Assessment of In-Lake Fisheries as related to Alamo Dam and Reservoir

David L. Rogowski and William T. Stewart

Arizona Game and Fish Department, Research Branch
5000 W. Carefree Hwy
Phoenix AZ 85086

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Abstract

Alamo Lake is a reservoir constructed in 1968 located in southwest central Arizona within the Bill Williams drainage. The operation of Alamo Dam and associated structures is the responsibility of the U.S. Army Corps of Engineers. Alamo Lake has been managed by Arizona Game and Fish Department (AGFD) for Largemouth Bass since construction of the dam. The Largemouth Bass fishery has experienced fluctuations throughout the years; at times it has been one of the best in the state. AGFD has been monitoring the largemouth bass fishery via electrofishing since 1982. The purpose of this study was to use existing data on the fishery and the reservoir (elevation, surface area, temperature, water quality, etc.) to investigate factors that might be affecting the sport fishery. Analyses were restricted to Largemouth Bass metrics: catch-per-unit effort, total length, relative condition, and recruitment. Higher yearly average water levels were negatively correlated with fall young of the year Largemouth Bass, while variation in spring elevation levels were not significantly related to recruitment or any other measured factor.

Introduction

In Arizona and in many areas in the southwest reservoirs are the only lentic bodies of water of any appreciable size. Historically reservoirs were typically constructed for flood reduction, water storage, and power generation, and generally without much thought to recreational activities. However, recreational activities on reservoirs have become an important part of the local economy; with many reservoirs actively managed for recreation, including sport fishing (Neher et al. 2013).

One of the challenges of managing fisheries on reservoirs is the fluctuating water levels (Beam 1983, Miranda and Meals 2013). Highly variable water levels during certain times of the year can have severe negative effects on the fishery. Many fish only spawn in specific habitats which can be lost when water levels are too high or low. Differences in water levels can also affect recruitment. Many juvenile fish depend on shallow vegetated nearshore habitat during their first year, with low water levels this type of habitat may no longer exist. In many reservoirs there is little to no nearshore aquatic vegetation due to fluctuating water levels.

Manipulating water levels can also be beneficial for some fishes. Increasing water levels in the spring above summer pool levels has resulted in an increased recruitment of Largemouth Bass (*Micropterus salmoides*) in an Alabama reservoir, although growth decreased due to the higher number of fish (Miranda et al. 1984).

Alamo Lake is a reservoir located in southwest central Arizona within the Bill Williams drainage. It was constructed in 1968 and the operation of Alamo Dam and associated structures is exclusively the responsibility of the U.S. Army Corps of Engineers. The primary operational consideration of the dam was flood control, but the Corps revised its Water Control Manual (which guides Alamo Dam operations) in 2003 to better meet other multiple resource objectives such as water conservation, water supply, recreation, and fish and wildlife benefits[1] (Evelyn and Hautzinger 2006). A target lake elevation of 1,125 feet elevation was selected to optimize riparian, fisheries, and wildlife and recreation resources (U.S. Army Corps of Engineers 2003). Water levels in excess of 1,132 feet are rapidly drawn down via the spillway (elevation 1,235 feet) and the dam gates, which have a maximum capacity of 7,000 cubic feet/second (cfs). With each further foot drop in lake elevation below 1,132 feet, the gates are reduced in 1000-cfs increments, until the 1,125-foot elevation is reached. At that point, releases are reduced to 50 cfs until the 1,100-foot elevation is

[1] Much of the information in this paragraph was paraphrased from Russ and Engel's 2012 report.

reached, when releases are further reduced to 25 cfs. Upon reaching the 1,070-foot elevation, releases are further reduced to 10 cfs (Brown and Engel 2013).

Alamo Lake has been managed by AGFD for Largemouth Bass since the construction of the dam. The Largemouth Bass fishery has experienced fluctuations throughout the years; at times it has been one of the best in the state. AGFD has modified regulation occasionally to address changes in the bass population. In 1989 an attempt was made to improve the fishery by instituting a 12 to 16-inch slot limit on Largemouth Bass, and adjusted again in 1992, to 13 to 16 inches, because fish below the slot limit were not being adequately harvested (Jacobson 1997). In 1995 the harvest of three bass within the slot was allowed in the daily bag limit, and the possession limit was doubled, in response to declining condition of bass, particularly within the size class greater than 15 inches. The decline in Largemouth Bass condition was attributed by AGFD to several factors, including falling lake elevation, reduced forage fish production, and a greater biomass of Largemouth Bass within the lake. It was thought that Largemouth Bass were not being harvested at a high enough rate, resulting in higher numbers of fish with relatively poor condition. In 2000 the possession limit was returned to the daily bag limit, with a single fish in the slot limit permitted. In 2013 the slot was eliminated at Alamo Lake in response to manager's belief that the restrictive regulation was no longer necessary (Brown and Engel 2013).

The primary purpose of this study was to investigate how reservoir operations have potentially affected the fishery, principally the Largemouth Bass fishery at Lake Alamo.

Methods

Alamo Lake

Alamo Lake is located on the Bill Williams River downstream of the confluence of the Big Sandy and Santa Maria Rivers (Figure 1), which join to create the Bill Williams River. Alamo Lake was created upon the completion of Alamo Dam in 1968. The earthen dam is 39 miles upstream of the confluence of the Bill Williams and Colorado rivers, at the southern end of Lake Havasu. Alamo Lake is approximately 3,680 acres (1489 hectares) in size at an elevation of 1,125 feet. The capacity of the lake during the study period ranged from a low of 39, 678 acre-ft and 460,016 acre-ft (48,923- 567,200 meter^3). Alamo lake is monomictic, generally turning over once in the winter (Wanjala 1985).

Largemouth Bass, Channel Catfish (*Ictalurus punctatus*), Flathead Catfish (*Pylodictis olivaris*), and bullfrogs (*Rana catesbeiana*) were initially stocked by Arizona Game and Fish Department (AGFD) in 1968, followed by Channel Catfish, Redear Sunfish (*Lempomis microlophus*) and bullfrogs in 1969. Channel Catfish and bullfrogs were again stocked in 1974, and 1978. 1978 was the last year of any officially stocking by AGFD.

