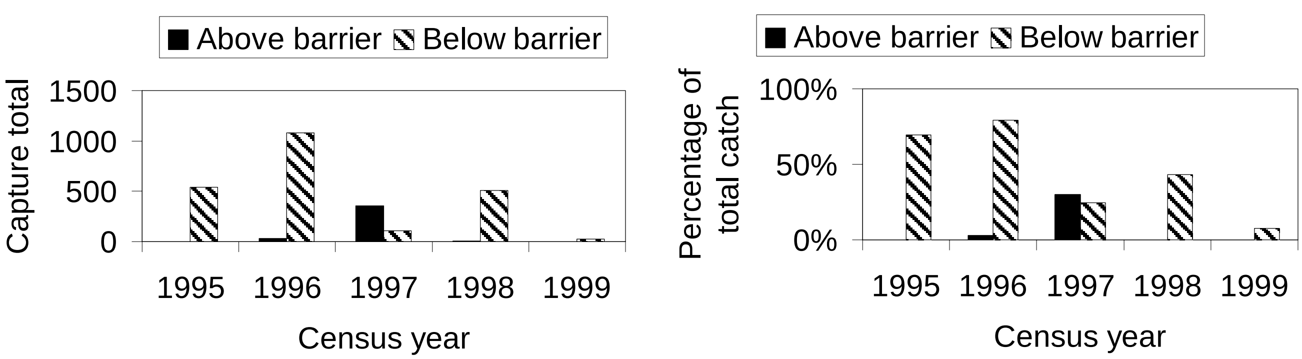


Figure E6. *Cyprinella lutrensis* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the SRP South Canal.

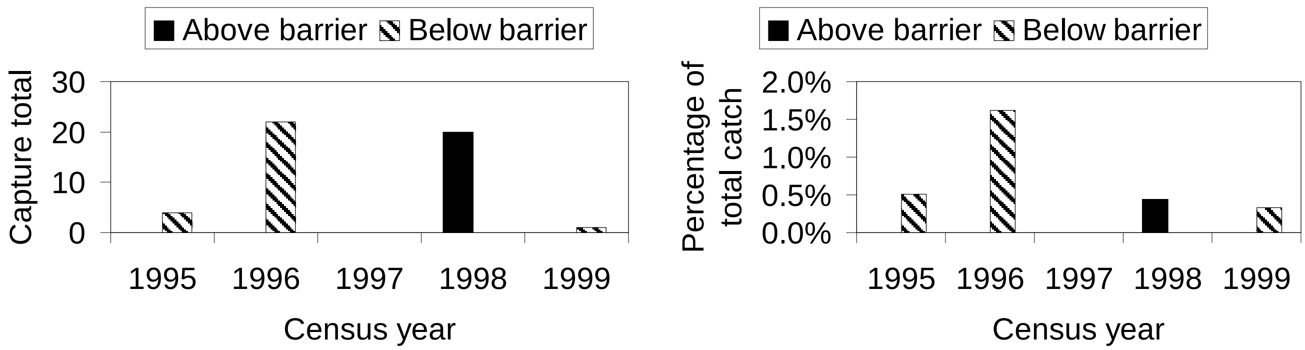


Figure E7. *Dorosoma petenense* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the SRP South Canal.

