

**FISHERY RESEARCH ARCH**



**PROJECT 5: LAKE AND RESERVOIR RESEARCH**

**ANNUAL PROGRESS REPORT**  
July 1, 2020 — June 30, 2021

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# **PROJECT 5: LAKE AND RESERVOIR RESEARCH**

**Annual Performance Report**

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**Project 5–Lake and Reservoir Research**

**Subproject 1: Factors related to long-term indices of crappie abundance at  
Brownlee Reservoir**

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## ANNUAL PERFORMANCE REPORT

### SUBPROJECT #1: FACTORS RELATED TO LONG-TERM INDICES OF CRAPPIE ABUNDANCE AT BROWNLEE RESERVOIR

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Subproject #1: Factors related to long-term  
indices of crappie abundance  
at Brownlee Reservoir

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#### ABSTRACT

Crappie (*Pomoxis* spp.) populations are challenging to manage because they often exhibit sporadic variability in year-class strength; however, such variability has rarely been investigated in western North America where crappie often occupy large, steep-sided reservoirs prone to severe drawdown. We investigated the influence that reservoir conditions related to reservoir volume, flow, and water temperature had on crappie abundance variability. Our primary findings were that: 1) autumn age 0 crappie abundance was higher in years when larval abundance and reservoir flow were higher in the summer; 2) spring age 1 crappie abundance was higher in years when fish were larger and more abundant entering their first winter, and when hydraulic residence time was reduced and the reservoir volume was higher during the winter; 3) age 0 crappie entering their first winter were larger in years with lower summer larval crappie abundance and warmer summer water temperature; and 4) spring age 2 crappie abundance was higher in years when more age 1 crappie were caught the previous spring, and when the reservoir volume and change in volume was lower the prior year. We recommend autumn electrofishing to monitor crappie populations in large canyon reservoirs—where shorelines are often too steep to sample fish with trap nets—because it provides an index of age 0 crappie abundance and size at the onset of their first winter as well as data on older crappie year classes and sympatric species; it also requires less sampling effort than summer trawling.

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## INTRODUCTION

Black Crappie (*Pomoxis nigromaculatus*) and White Crappie (*P. annularis*) fisheries can be challenging to manage because crappie populations often exhibit sporadic fluctuations in recruitment (Allen 1997; Boxrucker and Irwin 2002; Maceina 2003; Martin and Maceina 2004). Assuming that year-class strength is determined by the abundance and success of spawning adults, egg survival, and early larval rearing, summer larval sampling may offer a reliable method of detecting strong and weak year classes of crappie and perhaps allow managers some predictive ability in terms of the expected quality of a fishery in upcoming years. For example, Sammons and Bettoli (1998) found that peak larval crappie density from neuston net trawling was highly correlated with the number of age 1 crappie captured in coves with rotenone the following year. However, if mortality is substantial and highly variable for age 0 crappie during the first winter (e.g., McCollum et al. 2003) or for age 1 crappie (McInerney and Degan 1991), then year-class strength indices based on summer larval sampling may be unreliable as a predictor of the resulting fisheries they create.

Crappie recruitment has often been characterized as being cyclic, with strong year classes recurring every 2-5 years (Swingle and Swingle 1967; Guy and Willis 1995; Allen and Miranda 2001). Recurring fluctuations suggest that recruitment is being controlled by density-dependent factors such as fish growth, competition, or predation. Others have observed fluctuations in crappie year-class strength to be more erratic, and in such instances, the variation has been more commonly attributed to environmental conditions such as water temperature, water quality, lake/reservoir bathymetry, and hydrology (Mitzner 1991; Maceina 2003; Pope et al. 2004). Allen and Miranda (2001) argue that crappie populations do not exhibit true cycles in abundance, but may show quasi-cycles depending on the interaction between density-dependent and density-independent mechanisms. As pointed out by Clark et al. (2008), the complex mix of factors that can affect centrarchid recruitment tend to make conclusions derived from field studies highly site-specific.

While recruitment variability and other characteristics of crappie populations have been investigated frequently in central and eastern North America, comparatively little research has been conducted on crappie populations in western North America where they have been introduced. In the intermountain west, canyon reservoirs are often larger, steeper, and deeper than waters that crappie typically occupy in other portions of the continent. For example, Brownlee Reservoir in southwestern Idaho is nearly 100 km long with an average depth of 32 m and a maximum depth of nearly 100 m, and it supports a popular multi-species fishery where anglers frequently target crappie among other species. The reservoir has been monitored for larval crappie year-class strength and general fish abundance for decades, providing a unique opportunity to evaluate density-dependent and density-independent factors affecting crappie abundance in a large, steep-sided, canyon reservoir.

### Objectives

- 1) Determine whether summer larval trawling or autumn age 0 electrofishing was a better indicator of subsequent year class strength of crappie at Brownlee Reservoir.
- 2) Determine what environmental factors contributed to strong and weak year classes of young crappie at Brownlee Reservoir.
- 3) Evaluate whether strong year classes of young crappie persisted into later age classes at Brownlee Reservoir.

## **METHODS**

### **Study Area**

Brownlee Reservoir is the uppermost reservoir of three impoundments known as the Hells Canyon Complex. Brownlee Dam was completed in 1958 and impounds 92 km of the Snake River along the Idaho-Oregon state border; the dam is located at river kilometer 460. The reservoir is confined within a deep, narrow canyon, thus the reservoir is narrow (300-900 m wide) and steep-sided, with shorelines typically consisting of bedrock or mixtures of boulders, sand, and gravel substrate. Reservoir volume peaks at about  $1.74 \times 10^9 \text{ m}^3$  of water and it has a surface area of 6,100 hectares. The elevation of the reservoir is 633 m above sea level at full pool. Large spring and autumn reservoir drawdowns are common and can reach 30 m. Reservoir refill periods are typically May-June following flood control operations, and October-November following summer flow augmentation for anadromous smolt outmigration and fall flow stability for Chinook Salmon (*Oncorhynchus tshawytscha*) spawning in the Snake River below the Hells Canyon Complex. Operational guidelines for Brownlee Dam are also designed to minimize reservoir drafting during peak crappie and Smallmouth Bass (*Micropterus dolomieu*) spawning periods (see below).