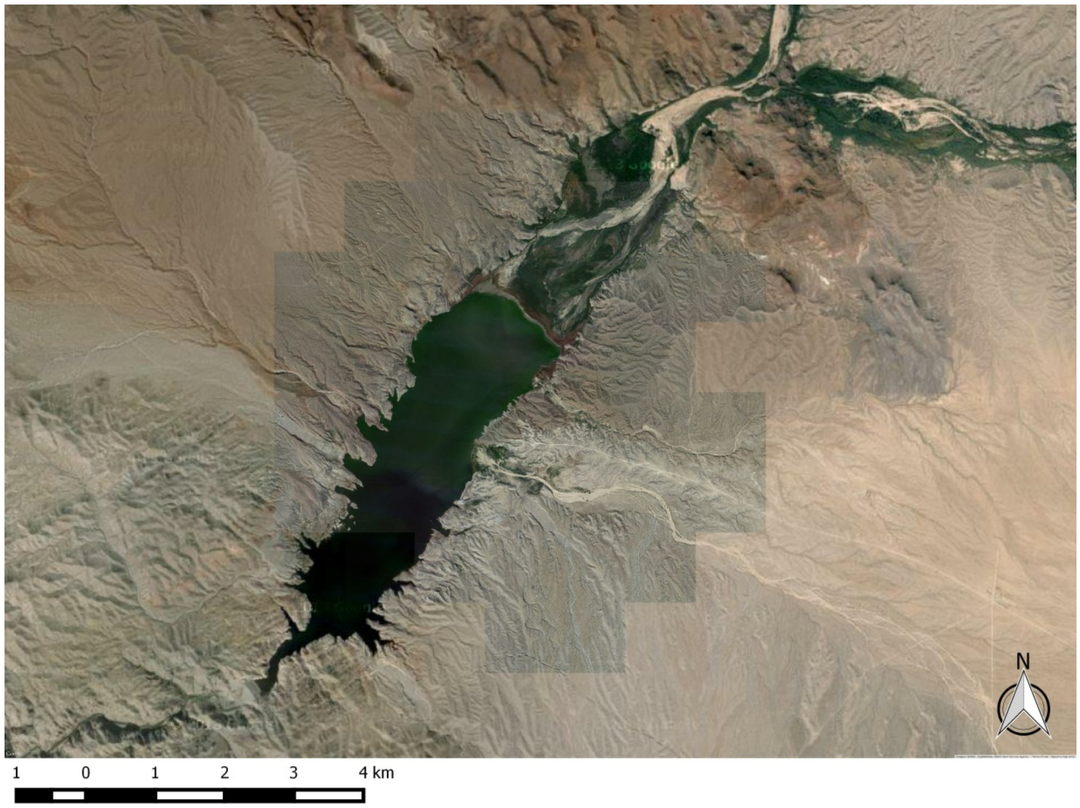

Figure 1. Image of Alamo Lake derived from Google Earth ®
Fish Stocking

Table 1. Species and number officially stocked in Alamo Lake by Arizona Game and Fish Department (1972-1978)

Common Name	Scientific Name	Total Stocked
Channel Catfish	*Ictalurus punctatus*	40,200
Redear Sunfish	*Lepomis microlophus*	3075
Largemouth Bass	*Micropterus salmoides*	130
Flathead Catfish	*Pylodictis olivaris*	400
Bullfrog - tadpole	*Rana catesbeiana*	50,100

Other fish were not legally stocked within Alamo Lake (Table 2). Black Crappie (*Pomoxis nigromaculatus*) are believed to have been illegally introduced by the public and or washed down from an upstream source during a 1993 flood, although no upstream source is known (Brown, AGFD 2015 personal communication). Black Crappie first started showing up in surveys in 1995, it is not believed that they were present prior to 1993 (Brown 2015 personal communication).

Table 2. Fishes present or formally present in Alamo Lake between 1982-2014.

Species	Common Name	Data source
Ameiurus natals	Yellow Bullhead	AGFD
Cyprinus carpio	Common Carp	AGFD
Dorosoma petense	Threadfin Shad	AGFD
*Ictularis punctatis**	Channel Catfish	AGFD
Lepomis cyanellus	Green Sunfish	AGFD
Lepomis macrochirus	Bluegill	AGFD
Lepomis microlophus	Redear Sunfish	AGFD
*Micropterus salmoides**	Largemouth Bass	AGFD
Notemigonus crysoleucas	Golden shiner	AGFD
*Pomoxis nigromaculatus**	Black Crappie	AGFD
Tilapia spp.	Tilapia Species	AGFD
Ameiurus melas	Brown Bullhead	Shafroth & Beauchamp 2006
Pilodictus olivaris	Flathead catfish	Shafroth & Beauchamp 2006
Carassius auratus	Goldfish	Shafroth & Beauchamp 2006
Gambusia affinis	Western Mosquitofish	Shafroth & Beauchamp 2006
Notropis lutrensis	Red Shiner	Shafroth & Beauchamp 2006

*Primary focus of electrofishing surveys

Sampling

In 2003 the AGFD initiated a standard fish sampling protocol for all state waters (Bryan *et al*. 2003), with the intent of standardizing survey methodology throughout the state. Prior to standardization sampling and monitoring of Alamo Lake was not consistent, and despite statewide standardization it was still not consistent or representative. Biologists would concentrate effort on capturing Largemouth Bass or other sport fish species, but would only collected one individual of each species for distribution information (Brown and Engel 2013). Biologists would concentrate effort on capturing Largemouth Bass or other sport fish species, but would only collected one individual of other species for distribution information (Brown and Engel 2013).

Sampling stations were generated at 500 m intervals using a topographic mapping program. From within this set of stations, a subset was randomly selected for sampling each survey. It was necessary to somewhat modify the randomly chosen subset, as a distance greater than 500 meters was often covered during a 900-second sampling session. When compiling a list of stations to survey, any station that was adjacent to a station previously selected was eliminated, and the next survey station in the randomly generated list meeting the criteria was chosen. If the randomly selected site was found to be unsuitable during the survey, the shoreline was followed in the direction of the survey methodology until a suitable station was located. Sites determined to be unsuitable were generally the result of the presence of human activity in or adjacent to the water that could raise safety or negative public perception issues.