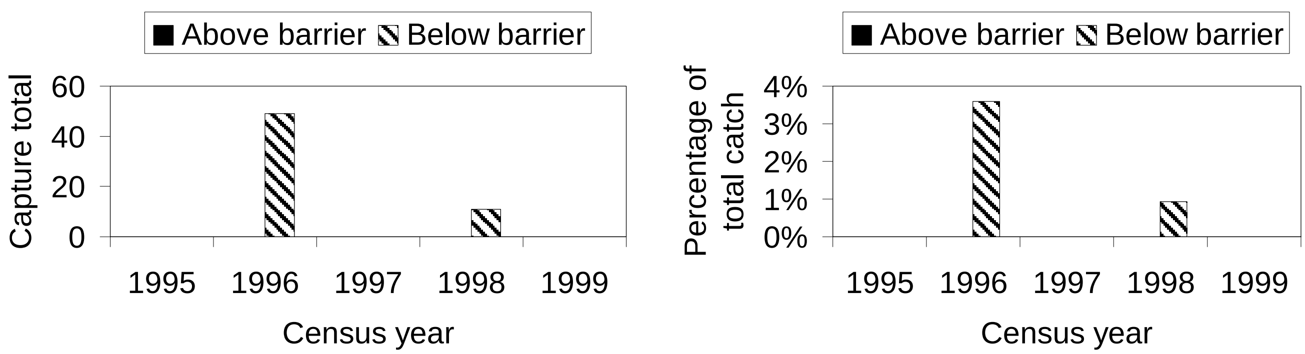


Figure E8. *Gambusia affinis* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the SRP South Canal.

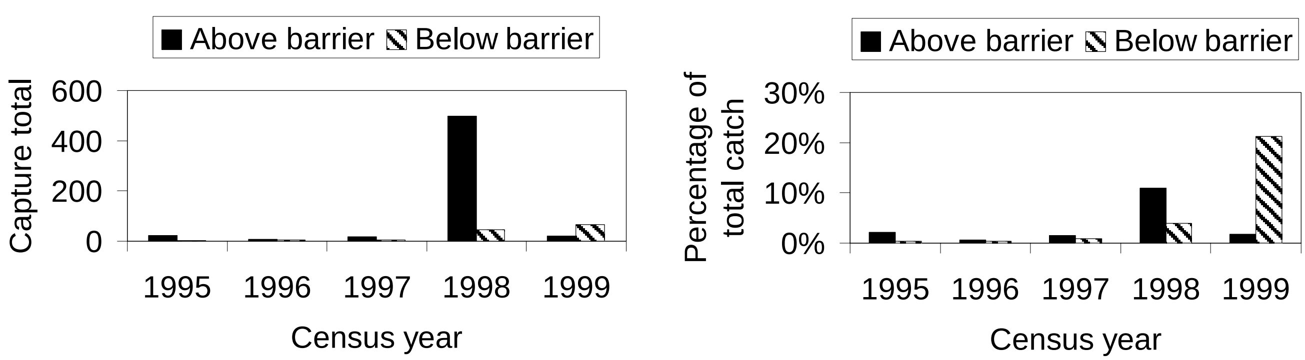


Figure E9. *Gila robusta* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the SRP South Canal.

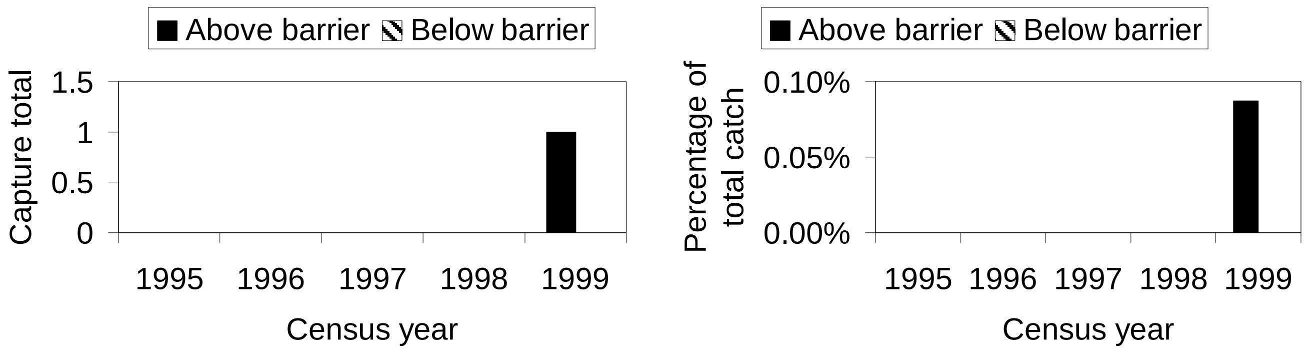


Figure E10. *Lepomis* hybrid total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the SRP South Canal.