The fish community in Brownlee Reservoir is dominated by nonnative warmwater sport fishes, including Smallmouth Bass, Black Crappie and White Crappie, Bluegill (*Lepomis macrochirus*), Yellow Perch (*Perca flavescens*), and Channel Catfish (*Ictalurus punctatus*) (Richter 2003; Richter et al. 2010). Black Crappie are slightly more abundant than White Crappie in the reservoir. Both reach a harvestable size of 200 mm (Miranda and Frese 1991) in Brownlee Reservoir at about age 2 (Lamansky 2011), and angler exploitation of harvestable-sized crappie in the reservoir typically ranges from 20-30% (Meyer and Schill 2014). Crappie in Brownlee Reservoir reach maximum ages of about seven, and feed almost exclusively on insects and zooplankton (Lamansky 2011). Although water temperature profiles within the reservoir were generally lacking for most of the study, water temperature for the Snake River where it meets Brownlee Reservoir is regularly monitored (see below) and generally exceeds 25°C in summer months, and often approaches 30°C.

### **Larval Crappie Sampling**

Larval crappie were sampled from 1993 to 1998 and again from 2005 to 2015. Early in the study, samples were collected approximately weekly from early to mid-May through mid-August. However, after several years of sampling it became apparent that, regardless of annual variation in environmental conditions, appreciable numbers of larval fish were only reliably captured from about June 10 to July 31 of each year. Thus all larval crappie data were summarized only between these two dates each year.

From 1993 to 1998, larval fish were collected by Idaho Power Company staff at various locations throughout the reservoir each year. At each location, one or two circular (0.5-m diameter) ichthyoplankton nets with 0.75-mm bar mesh were attached to the sides of the boat (opposite sides when two nets were towed). Tows were made at five depths (0-4 m) for one minute at each depth for a total of five minutes at a speed of about 1.3 m/s. Nets were towed approximately 12 m behind the boat. All tows at a particular location were combined for a single sample. The volume of water sampled was estimated using a flow meter attached within the net opening, and averaged  $166 \text{ m}^3$  for each location sampled each night. On average, 11 locations were sampled each night (range 3-13). All larval samples were immediately chilled.

From 2005 to 2015, larval samples were collected by Idaho Department of Fish and Game staff at various locations throughout the reservoir by towing a rectangular, 1-m × 2-m, neuston net with 1-mm bar mesh. At each location, the net was towed at the surface for five minutes at a boat speed of about 2.6 m/s. The volume of water sampled at each location was determined from a flow meter mounted within the net opening; mean tow volume was 362 m<sup>3</sup>. In contrast to the smaller circular nets, which were attached off the sides of the boat, the neuston net was attached by rope to a boom in the center of the boat, so tows were made by driving the boat in a circular fashion to keep the net out of the wake and in undisturbed water. The net was towed approximately 20 m behind the boat. The number of locations sampled each night ranged from 6-11, with 10 or 11 locations being sampled for >90% of the nights. Samples from each location were immediately preserved in a 10% formalin solution and later transferred to ethanol.

For both time periods, samples were collected at night from about 2200 to 0200 hr. Larval fish were identified in the laboratory using meristic features described by Auer (1982). While larval fish of multiple species were collected, only crappie were enumerated and measured to the nearest millimeter. Larval crappie were not identified to species because the differences in meristic characteristics at that size are unreliable (Sammons and Bettoli 1998). An index of larval crappie abundance (i.e., catch-per-unit-effort, or CPUE) was calculated by dividing the number of larval crappie captured in a net tow by the volume of water sampled (i.e., fish/m<sup>3</sup>) and averaging those values for each date. Mean and peak larval abundance was calculated for each year from the means for each sample date within a year, but annual mean and peak abundance was highly correlated (Pearson's correlation coefficient,  $r = 0.91$ ), so peak abundance was removed from further consideration.

### **Electrofishing Surveys**

While trap nets are considered the gear of choice for sampling crappie in large lentic systems (Miranda and Boxrucker 2009), at Brownlee Reservoir trap nets are largely ineffective because the shorelines are generally too steep-sided. Therefore, the abundance of juvenile and adult crappie was indexed by spring and autumn nighttime boat electrofishing from 1993 to 2018. The boat electrofisher consisted of a Smith-Root GPP Model 5.0 powered by an on-board 5000 W generator, with two anode booms and with the boat serving as the cathode. The GPP electrofisher settings were held relatively constant throughout the study, at 60 Hz, 40-60 Percent of Power, and using the low Range selector setting. These settings consistently produced 4-6 amps of average power output (depending on shoreline depth). Spring sampling across all years occurred from early April to late May but primarily from mid-April to early May, whereas autumn sampling occurred from early September to mid-October but primarily from mid- to late September.

For each sampling night, randomly selected 100-m shoreline electrofishing reaches (an average of 24 per year) were delineated before dark with reflective posts that were clearly visible after dark by the boat electrofishing lights. Electrofishing occurred from about 2200 to 0200 hr each night. One electrofishing netter was used while another person operated the boat and electrofishing equipment. All stunned fish (not just crappie) were netted and placed in a live well until the reach was completely sampled. Fish were released at the site once species, total length (mm), and weight (g) were recorded for each captured fish. Black Crappie and White Crappie captured during electrofishing were pooled for data analyses because crappie captured during larval trawling were pooled (since they cannot be accurately distinguished to species), and anglers do not distinguish between the two species.