Each sampling session began as near a UTM coordinate designating the sampling station as possible. Sampling locations often began a significant distance from an established survey station due to fluctuations in water levels. For all surveys beginning in 2006, current was applied for approximately 30 seconds, followed by a rest of 15 seconds until a total of 900 seconds of pedal time was reached. If, during the 15 seconds of “off” pedal time the boat did not travel a distance of at least 1-½ boat lengths from the spot last shocked, the pedal operator waited until the boat was in position to apply electricity.

Electrofishing surveys employed a 17-foot aluminum utility boat outfitted with a 5,000-watt generator and a Coffelt VVP-15 electrofishing control unit set between 7 to 9 amps of pulsed DC current and 100 to 200 volts. Frequency was set at 80-120 pulses per second with a pulse width of 40-50 percent. Fish were collected using long-handled dip nets, identified to species, weighed (g) and total length measured to the nearest mm. All target fish netted were retained in a live well until the survey station was completed. Fish were then processed and released before transit to the next station.

Note that for most years (1988 - 2009) electrofishing surveys netted only game fish of interest (e.g. Largemouth Bass, Channel Catfish, and Black Crappie) other fish that were stunned via electrofishing were generally not netted or processed. For a number of years (1982-2002) it appears that AGFD only surveyed habitat that they thought was good Largemouth Bass habitat, in other words surveys were not a random sample, nor representative of the lake as a whole. In 2003 they began using a random sampling approach. This approach can also produce bias in size structure estimates (Hubbard and Miranda 1988).

Consequently our response variables were restricted to those pertaining to Largemouth Bass (CPUE, condition, and mean length), and Channel Catfish CPUE, while our explanatory variables were restricted to abiotic factors (e.g. temperature, water level, precipitation, etc.). We were not able to include any information on forage fishes in the model as we don't have consistent reliable data of fishes other than Largemouth Bass, and Channel Catfish.

For the years 1982 to 1997 we were unable to obtain the original raw data sheets of site data. During this time period it is believed that only four to six samples were collected per year. While we have data on individual fish captured and processed along with total time of electrofishing, we do not have site information (e.g.: electrofishing time/site, or number of fish/site). As a consequence, CPUE values for 1982-1997 are total fish/total time electrofishing. Calculation of CPUE this way tends to underestimate the average CPUE for data that is not normally distributed typical of catch data (e.g.: lognormal, Poisson, and negative binomial), additionally variances about the mean cannot be calculated. In 2004 there were a number of fish captured but we were unable to determine which site they belonged to, as no site names were provided for those fish, thus they were not included in the analyses.

AGFD primarily conducted fall surveys; however a spring survey was added in 1990 and subsequent years. For this report we concentrate primarily on the fall collected data, as it is the most consistent and provides us with the longest time period (greater sample size). For the fall samples in the years 1995 and 1997 we did not have the effort available (time electrofishing) to calculate CPUE, thus these years were not included in our analyses. Effort levels were not recorded for spring sampling during the years 1995 through 1998, thus we have no CPUE information for those years, leaving 21 years of data for use in analyses of the spring data.

Creel data (angler surveys) were collected by AGFD from 1978 to 1994 however, most of the data has not been entered in a usable format and thus at the time of this report was not available. Consequently data on harvest or angler CPUE was not included in the analyses.

Data

Weather data was obtained from the National Centers for Environmental Information of NOAA (http://www.ncdc.noaa.gov) for the weather station nearest Alamo Lake Reservoir, Lake Havasu City which located approximately 75 km northwest of the reservoir. Variables used in the model are listed in Table 1. Meteorological (e.g. temperature, precipitation…) and reservoir (e.g. elevation, variation…) annual data was based on a year from 1 October till 30 September of the following year for the fall analyses and for spring we used data from the years preceding the spring sampling (e.g. for 1982 we use data collected from 23 April 1981 to 22 April 1982). This accounted for weather and reservoir management during the preceding year of sampling, which is more relevant than a calendar year. The spring variance in reservoir elevation metric was calculated based on the sum of the daily differences in elevation of the lake from March through April when Largemouth Bass are most likely reproducing and juvenile recruitment is occurring. We also used the same time period to calculate the average spring reservoir elevation. Largemouth Bass young of the year (YOY) CPUE was calculated for fish < 150 mm (Shelton *et al*. 1979). Adult Largemouth Bass were considered as those fish ≥ 300 mm (following Jackson and Noble 2000). The length selected for "adult" bass was also the length considered as a quality Largemouth Bass (Anderson and Neumann 1996). For some analyses we used a time lag adjustment. For example we used the previous year's YOY CPUE to investigate overall Largemouth Bass CPUE.

Water quality data has been collected by the US Fish and Wildlife Service and Arizona Department of Environmental Quality (ADEQ) for a number of years (2000-current) at varying frequencies depending on the analyte. We were provided a spreadsheet of this data covering the years 2000-2013 from ADEQ. However a cursory examination of the spreadsheet revealed a large number of obvious data entry errors within the spreadsheet. See Appendix A for more details. As this is not our data and we do not have access to the original data sheets, the data was deemed unusable, and consequently not included in the analyses.

To determine surface area of the reservoir, 29 unique satellite images captured on different days were obtained from the USGS TerraLook website (TerraLook). Areal extent of the surface area was quantified within ImageJ (http://imagej.nih.gov/ij/). The images we used were from the advanced spaceborne thermal emission and reflection radiometer (ASTER). Image contrast was enhanced to maximize the difference in color of the reservoir with the surrounding terrain when necessary. The surrounding area was cropped out and using the histogram function we summed the selected pixels that defined the reservoir. This allowed us to obtain the number of pixels that defined the reservoir and then calculate the square km. Three individuals quantified each image and an average value was used for each image. Some satellite images were not used due to clouds and or shadows obscuring the reservoirs boundary. Using the satellite data we created a model for surface area in relation to reservoir elevation [$r^2 = 0.96$; surface area (pixels) = $(0.00002)^{0.0194*\text{elevation}}$)] and used these values in the analyses. For the final analyses surface area was ultimately not used as it was strongly correlated with elevation (99%).