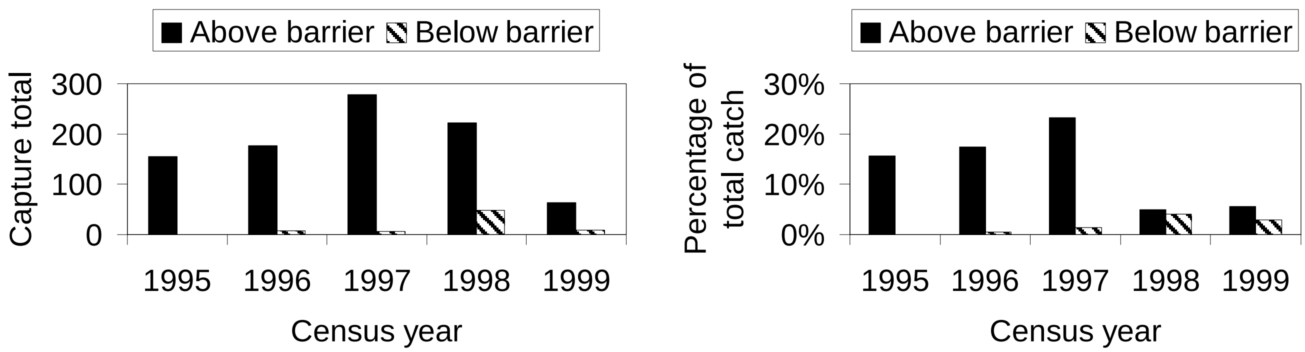


Figure E11. *Ictalurus punctatus* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the SRP South Canal.

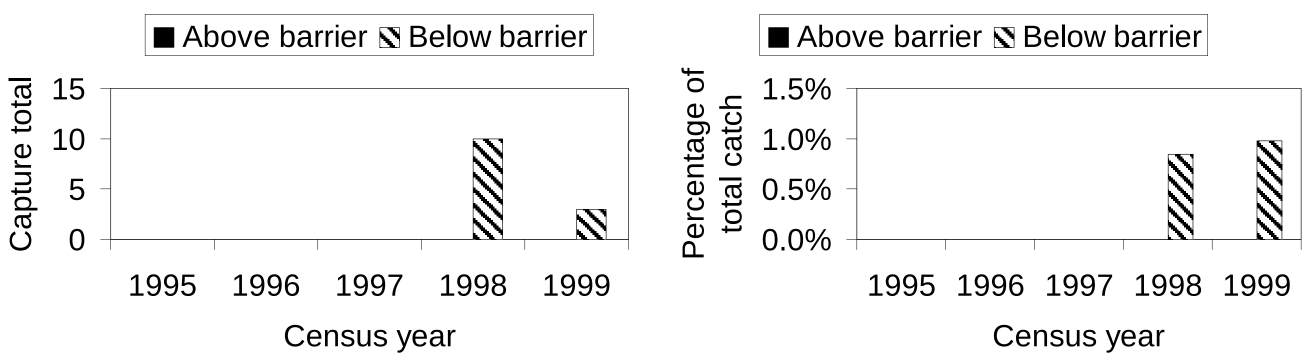


Figure E12. *Lepomis cyanellus* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the SRP South Canal.