The average number of crappie caught electrofishing for each 100-m reach of shoreline was calculated for each age class, year, and sampling period. Age classes were determined from a combination of length-frequency analyses, prior growth analyses at Brownlee Reservoir, and the literature. For example, length-frequency analyses indicated that during autumn electrofishing, age 0 crappie consistently reached a maximum size of about 120 mm (Figure 1). Length-frequency analyses also revealed that age 1 crappie captured the following spring had grown slightly, with a more appropriate size cutoff consistently being <140 mm for spring age 1 crappie catch (Figure 1). This cutoff was also consistent with an earlier study by Lamansky (2011) who back-calculated length-at-age for Brownlee Reservoir crappie and found that fish  $\leq 145$  mm TL in the spring (i.e., at annulus formation) were age 1. This same study found that age 2 crappie were typically 145-188 mm at annulus formation, so we assumed that all crappie 140-185 mm in length were age 2 fish for spring sampling. While we recognize that by age 2 there was undoubtedly some overlap in size with older aged crappie (Guy and Willis 1995, Allen et al. 1998), age 2 fish would still have made up the vast majority of fish 140-185 mm in length, and this was considered to be a more practical assumption to make to index age 2 abundance than relating younger crappie age classes to adult-sized fish of all ages (cf. Mitzner 1991). Finally, across all years, the average maximum length of crappie captured annually was 299 mm TL (mean sample size of 430 fish for each year), and it is well established that size at first maturity in fishes is typically about 0.6 times the maximum size in a population (see Pauly 1984, Charnov 1993, Froese and Binohlan 2000). Consequently,  $\geq 179$  mm was used as the size cutoff for crappie spawners in our study; such a cutoff is consistent with published accounts of crappie length- and age-at-maturity (e.g., Thomas and Kilambi 1981, Smith et al. 1994, Scott and Crossman 1998).

### **Data Analyses**

The same environmental conditions were summarized (i.e., averaged, except for the change in reservoir volume) for each time period (as described below), with metrics representing reservoir flow, volume, and water temperature. Reservoir flow metrics included mean daily inflow, outflow, and hydraulic residence time. Reservoir volume metrics included mean daily volume as well as the maximum change in volume over the entire time period. Water temperature was summarized as mean daily temperature for a particular time period.

We used general linear models to evaluate the influence of biotic and abiotic factors on crappie abundance. First, we investigated whether summer larval crappie abundance (as indexed by summer larval trawl CPUE) was affected by the abundance of spawning-sized crappie during the spawning season (as indexed by spring electrofishing CPUE) as well as reservoir flow, volume, and water temperature conditions the spawning adults and resulting larvae experienced during the spawning period. Crappie spawn in the spring when water temperature is 14-23°C, and peak spawning generally occurs at 16-20°C (Scott and Crossman 1998). This has been corroborated at Brownlee Reservoir, where over an eight-year period in the 1990s, crappie spawning on average lasted 48 days and ceased on June 30 (Richter 2003). Water temperature during those spawning periods ranged from 12-22°C with peak spawning occurring at 18-20°C. As mentioned above, Brownlee Reservoir generally starts refilling (after a spring flood control release period) on May 1 and refill usually extends to about June 20. Based on this combined information, we considered May 1 to June 20 to be the annual crappie spawning period. To evaluate whether the two different trawl nets influenced larval CPUE, trawl type (i.e., circular ichthyoplankton nets or rectangular neuston net) was included as a categorical predictor variable.

Next, we investigated whether electrofishing CPUE of age 0 crappie in autumn was a function of summer larval trawl CPUE as well as the environmental conditions the larval fish experienced over the summer as they transitioned out of the larval stage. Brownlee Reservoir



generally reaches full pool by June 20 and is held stable through July 4, after which the reservoir begins a long period of summer drawdown that extends through September. However, since autumn electrofishing usually occurred in mid-September, we used July 4 to September 15 to represent the summer time period to avoid including environmental data collected after the electrofishing data were already collected.

Similarly, we examined whether electrofishing CPUE of age 1 crappie in the spring was a function of the environmental conditions those fish experienced during winter as well as the abundance and size of age 0 fish entering their first winter. Again, rather than using strict winter calendar dates, we considered reservoir operation prior to and during winter. After the summer/autumn drawdown, the reservoir is refilled by December 10, and then is drawn down again through the end of April for flood control. Considering that spring electrofishing generally occurred in mid-April, we used December 10 to April 15 to represent the winter time period. Finally, we examined whether spring electrofishing CPUE of age 2 crappie was influenced by the environmental conditions experienced throughout the prior year, as well as the spring electrofishing abundance of the same cohort of fish when they were age 1 the prior year.

Prior to model construction, collinearity between the environmental predictor variables was assessed using correlation analysis. For each of the four time periods described above, flow into and out of Brownlee Reservoir were highly correlated ( $r \geq 0.98$ ) and estimates of variance inflation factor (VIF) for outflow exceeded 10 in all models, indicating excessive collinearity (Neter et al. 1985), thus outflow was discarded from further analyses. While other environmental variables were also somewhat correlated, VIFs during model development were  $< 10$  in all instances, therefore no other variables were excluded from any models.

All parameter combinations were considered during general linear model construction, and models were ranked using Akaike's information criterion corrected for small sample size ( $AIC_c$ ; Burnham and Anderson 2002). Interaction terms were not considered due to the small sample size of our overall data set. We considered the most plausible models to be those with  $AIC_c$  scores within 2.0 of the best model (Burnham and Anderson 2004), and used  $AIC_c$  weights ( $w_i$ ) to assess the relative plausibility of each of the most plausible models. Coefficient of determination ( $r^2$ ) was also reported to describe the amount of the variation in CPUE explained by the parameters in the most plausible models. Coefficient estimates are reported only for the most plausible model. All CPUE data were  $\log_{10}$  transformed prior to data analyses to better meet the assumptions of normality, linearity, and homogeneity-of-variance. For 4 of the 95 individual estimates of CPUE, we added one fish to the total catch in order to remove zeros from the response variables. All analyses were conducted using the SAS statistical software package (SAS Institute 2009).