Table 1. Factors used in analyses of fishes in Alamo Lake

Factor	Unit of measure
Channel Catfish CPUE	Fish/hour
Average reservoir elevation/year	Feet above sea level
Variation in water levels during spring (March-April)	Sum of difference from one day to the next from March-April
Sum of inflow	Cubic feet per second
Sum of outflow	Cubic feet per second
Heating degree days*	Degree days
Average air temperature	° C
Yearly precipitation*	Sum (mm)
Largemouth Bass CPUE	Fish/hour
Largemouth Bass mean total length	mm
Largemouth Bass relative condition (Wr)	Unitless
YOY Largemouth Bass (<150 mm) CPUE	Fish/hour
Adult Largemouth Bass (≥ 300 mm) CPUE	Fish/hour

*Weather data from nearest station: Lake Havasu City, AZ (COOP: 024759 and 024761)

Relative weight (W_r) was used to assess the condition of Largemouth Bass. Only fish 150 mm or larger were used for relative weight calculations. Any fish whose W_r was above 160 or less than 30 was not included in any analyses; these were most likely a result of data entry errors in length or weight. We used the equation: $W_r = (W/W_s)*100$, where $Log_{10}(W_s) = -5.528+3.27(Log_{10}\ TL)$ (Blackwell *et al*. 2000).

W_r = relative condition
W = actual weight of fish (g)
W_s = standard weight of theoretical fish
TL = total length of fish (mm)

Statistical Analyses
To investigate how factors were related to the fish community (CPUE of Largemouth Bass and Channel Catfish) we used a direct constrained ordination technique, redundancy analysis (RDA) using package "vegan" (Oksanen *et al.* 2015) within R (R Core Team 2015). RDA is a regression based approach, thus where appropriate variables were log transformed to approximate a normal distribution. As many explanatory variables of interest were correlated with one another (e.g. outflow and elevation difference $r^2 = 0.97$) this precluded using a multiple regression approach where the explanatory variables are assumed to be independent and not correlated. The RDA approach allows the inclusion of correlated variables and results can be presented using a biplot of the relationships between species and explanatory variables. In the biplot the larger the vector (line with arrow) the more variance is explained. Vectors pointing towards a response variable (e.g. CPUE YOY, CPUE Largemouth Bass) indicate a positive relationship and those away a negative relationship with that response variable. Other statistical analyses were conducted using program JMP™ (V. 5.01a).

Black Crappie were not analyzed in the RDA models as only 12 years of data was available. Preliminary investigations into CPUE of Crappie with our available environmental and biological data did not reveal any valid or satisfactory method for determining species environment relationships. Thus Black Crappie were not addressed in this report.

Results
From 1982 to 2015 the reservoir had a minimum and maximum elevation of 1081.5 and 1182.5 ft respectively, with a mean [and 95% CI] of 1112.4 ft [1112.6, 1112.0] (Figure 2). During the actual days of fall sampling the lake elevation minimum and maximum was 1087.8 and 1159.8 ft respectively, a difference of 72 feet.

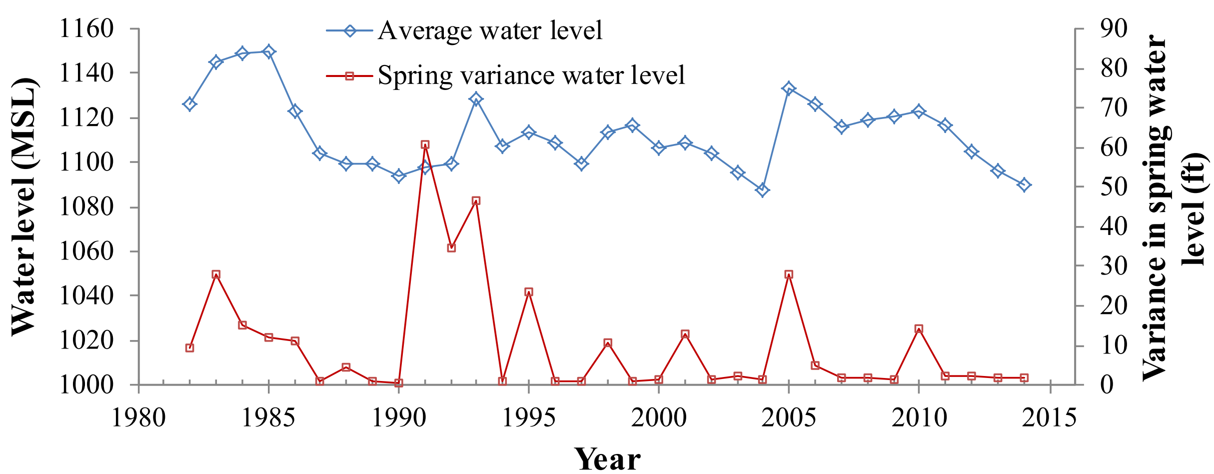

Figure 2. Mean water elevation (October through September) and spring (March-April) variance in water elevation at Alamo Lake, AZ from 1982 to 2014.

CPUE for Largemouth Bass and Channel Catfish fluctuated throughout the years (Figure 3), as did length frequency (Figure 4) and relative condition (Figure 5).

An initial RDA included Largemouth Bass mean total length as a response variable. Largemouth Bass total length accounted for most of the variation in the model with the effect of rendering the other response variables as insignificant, consequently we ran another RDA without total length to gain a better understanding of the other response variables. In an ANOVA Largemouth Bass mean total length was significantly related to yearly average elevation (R^2=0.278, $F_{1, 31}$ = 11.9, P= 0.0016).

Results of the reduced (missing mean total length) RDA are presented in Table 2. The amount of variation in "species" explained by the model was 20.4 % (the amount of variance in species scores explained by our environmental factors). The first axis (RDA1) explained 12.8 % of that variation, and the second (RDA2) explained 4.7 % of the overall variation. Only average elevation was significant. Other reduced models were investigated (e.g. removing variables: outflow and Wr), but they did not improve the model fit or result in the remaining factors becoming significant. CPUE of young of the year and all Largemouth Bass were negatively correlated with average water elevation of the lake (Figure 6). The higher the yearly average elevation of the lake the lower the CPUE of YOY and in general CPUE all Largemouth Bass. Inflow was strongly correlated with CPUE of Channel catfish, CPUE of adult Largemouth Bass, and to a lesser extent CPUE of all Largemouth Bass. YOY were negatively correlated with heating degree days, thus colder winters were correlated with lower CPUE for YOY Largemouth Bass captured in the fall. CPUE for all and adult Largemouth Bass was negatively correlated with annual precipitation, although this was not a significant relationship (Table 2).