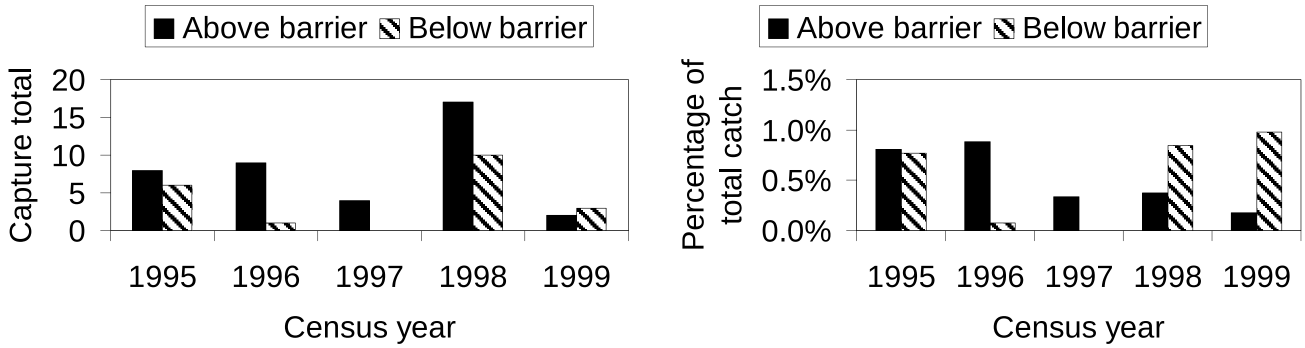


Figure E13. *Lepomis macrochirus* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the SRP South Canal.

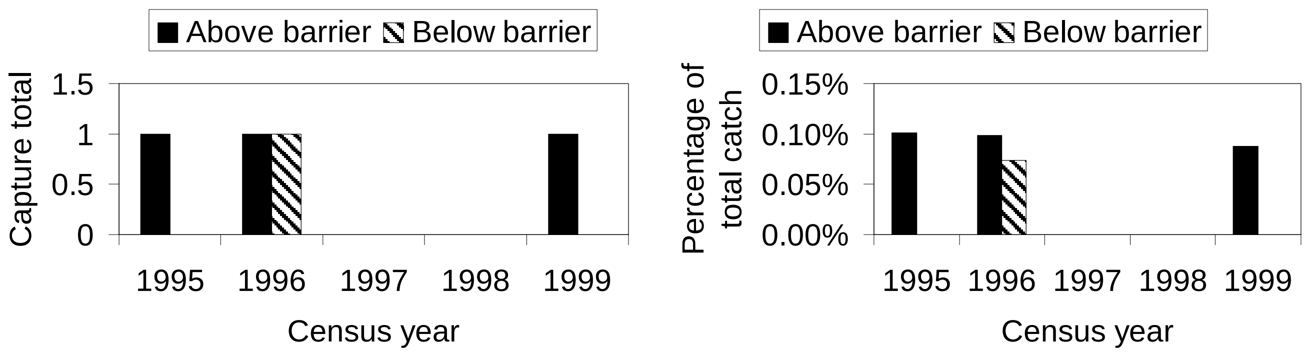


Figure E14. *Micropterus dolomieu* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the SRP South Canal.

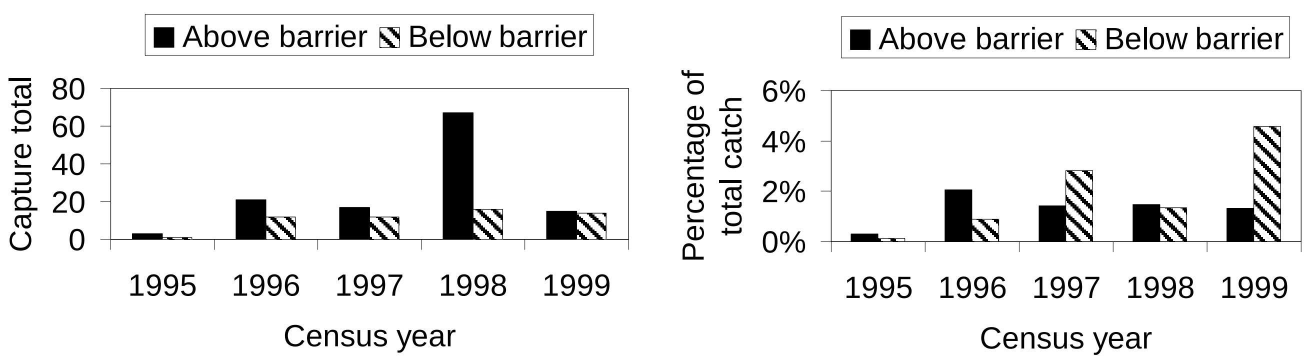


Figure E15. *Micropterus salmoides* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the SRP South Canal.