## RESULTS

### Crappie Population Characteristics

On average, a total of over 5,000 larval crappie were captured each summer in night trawls conducted between June 10 and July 31. Mean annual larval crappie CPUE in Brownlee Reservoir trawls was 0.38 fish/m<sup>3</sup> (SE = 0.11) and varied over two orders of magnitude, from a low of 0.01 fish/m<sup>3</sup> in 2007 to a high of 1.62 fish/m<sup>3</sup> in 2010 (Figure 2); the coefficient of variation (CV) was 116.4. Among individual trawling days, the minimum and maximum CPUE for larval crappie ranged from 0.00-4.12 fish/m<sup>3</sup>.

On average, 531 and 470 crappie were captured each year in spring and autumn night electrofishing, respectively. Crappie captured with electrofishing ranged in size from 41-375 mm in the spring and from 20-340 mm in the autumn (Figure 1). Crappie electrofishing CPUE for all sizes combined was highly variable through time, with a mean of 21.1 fish/100 m of shoreline across all years (SE = 2.2), and a CV of 74.3. Mean total length of age 0 crappie in autumn electrofishing catch averaged 78.4 mm (SE = 2.7) across years, and ranged from a low of 52.8 mm in 2016 to a high of 108.9 mm in 2014. It was evident that particularly strong year classes formed and persisted for several years, but such year classes were rather intermittent.

The  $\log_{10}$  CPUE of summer larval and autumn age 0 crappie age classes were positively related to the same age class in the subsequent sampling period (Figure 3). There was also a positive relationship between the length of age 0 crappie entering their first winter and the  $\log_{10}$  of age 1 CPUE the following spring.

### **Factors Affecting Crappie CPUE**

None of the environmental conditions during the crappie spawning time period explained much of the variation in summer larval crappie CPUE, nor did the abundance of spawning-sized crappie (Tables 2 and 3). The best six models were all single factor models that individually included each of the six biotic and abiotic predictor variables, but the best model (which included water temperature during the spawning period) only explained 11% of the variation in larval crappie CPUE (Table 2).

The best model for predicting autumn age 0 crappie CPUE included summer larval crappie CPUE and mean daily summer inflow (Table 2). Coefficient estimates indicated that age 0 crappie CPUE was higher in the autumn when larval catch and inflow was higher in the summer (Table 3). There was also some support for a model containing these two parameters as well as mean daily summer reservoir volume (negative relationship) and the maximum change in reservoir volume (also a negative relationship) over summer. Each of these models explained more than 50% of the variation in autumn age 0 crappie CPUE.

For spring age 1 crappie CPUE, the best model included terms for the size and abundance of age 0 crappie the previous autumn, as well as winter hydraulic residence time and reservoir volume (Table 2). This model explained 63% of the variation in spring age 1 crappie CPUE, and coefficient estimates indicated that spring age 1 crappie abundance was higher in years when fish were larger and more abundant entering their first winter, and when hydraulic residence time was reduced and the reservoir was fuller during winter (Table 3). There was also support for several other plausible models (which explained similar amounts of variation in spring age 1 crappie CPUE) that included various combinations of these same variables as well as winter inflow (positive relationship) and winter change in volume (also a positive relationship; Table 2).

The only plausible model explaining the variation in mean length of age 0 crappie captured in autumn included a term for summer larval crappie CPUE and water temperature (Table 2). This model explained 46% of the variation in mean length of age 0 crappie captured in the autumn, and coefficient estimates indicated that age 0 crappie going into their first winter were larger in years with lower summer larval crappie CPUE and when summer water temperature was warmer (Table 3).

Finally, the most plausible model for spring age 2 crappie CPUE included terms for age 1 crappie CPUE the previous spring, and reservoir volume and volume fluctuation the previous year (Table 2). Coefficient estimates indicated that age 2 crappie CPUE was highest in the spring in

years when more age 1 crappie were caught the previous spring, and when the reservoir volume was lower and there was less change in volume the prior year (Table 3). There were several other plausible models that included various combinations of these same variables as well as prior year hydraulic residence time (positive relationship) and prior year inflow (negative relationship). These models explained 56-61% of the variation in spring age 2 crappie CPUE.

## DISCUSSION

In a large, fluctuating, steep-sided reservoir that is common for water storage facilities built throughout the arid western U.S., we observed the same extreme variability in larval and age 0 crappie abundance that has been observed elsewhere in North America (cf. Mitzner 1991; McDonough and Buchanan 1991; Sammons and Bettoli 1998). Crappie recruitment fluctuations were apparent in CPUE data from both summer larval trawling and autumn age 0 electrofishing, and summer larval CPUE was a good indicator of autumn age 0 CPUE, as has been observed in earlier studies (McDonough and Buchanan 1991; Sammons and Bettoli 1998; St. John and Black 2004). However, while prior studies have found that various biotic and abiotic factors influence larval abundance, including spawner abundance, water storage levels, and reservoir flow (McDonough and Buchanan 1991; Mitzner 1991; Dockendorf and Allen 2005), we found no such relationships. A potential limitation in our study design was the use of two different larval trawl nets, although this also appeared to have little influence on summer larval crappie CPUE. In Brownlee Reservoir, it appears that other factors we did not measure, potentially including such conditions as water clarity, prevailing winds, and the abundance of other centrarchids (that could potentially compete for nesting sites and larval food, or prey upon larval crappie) may have had more influence on larval crappie abundance (McDonough and Buchanan 1991; Mitzner 1991). Whether the lack of abiotic impacts on larval crappie abundance that we observed is common for such large, steep-sided reservoirs often found in western North America warrants further research. Nevertheless, there were reasonably strong relationships for CPUE between each subsequent crappie age classes in Brownlee Reservoir, suggesting that once conditions permitted a strong year class of larval crappie to materialize, that year class generally persisted through time.