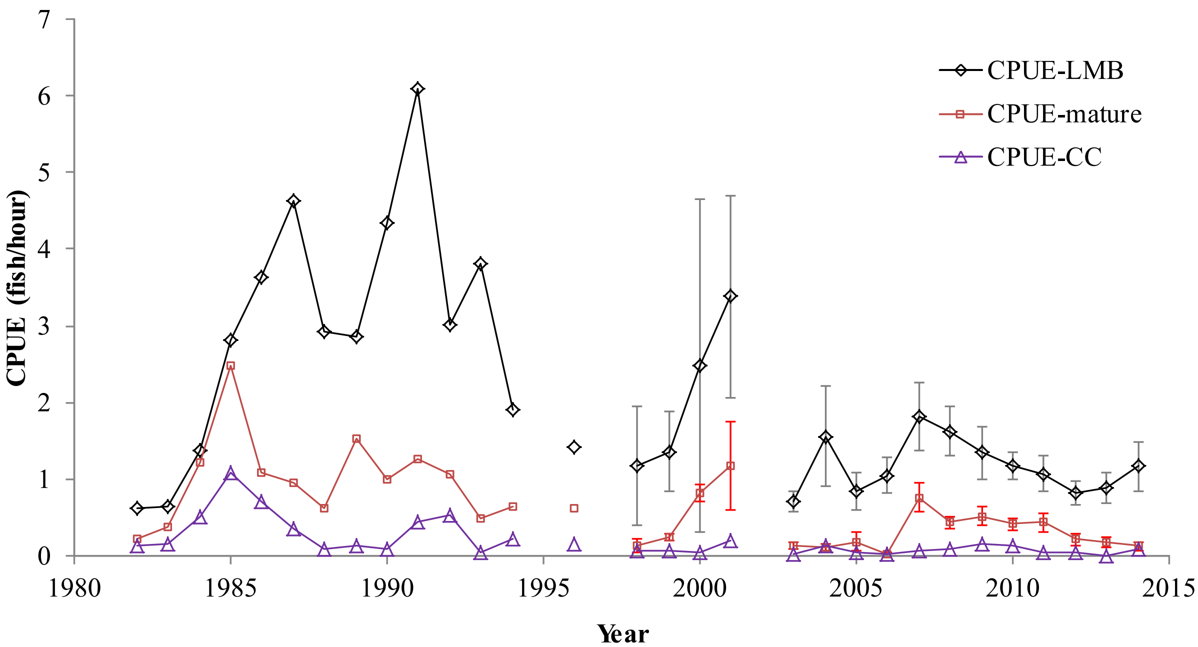

Figure 3. Average CPUE for all Largemouth Bass (LMB), adult Largemouth Bass (≥ 300 mm), and Channel Catfish (CC) in Alamo Lake captured via electrofishing in the fall. Error bars represent 95 % confidence intervals and are only presented for data after 1997. Prior to 1997 CPUE effort was reported as total fish caught divided by total time of electrofishing, consequently there was no information on variance.