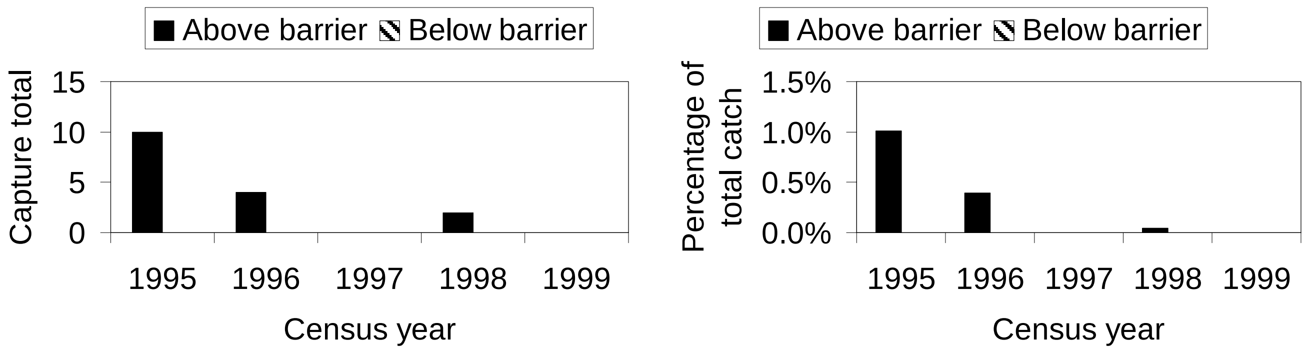


Figure E16. *Morone mississippiensis* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the SRP South Canal.

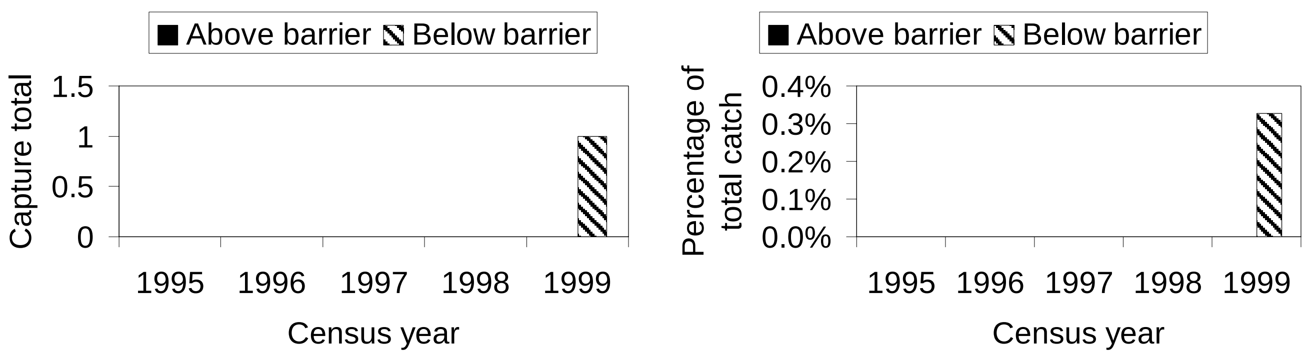


Figure E17. *Morone saxatilis* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the SRP South Canal.