The highest CPUE of autumn age 0 crappie in Brownlee Reservoir occurred in years when larval abundance was higher but also when summer inflow (or outflow) into the reservoir was higher; considering the high correlation between inflow and outflow, these two factors cannot be decoupled. Larval crappie are susceptible to entrainment through dams (Sorenson et al. 1998; Fryda et al. 2006) because their pelagic behavior extends from the time of hatching through much of their first summer (Post et al. 1995; Dockendorf and Allen 2005), thus it was surprising that increased reservoir flow in the summer was positively related to autumn age 0 crappie CPUE. However, because Brownlee Reservoir is almost 100 km in length, higher summer reservoir flow may have little impact on annual levels of crappie larval entrainment. In fact, with summer hydraulic residence time averaging 51 days over the course of the present study and rarely (4 of 25 years) dropping below 40 days, water retention time in Brownlee Reservoir is not particularly short compared other reservoirs where crappie year class strength investigations have been conducted (e.g., Maceina and Stimpert 1998; Sammons et al. 2002). Several studies have found higher larval crappie abundance in years with longer hydraulic residence time and higher water levels either before, during, or after spawning (e.g., McDonough and Buchanan 1991; Sammons and Bettoli 2000; Sammons et al. 2002; Maceina 2003), but these studies occurred in reservoirs with vastly different hydrologic and morphologic characteristics than Brownlee Reservoir. We speculate that higher summer flow into Brownlee Reservoir may improve water quality in the reservoir (Nürnberg 2002), including dissolved oxygen concentrations at the surface where larval

crappie reside for much of the summer. Indeed, Botelho and Imberger (2007) discovered that the surface layer in the upper reaches of Brownlee Reservoir becomes hypoxic during the summer, an unusual condition known as an “oxygen block,” and higher summer inflow likely minimizes this condition. Higher summer inflow may also increase turbidity and therefore reduce predation on larval crappie (Kim and DeVries 2001), and may provide more organic and inorganic material and nutrients, increasing primary and secondary production during the growing season and thus boosting the survival of larval crappie.

Our results suggest that, while the number of age 1 crappie caught in the spring depended in part on how strong the age 0 cohort was the prior autumn, the size that age 0 crappie reached by the end of their first growing season had the most influence on age 1 crappie abundance the following spring. Numerous studies have highlighted centrarchid susceptibility to size-related winter mortality (e.g., Chang 1971; Toney 1977; Toney and Coble 1979; Bernard and Fox 1997), most likely due to the well-established overwinter metabolic deficit fish commonly experience in northern latitudes (Garvey et al. 2004). Thus in years when summer growth was reduced for age 0 crappie in Brownlee Reservoir, winter survival was also reduced, and this may have been exacerbated by the severity of winters (McCollum et al. 2003). Indeed, McCollum et al. (2003) demonstrated reduced age 0 white crappie survival when water temperatures dropped below 4°C, which in Brownlee Reservoir occurred 41% of the time during winter. Our modeling results suggest that the condition creating slower age 0 crappie growth in the summer was primarily lower mean water temperature, which concurs with numerous previous studies linking centrarchid larval fish growth to warmer water temperature (e.g., Sabo and Orht 1995; Claramunt and Wahl 2000; Pine and Allen 2001). However, a density dependent response was also observed for age 0 crappie summer growth. Our results therefore highlight a trade-off in crappie year class strength, where years with higher summer larval abundance led to more age 0 crappie in the autumn, but that diminished their summer growth, which negatively influenced the abundance of age 1 crappie the following spring, apparently by reducing overwinter survival.

Although the relationships we observed between crappie indices of abundance and reservoir environmental conditions are biologically reasonable, they are correlative in nature and may in fact be influenced by other abiotic factors that we did not directly monitor. For example, warmer summer water temperature may not have led directly to better growth for larval crappie, but instead may have indirectly benefitted crappie growth by increasing zooplankton abundance in warmer years. Another factor we did not include that may have influenced crappie year class strength was the abundance of other centrarchids in the reservoir, particularly smallmouth bass, which had the highest CPUE of any species in spring and autumn electrofishing. While concurrent data were available for smallmouth bass abundance, they were not included as a potential limiting factor for any crappie age classes because in Brownlee Reservoir, they are largely planktivorous and rarely consume crappie (Dunsmoor et al. 1991). Considering how much larger, deeper, steep-sided, and fluctuating some western waters—such as Brownlee Reservoir—are from those in central and eastern North America, we urge additional investigations of the factors influencing crappie year class strength in study waters comparable to ours to further highlight similarities and differences in crappie population dynamics in such disparate environments.

While larval summer, autumn age 0, and spring age 1 CPUE all appeared to accurately depict crappie year class strength, autumn age 0 electrofishing data had several advantages for monitoring the strength of crappie year classes at Brownlee Reservoir. First, electrofishing provided an index of abundance not only for age 0 crappie but also for older age classes of crappie and for other species. Second, electrofishing provided immediate data whereas larval sampling required a great deal of sample processing in the lab to identify larvae to species and enumerate them. Third, the advantage of electrofishing in the autumn rather than the spring was that autumn

data provided information on the size of age 0 crappie entering their first winter, which was apparently important for age 0 overwinter survival. Finally, the sampling effort needed to collect adequate crappie information with boat electrofishing was much shorter (usually one week) than the window needed to monitor larval crappie abundance over the summer (several weeks). Although peak and mean larval CPUE were highly correlated, sampling for peak rather than mean larval abundance would still take several weeks because peak abundance varied annually by almost six weeks during our study. The factors contributing to strong or weak year classes of larval crappie in the summer appear to be elusive at Brownlee Reservoir, but strong age 0 year classes in the autumn consistently persisted to older year classes, thus age 0 autumn electrofishing CPUE appears to be a better indicator of subsequent crappie year class strength than summer larval trawl CPUE. Comparison of crappie catch from summer larval trawls and autumn electrofishing of multiple age classes at other steep-sided canyon reservoirs—where shorelines are often too steep to sample fish with trap nets—would be useful to support or refute this conclusion.