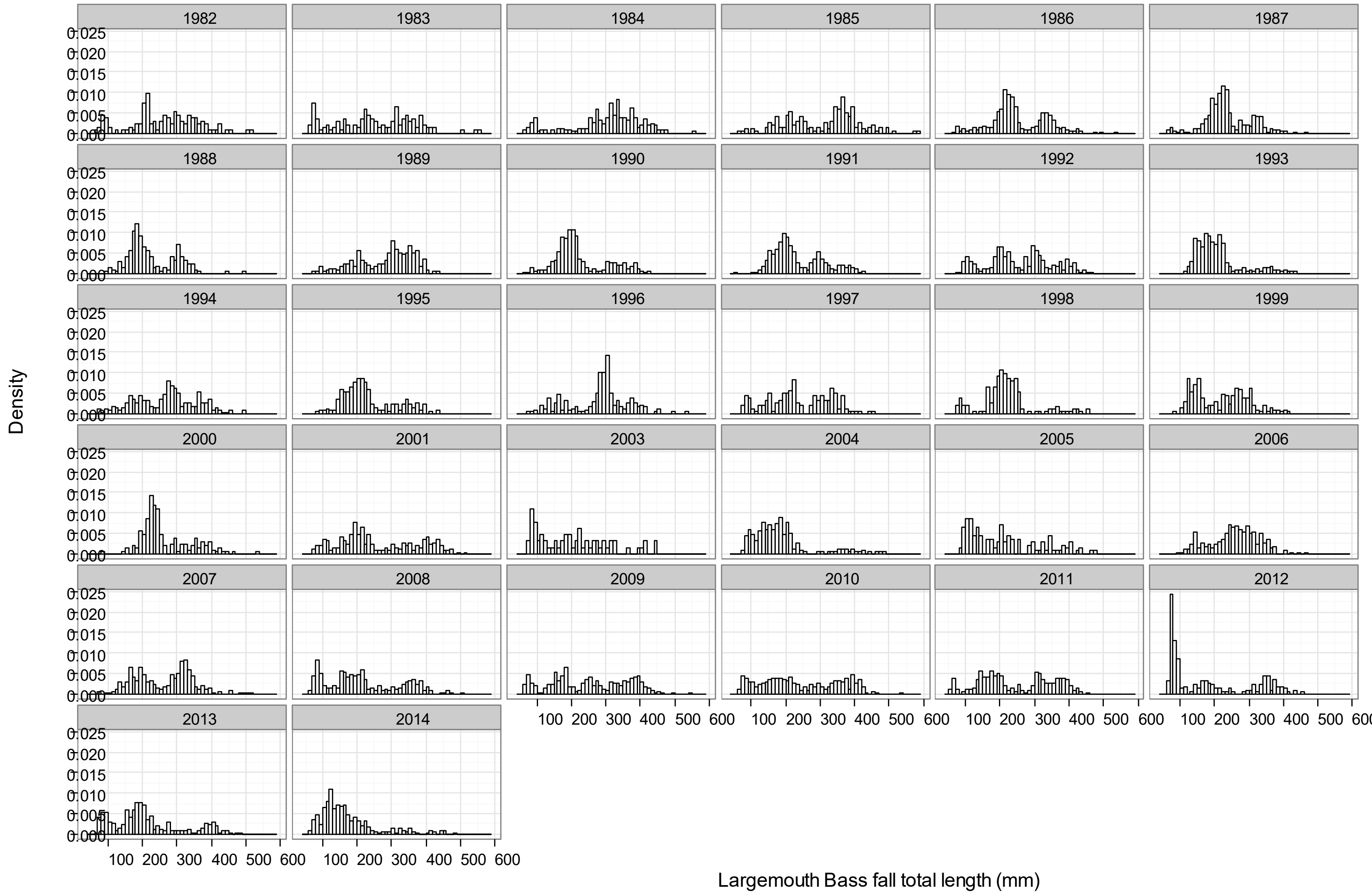

Figure 4. Length frequency of Largemouth Bass collected in the fall (~October) by year.

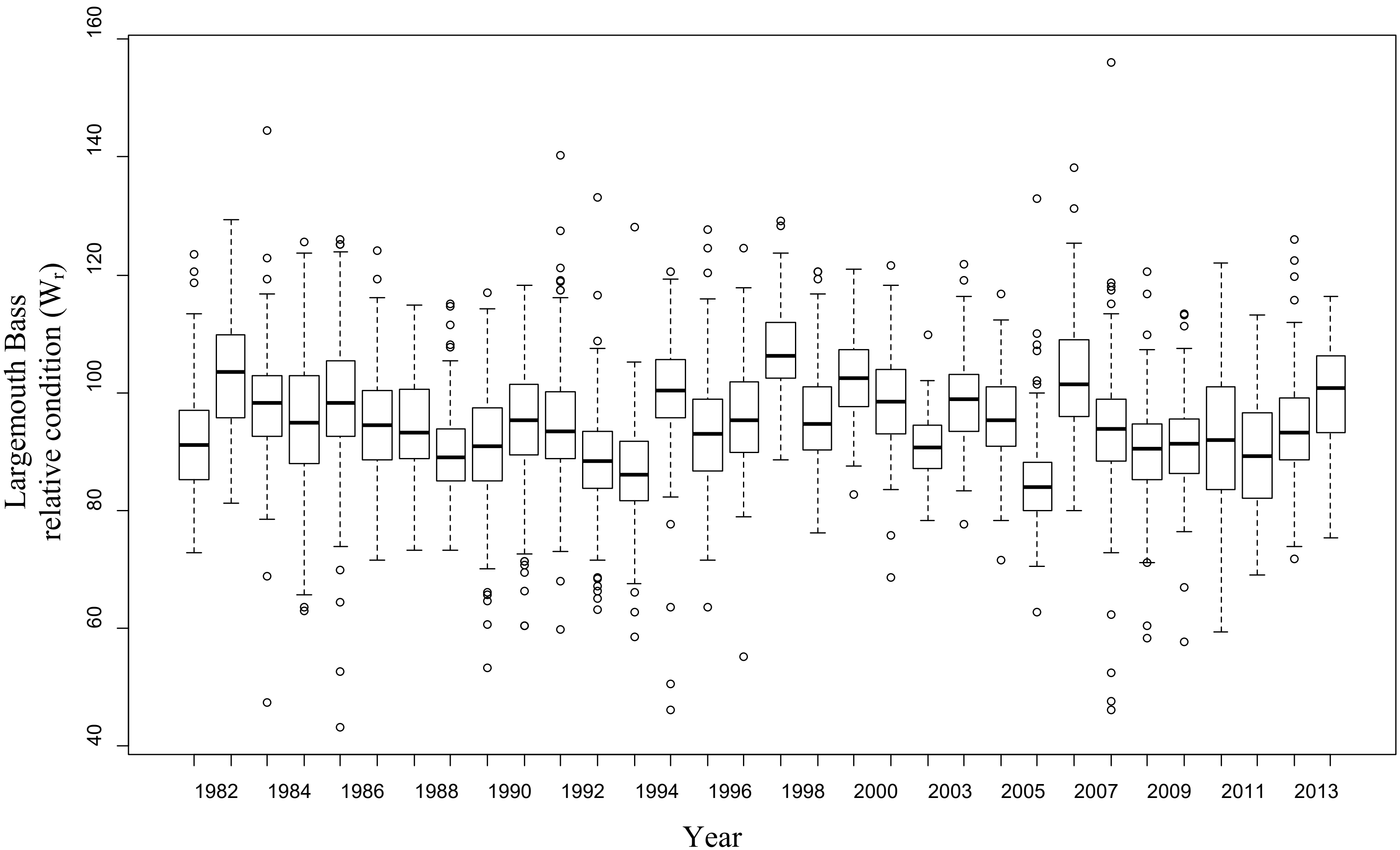

Figure 5. Boxplot of Largemouth Bass (≥150 mm) relative condition (W_r) of fish captured in the fall by year from Alamo Lake.

Table 2. Results of redundancy analysis of Largemouth Bass (all, adults, YOY) and Channel Catfish CPUE from fall electrofishing 1982-2014 in Alamo Lake.

Factor	RDA1	RDA2	r^2	*P* (>r)
LMB Wr	0.53250	0.84643	0.0450	0.531469
Average elevation lake	0.44669	0.89469	0.319	**0.003996**
Inflow of lake	0.98811	0.15377	0.164	0.083916
Outflow of lake	0.97006	-0.24288	0.0201	0.761239
Lake elevation difference (sum of day to day difference)	-0.01116	-0.99994	0.0591	0.466533
Heating degree days	0.30426	0.95259	0.0932	0.280719
Average air temperature	-0.00845	-0.99996	0.0588	0.450549
Annual precipitation	-0.56641	0.82412	0.130	0.161838
Spring (March, April) variation in lake elevation	0.98151	0.19143	0.0587	0.458541
Spring (March, April) avg. lake elevation	0.49858	0.86684	0.1950	0.051948