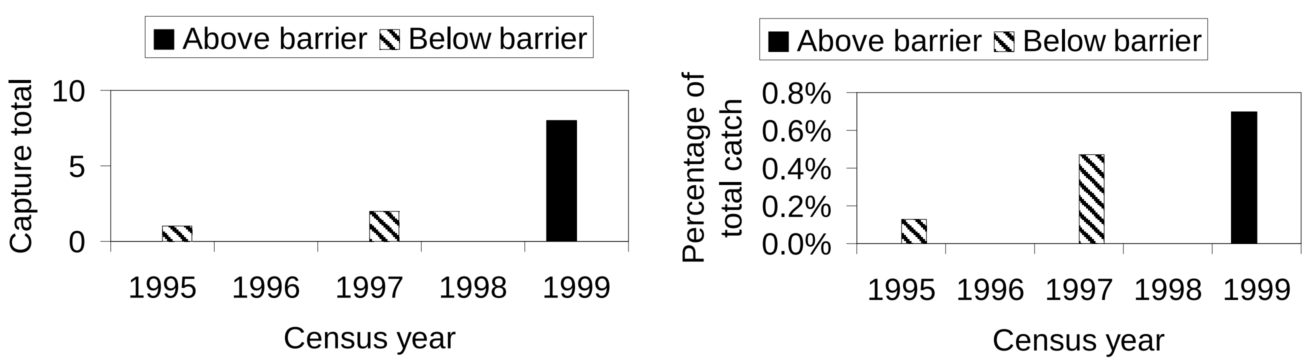


Figure E18. *Oncorhynchus mykiss* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the SRP South Canal.

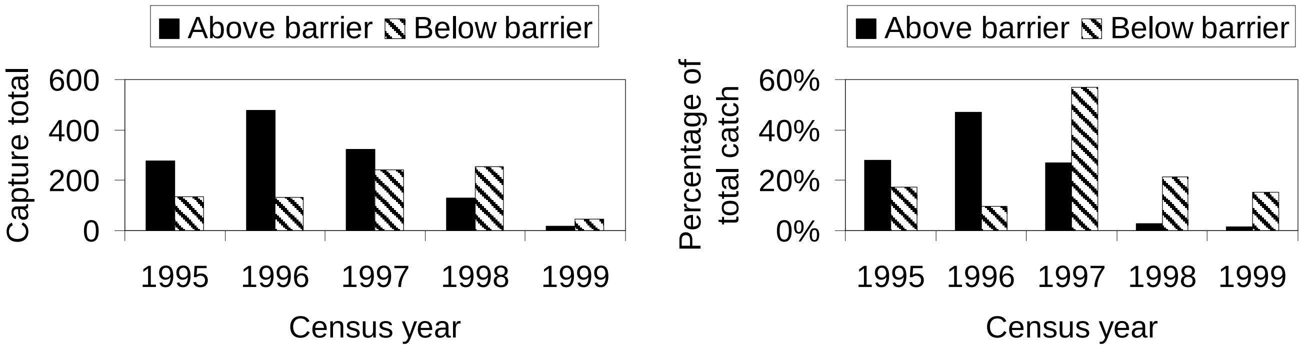


Figure E19. *Pantosteus clarki* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the SRP South Canal.

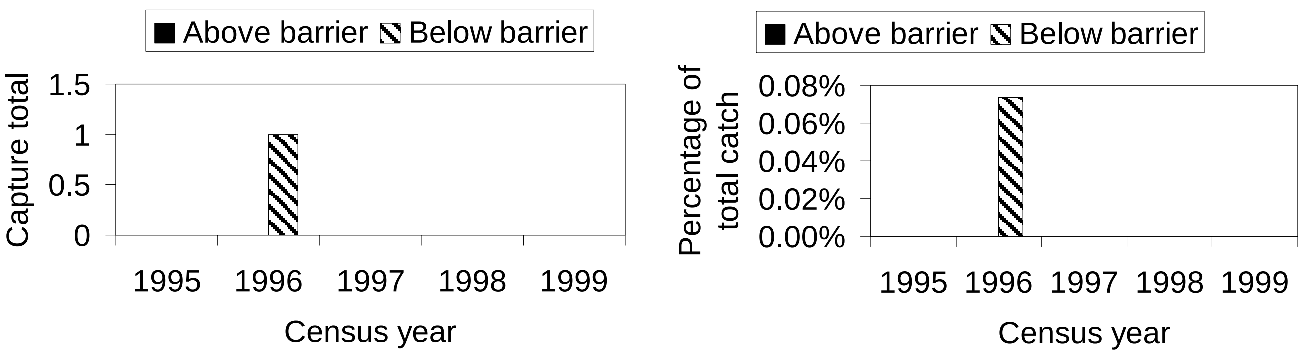


Figure E20. *Pomoxis nigromaculatus* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the SRP South Canal.