A better understanding of crappie fisheries in general in the waters of western North America is critical for managing them in this region, especially considering that crappie fisheries are often supported by only one or two age classes due to extreme annual recruitment variability (e.g., Allen 1997; Boxrucker and Irwin 2002; Maceina 2003; Martin and Maceina 2004). While previous studies have highlighted several factors that may influence crappie recruitment variability in other regions of North America, our results suggest that applying those generalizations to large, fluctuating, steep-sided reservoirs in the arid western U.S. may be inappropriate. Our results suggest that autumn near-shore electrofishing can be used to annually characterize age 0 crappie recruitment as well as or better than summer surface larval trawls, while also providing additional information on size and abundance of other crappie age classes and other sympatric species which may affect crappie year class strength in a density dependent manner. Long-term monitoring of crappie populations in other waters of western North America would not only facilitate a better understanding of crappie fisheries in this region, but also help establish standard monitoring methods for crappie populations in steep-sided canyon reservoirs where more traditional sampling methods may be inappropriate, and allow better communication with angling groups regarding annual expectations of the quality of crappie fisheries in such waters.

## **MANAGEMENT RECOMMENDATIONS**

1. Sample crappie at Brownlee Reservoir in the autumn using nighttime electrofishing to monitor the fishery; this provides the best index of age 0 production for that year, and provides important information on other age classes as well as other species.

## **ACKNOWLEDGEMENTS**

Jeff Dillon reviewed earlier drafts of the manuscript and provided valuable suggestions to improve the paper. Funding for this work was provided in part by anglers and boaters through their purchase of Idaho fishing licenses, tags, and permits, and from federal excise taxes on fishing equipment and boat fuel through the Sport Fish Restoration Program.

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## TABLES

Table 1. Reservoir conditions during several time periods from 1993 to 2018 in Brownlee Reservoir, Idaho.

Parameter	Spawning period (May 1 - Jun 20)		Summer period (Jul 4 - Sep 15)		Winter period (Dec 10 - Apr 15)		Annual (Jan 1 - Dec 31)	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Reservoir volume (billion m <sup>3</sup> )	1.560	0.560 - 1.744	1.491	1.120 - 1.740	1.471	0.689 - 1.740	1.466	0.560 - 1.744
Change in reservoir volume (billion m <sup>3</sup> )	0.401	0.019 - 1.131	0.371	0.266 - 0.620	0.471	0.128 - 1.053	0.635	0.343 - 1.178
Reservoir inflow (m <sup>3</sup> /s)	689	193 - 2,200	291	167 - 844	494	220 - 2,322	452	167 - 2,322
Reservoir outflow (m <sup>3</sup> /s)	712	178 - 2,645	371	153 - 968	585	238 - 2,778	505	153 - 2,778
Hydraulic residence time (days)	36	4 - 112	51	19 - 110	38	5 - 80	44	4 - 114
Water temperature (°C)	16.7	7.0 - 25.4	22.9	12.3 - 28.7	5.9	0 - 17.5	12.9	0 - 28.7

Table 2. Generalized linear model results used to relate biotic and abiotic factors to crappie catch-per-unit-effort (CPUE) for various age classes in Brownlee Reservoir, Idaho. Only the most plausible models, whose AIC<sub>c</sub> scores were within 2.0 of the top model, are shown. Akaike weights ( $w_i$ ) demonstrate the relative plausibility of all the models, and the coefficient of determination ( $r^2$ ) displays the amount of variation in CPUE that was explained by each model.

Model	$k$	AIC <sub>c</sub>	$\Delta$ AIC <sub>c</sub>	$w_i$	$r^2$
<b>Log(summer larval)</b>					
Spawning temperature	1	4.07	0.00	0.21	0.11
Spawning volume	1	4.64	0.57	0.16	0.08
Spawning inflow	1	4.66	0.59	0.16	0.08
Spring log(spawner CPUE)	1	4.84	0.77	0.14	0.07
Spawning change in volume	1	5.01	0.94	0.13	0.06
Spawning residence time	1	5.27	1.20	0.12	0.05
Trawl type	1	6.05	1.98	0.08	< 0.01
<b>Log(autumn age 0 CPUE)</b>					
Summer log(larval CPUE) + summer inflow	2	-11.10	0.00	0.73	0.52
Summer log(larval CPUE) + summer volume + summer inflow + summer change in volume	4	-9.13	1.97	0.27	0.57
<b>Autumn age 0 mean length</b>					
Summer log(larval CPUE) + summer temperature	2	75.16	0.00	1.00	0.46
<b>Log(spring age 1 CPUE)</b>					
Prior autumn age 0 length + prior autumn log(age 0 CPUE) + winter hydraulic residence time + winter volume	4	-21.62	0.00	0.22	0.63
Prior autumn age 0 length + prior autumn log(age 0 CPUE) + winter inflow	3	-21.37	0.25	0.20	0.60
Prior autumn age 0 length + prior autumn log(age 0 CPUE)	2	-21.04	0.58	0.17	0.56
Prior autumn age 0 length + prior autumn log(age 0 CPUE) + winter residence time	3	-20.71	0.91	0.14	0.58
Prior autumn age 0 length + prior autumn log(age 0 CPUE) + winter volume + winter change in volume	4	-19.99	1.63	0.10	0.60
Prior autumn age 0 length + prior autumn log(age 0 CPUE) + winter change in volume	3	-19.77	1.86	0.09	0.56
Prior autumn age 0 length + prior autumn log(age 0 CPUE) + winter volume + winter inflow	4	-19.72	1.90	0.09	0.60
<b>Log(spring age 2 CPUE)</b>					
Log(prior year spring age 1 CPUE) + prior year change in volume + prior year volume	3	-19.64	0.00	0.24	0.61
Log(prior year spring age 1 CPUE) + prior year change in volume	2	-19.33	0.31	0.20	0.58
Log(prior year spring age 1 CPUE) + prior year hydraulic residence time	2	-19.16	0.48	0.19	0.58
Log(prior year spring age 1 CPUE) + prior year inflow	2	-19.11	0.53	0.18	0.58
Log(prior year spring age 1 CPUE) + prior year volume + prior year hydraulic residence time	3	-17.92	1.72	0.10	0.59
Log(prior year spring age 1 CPUE)	1	-17.89	1.75	0.10	0.56

Table 3.