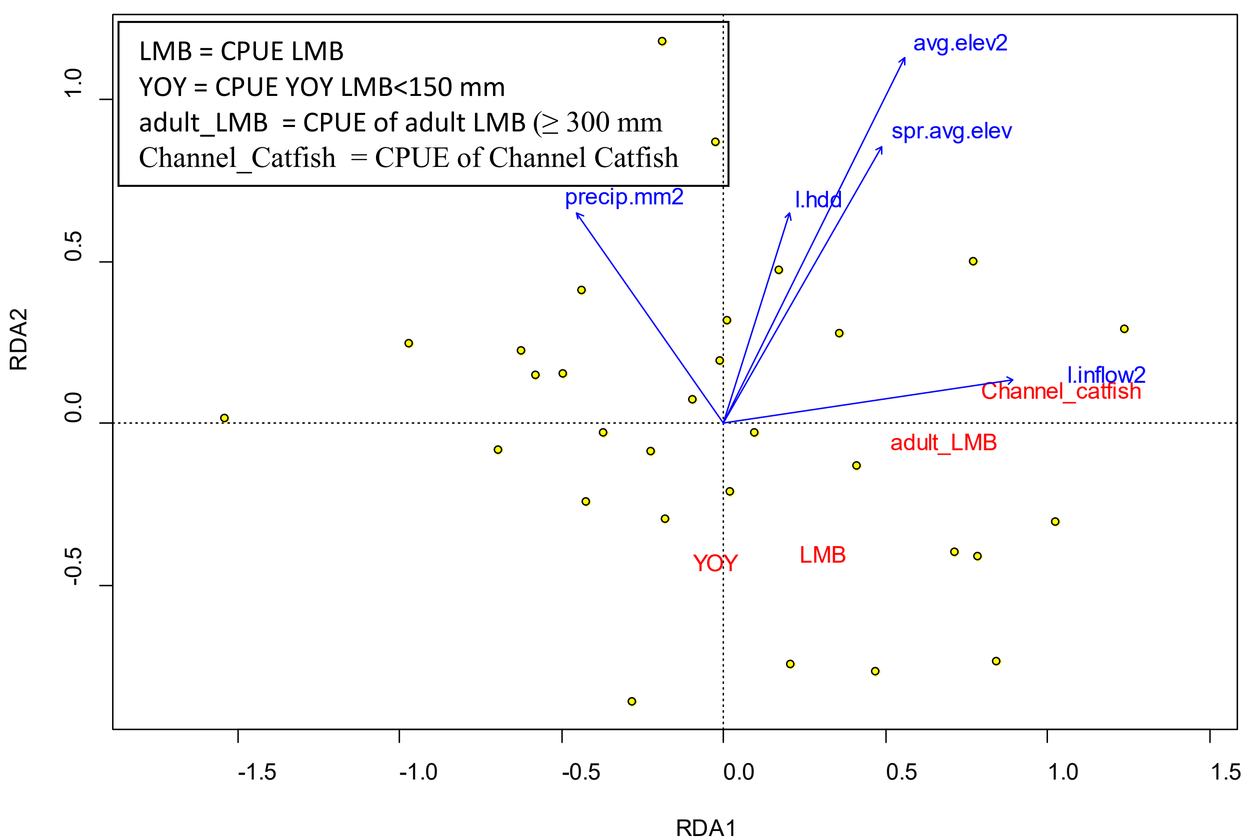

Figure 6. Ordination plot from an RDA of Largemouth Bass (LMB) and Channel Catfish in relation to explanatory variables (blue vectors). Response variables (e.g. species) are in red, and samples are in indicated by points. For clarity only those vectors below a P value of 0.3 are presented.

Spring sampling
The analysis of factors related to spring Largemouth Bass CPUE and mean total length did not reveal any significant relationships (results not presented). RDA like most statistical approaches is not very robust with small sample sizes, particularly when quite a few explanatory variables are included in the model. We reduced the number of explanatory variables that were correlated with other variables (mean elevation, and sum outflow) in an attempt to improve the model, to no avail.

Discussion
If one were to design a study investigating Largemouth Bass population dynamics in a reservoir, ideally one would want information on both the biotic and abiotic variables (Siepker and Michaletz 2013). Biotic factors of interest would include the presence and density of other species in relation to the effects of competition, predation, and available prey. Abiotic factors such as water levels, temperature, dissolved oxygen, pH, and nutrient levels all can affect population dynamics (e.g.: Jackson and Noble 2000, Paukert and Willis 2004, Siepker and Michaletz 2013). It has been shown that Threadfin Shad make up the bulk of the diet of Largemouth Bass in Alamo Lake (Wanjala *et al*. 1986). Thus one would expect that Largemouth Bass population dynamics would somewhat track Threadfin Shad population dynamics (Storck 1986, Michaletz 1997). Unfortunately we do not have much information on Threadfin Shad or other potential prey (sunfishes) within Alamo Lake. Additionally, while water quality information on Alamo Lake was collected and provided to the authors, the data quality was such that it was not useable (see Appendix A). The biotic and abiotic data available for Alamo Lake was not designed for determining how reservoir operations affected Largemouth Bass population dynamics. Additionally much of the data provided was in need of quality assurance and quality control prior to use and lack of adequate time prevented a full scales analysis particularly as it relates to water quality parameters. Thus there were some limitations to our analyses.

While AGFD had electrofishing data going back to 1982, the lack of consistent electrofishing methods severely hampered our ability to model Largemouth Bass population dynamics. For the majority of years included in our analyses AGFD personnel only targeted focal game species, Largemouth Bass, Channel Catfish, and to a lesser extent Black Crappie. Thus in our analyses biological data was restricted primarily to Largemouth Bass and Channel Catfish. Explanatory variables were restricted to factors related to operation of the dam (e.g. water levels, and variation in water levels) and some indirect environmental variables such as precipitation, and average air temperature.

Largemouth Bass are relatively large piscivores, and information on potential forage fish in a system is important in modeling population dynamics. While relative condition of Largemouth Bass has been shown to correlate well with forage fish biomass (Wege and Anderson 1978), condition is also dependent on the density of Largemouth Bass. That is, fish condition is dependent on the available forage fish in relation to the density of Largemouth Bass (Garvey *et al.* 2000). We saw no relationship between Largemouth Bass CPUE and relative condition in this study (Table 2), thus in this system condition might be more related to available forage fish, but this is unknown as we do not have enough data on forage fish to test this hypothesis.