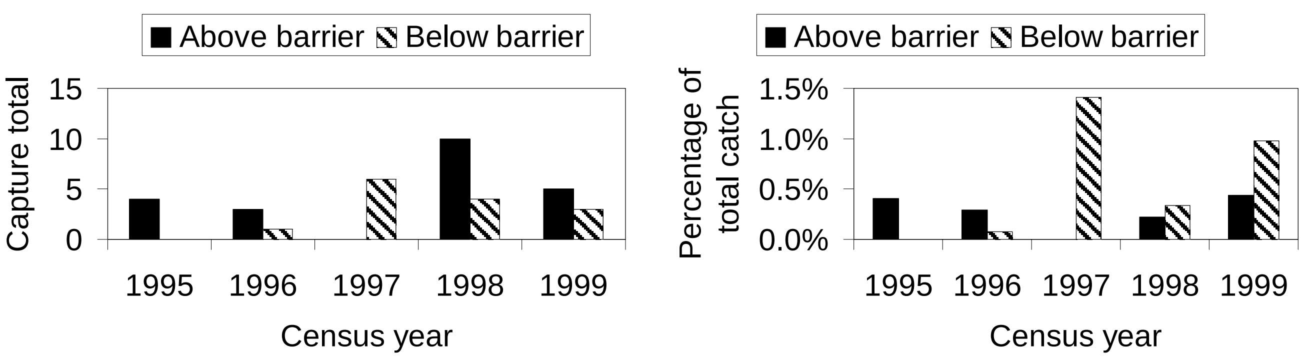


Figure E21. *Pylodictus olivaris* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the SRP South Canal.

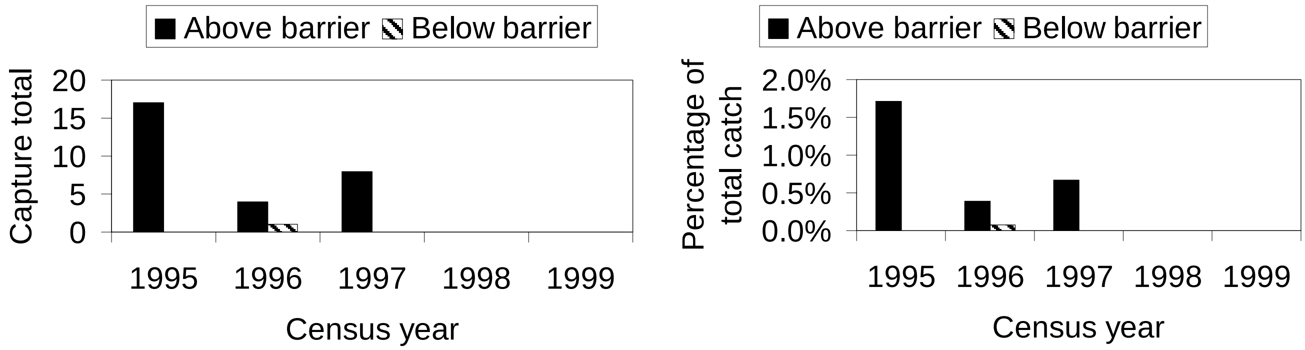


Figure E22. *Stizostedion vitreum* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the SRP South Canal.