Coefficient estimates (and standard errors [SE]) for the top generalized linear model relating biotic and abiotic factors to crappie catch-per-unit-effort (CPUE) for four age classes in Brownlee Reservoir, Idaho.

Model	Coefficient	SE
<b>Log(summer larval CPUE)</b>		
Intercept	1.330	1.506
Spawning temperature	-0.124	0.090
<b>Log(autumn age 0 CPUE)</b>		
Intercept		
Log(summer larval CPUE)	0.842	0.278
Summer inflow	0.006	0.002
<b>Autumn age 0 mean length</b>		
Intercept	-54.770	49.662
Log(summer larval CPUE)	-15.149	4.796
Summer temperature	5.450	2.148
<b>Log(spring age 1 CPUE)</b>		
Intercept	-6.175	2.330
Prior autumn age 0 mean length	0.038	0.009
Log(prior fall age 0 CPUE)	0.624	0.173
Winter residence time	-0.033	0.014
Winter volume	$3.08 \times 10^{-9}$	$1.69 \times 10^{-9}$
<b>Log(spring age 2 CPUE)</b>		
Intercept	8.273	5.011
Log(prior year spring age 1 CPUE)	0.897	0.142
Prior year change in volume	$-2.84 \times 10^{-9}$	$1.21 \times 10^{-9}$
Prior year volume	$-4.75 \times 10^{-9}$	$2.95 \times 10^{-9}$

## FIGURES

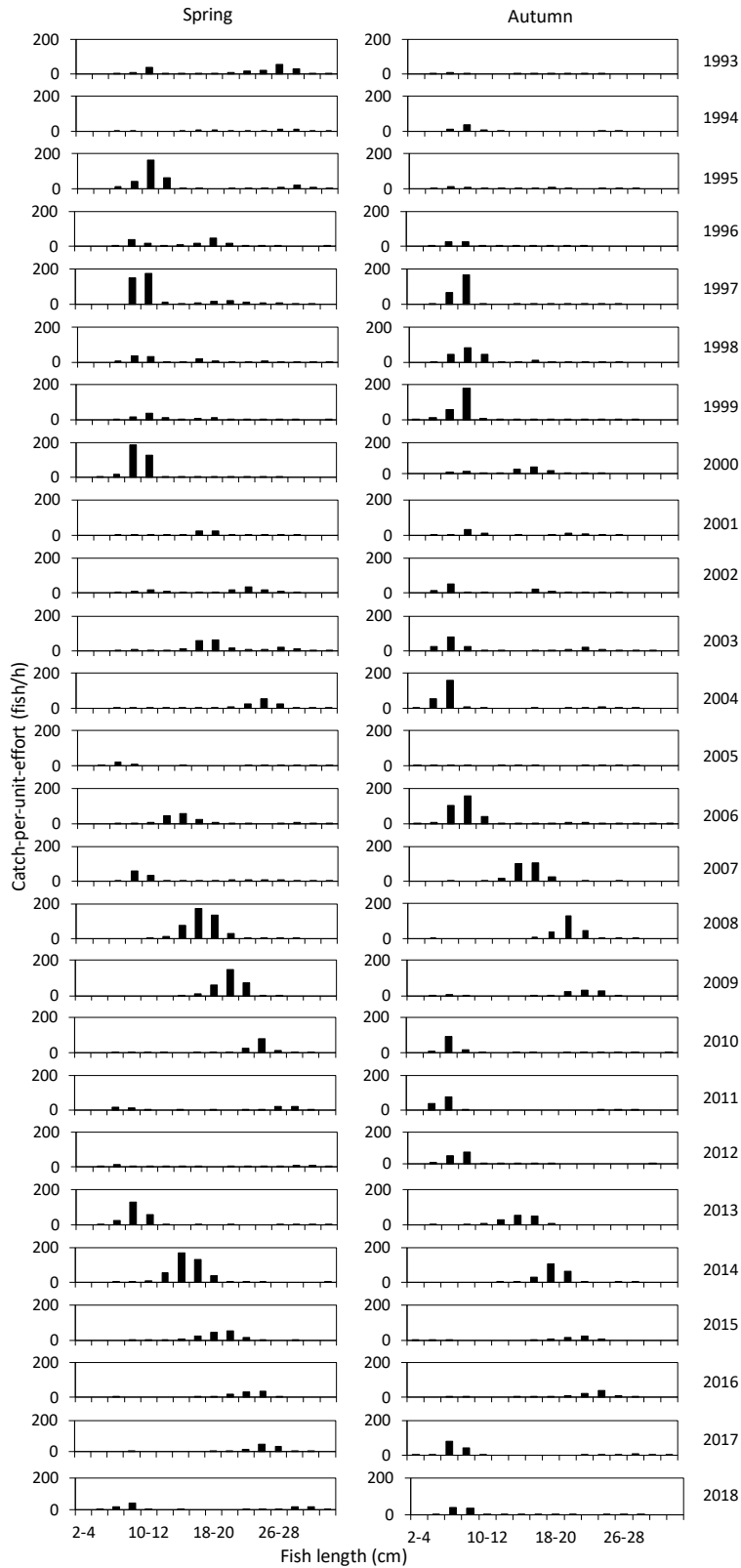


Figure 1. Length-frequency of crappie captured with nighttime spring and autumn boat electrofishing from 1993 to 2018 in Brownlee Reservoir, Idaho.