While we have a long term data set of 32 years for fall surveys, due to missing data we actually only have a sample size of 29, which is a fairly small number for statistically investigating multivariate relationships. However, we did find some interesting and significant relationships with our explanatory variables. The factor that explained the most variation and the only statistically significant factor related to Largemouth Bass CPUE was average elevation of the lake. Average elevation was negatively related to CPUE of YOY and slightly negatively related to all Largemouth Bass CPUE. Higher average levels of water will lead to reduced density and most likely reduced capture probability. This highlights one of the problems with using CPUE as a metric in a system with fluctuating water level. For example, assume fish population levels were stable between years. As water levels change, fish density changes as does capture probability and subsequently CPUE, while in actuality there was the same number of fish in the system (e.g. the population remained stable).

The mean length of Largemouth Bass was positively related to the average elevation of the reservoir, and consequently spring average elevation. However, both the yearly and spring average elevation are highly correlated ($r^2 = 0.95$), thus it is not possible to determine which might be more important. It is not clear as to why Largemouth Bass total length is positively correlated with mean average elevation of the reservoir. An initial thought would be that growth was greater during higher water levels, as the shoreline becomes inundated nutrient levels increase leading to greater fish growth. If growth was actually greater we would expect to see greater fish condition during years of higher water, but there was no relationship between Largemouth Bass condition and water levels. A potentially plausible explanation is that when water levels are higher, electrofishing as conducted, is biased towards larger fish. As water levels increase more of the shoreline and vegetation is inundated and electrofishing potentially becomes less efficient at capturing small fish, resulting in an increase in mean total lengths during higher water levels. Length measurements collected annually provide very coarse information on growth. The inclusion of age with length can provide a lot more information on population dynamics. Depending on conditions Largemouth Bass three to four years old may still be less than 150 mm (Saiki and Ziebell 1976). These changes (varying growth rates) could be measured via back calculating growth rates from fish annuli (scales, otoliths) to provide information on how growth rates may change with density, available forage, or other environmental factors such higher water levels.

Channel Catfish and adult Largemouth Bass CPUE were positively related to inflow, although this was not statistical significant. Perhaps with higher inflows, more nutrients were being washed into the system, resulting in a more productive system that results in greater survival and thus a greater CPUE for Channel Catfish and adult Largemouth Bass (≥ 300 mm).

In our analysis of data collected in the spring we were unable to find any significant relationships with CPUE or average total length of Largemouth Bass. This is most likely due to the relatively small sample size ($n = 22$). This is not to say that there is no relationship present, just that with the data we have available we were unable to detect a statistically significant relationship. With our small sample size there would have to be a fairly strong relationship for us to be able to detect it, as our statistical power was pretty low.

The lack of significance for some of our explanatory variables was somewhat surprising. Despite the negative public perception of the effects of fluctuating water levels during spring when Largemouth Bass are reproductively active and recruitment occurs, we did not find a significant relationship between variation in spring water levels and CPUE of Largemouth Bass (YOY, adults, or all Largemouth Bass). One of the factors included in our model represented the change in lake levels (variation in lake elevation) throughout the year and this was not related to any of the fish CPUE. Years where variation in water levels was higher did not lead to a noticeable difference in CPUE of Largemouth Bass or Channel Catfish. Jackson and Noble (2000) also did not see a significant relationship between fluctuating reservoir water levels and YOY Largemouth Bass cohorts. This does not mean that fluctuating water levels do not have an effect on fish in Alamo Lake. That effect may not be detectable in this analysis, other factors accounted for more variance, or sampling was not at a fine enough scale to detect the effects of fluctuating water levels. Changes related to fluctuating water levels may occur over the lifetime of a fish, which for a Largemouth Bass could be up to 15 years (Stuber et al. 1982), and affect different life stages (e.g.: eggs, larvae, juveniles, subadults, and adults) and life histories (eg: growth, maturation, reproduction, fecundity, and lifespan). Or the relationship may be more complicated and related to density and prey where carrying capacity and food availability must increase with water levels to have a positive effect on YOY year class (Miranda *et al.* 1984).

Similarly water level fluctuation could be impacting the YOY Largemouth Bass in the spring; however other factors may be affecting recruitment from that time period to the autumn when sampling occurs. Thus, the major impact on recruitment is probably not related to water level fluctuations. It could be related to available habitat for reproduction and or cover for larval and juvenile fish. Recruitment of Largemouth Bass is dependent on a variety of factors affecting growth and survival across multiple life stages from hatching, ontogenetic diet shift to piscivory, accumulation of lipids, and first winter survival (Ludsin and DeVries 1997).

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Appendix A: Water Quality Data

Water quality data has been collected by the US Fish and Wildlife Service, Arizona Department of Environmental Quality (ADEQ) for a number of years (2000-current) at varying frequencies depending on the analyte. Limnological measurements were collected every month (water temperature, dissolved oxygen, specific conductance, pH, oxidation reduction potential, Secchi and disk, and sulfide). General chemistry was collected eight months of the year (January, April, May, June, July, August, September, and October). Measurements include: total phosphorous, total suspended solids, total dissolved solids, Kjeldahl nitrogen, total residue, ammonia (as N), alkalinity (as CaCO3), turbidity, nitrate (NO3-NO4), and sulfate (SO4). Chlorophyll *a* and pheophytin *a* was collected June, July, August, September and October. January, April, July and October samples were analyzed for: iron, manganese, arsenic, boron, magnesium, chromium, mercury, and total organic carbon.

We were provided a data spreadsheet covering the years 2000-2013 from ADEQ. However a cursory examination of the spreadsheet revealed a large number of obvious data errors within the spreadsheet. These are not isolated errors as might be expected from normal data entry errors. For example dissolved oxygen levels were consistently recorded above 100 mg/l, Kjeldahl nitrogen levels greater than 100 mg/l, over a thousand entries of specific conductivities below 50 µmhos/cm (847 < 1 µmhos/cm) out of 3,323 data values. These values are practically impossible to obtain in natural systems. These errors are numerous and occur over many years as evidenced by the specific conductivity values. In some instances we assume that the wrong unit of measure was used when entering the data. However, as we do not have access to the original data we do not know for sure. This data set needs to be properly checked for quality assurance and quality control (QA/QC) before it can be utilized.