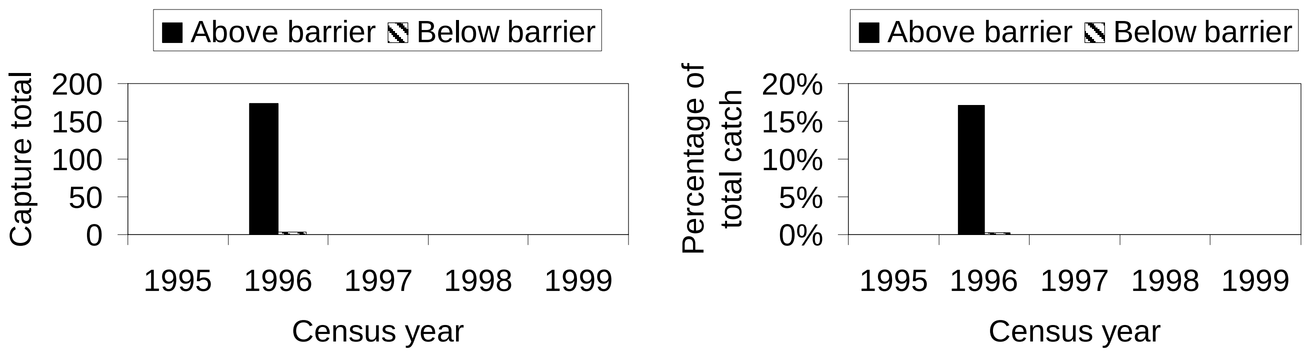


Figure E23. *Tilapia aurea* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the SRP South Canal.

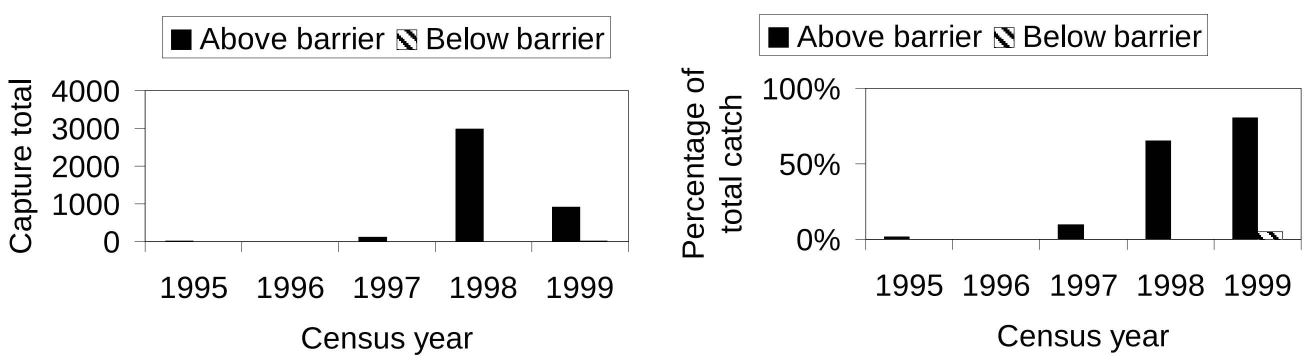
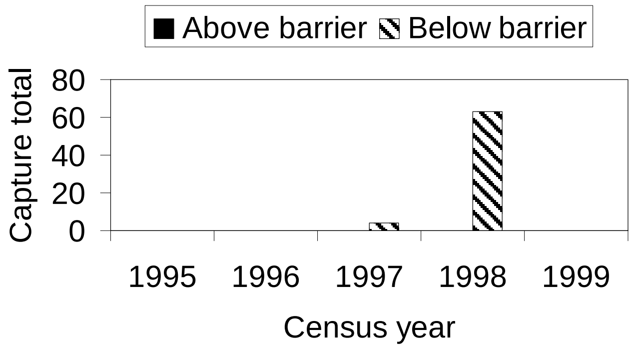


Figure E24. Undetermined *Tilapia* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the SRP South Canal.



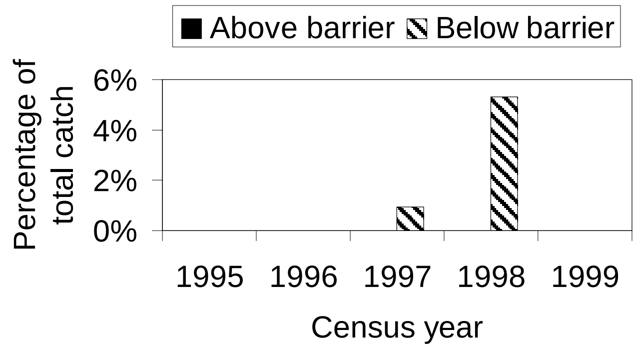


Figure E25. *Tilapia zilli* total catch (left) and proportion of catch (right) from annual sampling efforts above and below the electrical fish barrier in the SRP South Canal.