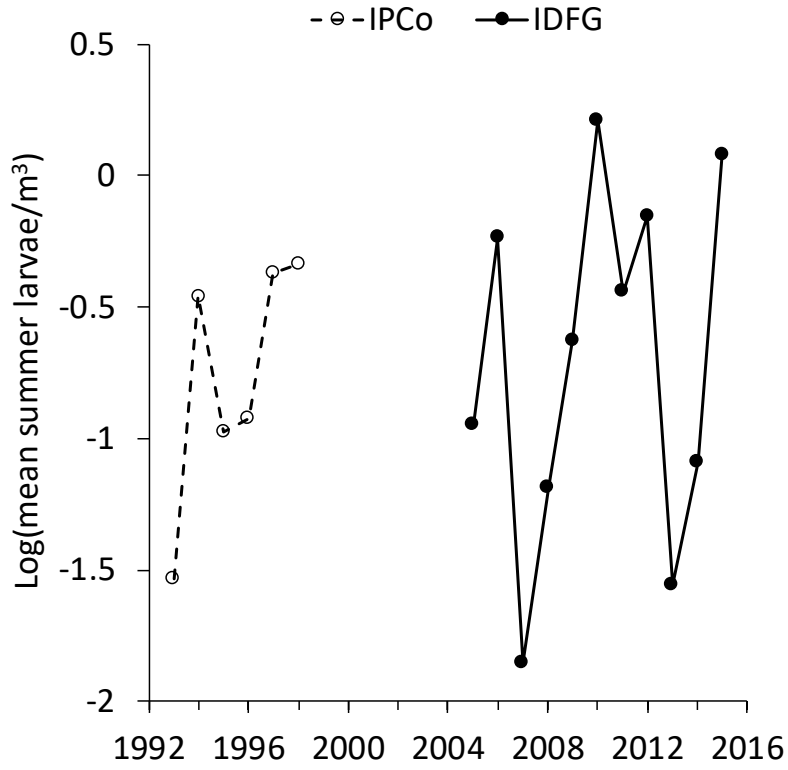


Figure 2. Crappie larval catch-per-unit-effort (CPUE) from summer larval trawls through time at Brownlee Reservoir, Idaho, conducted by Idaho Power Company (IPCo) and Idaho Department of Fish and Game (IDFG) staff.

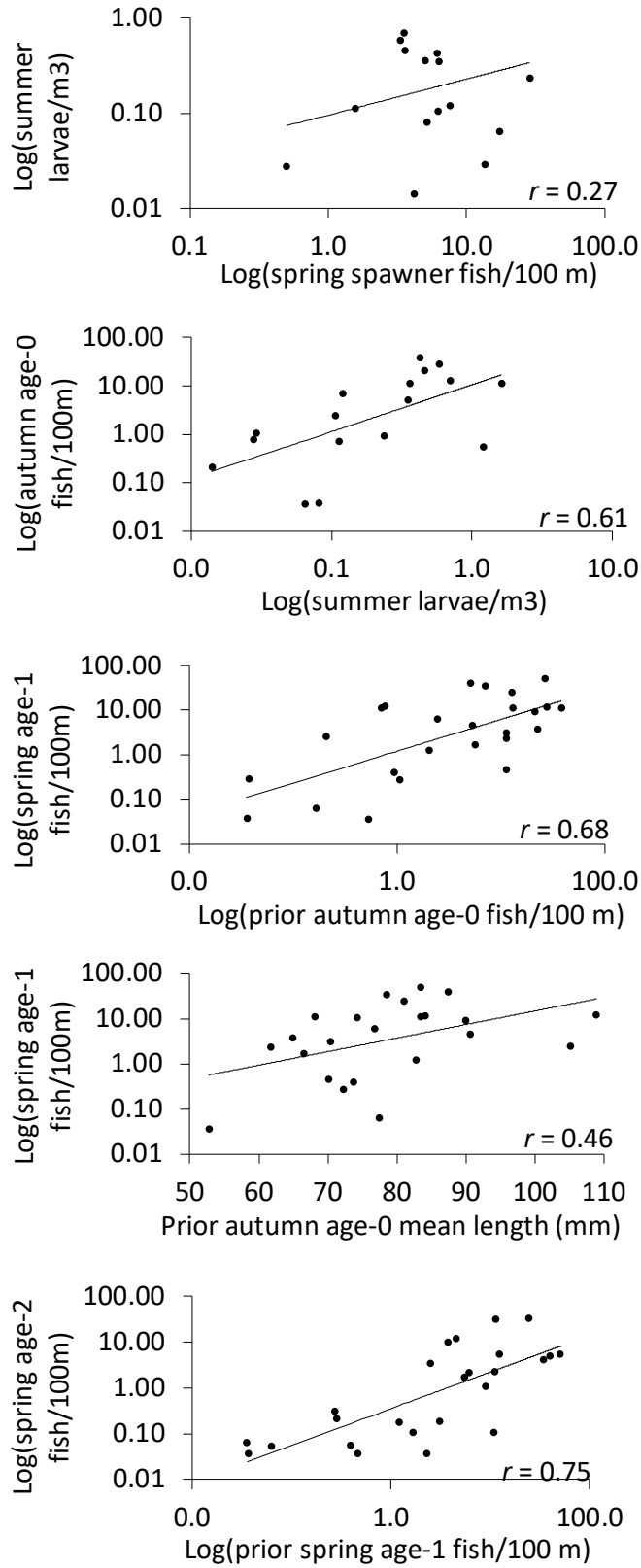


Figure 3. Relationships between crappie catch-per-unit-effort in successive age classes from 1993 to 2018 in Brownlee Reservoir, Idaho.

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