Lake Powell Fisheries Investigations

Completion Report
May 15, 2015 – April 30, 2020

Utah Department of Natural Resources
Utah Division of Wildlife Resources
1594 West North Temple, Suite 2110
Salt Lake City, UT 84114

Rory Reynolds
Director

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INTRODUCTION

Since 1963 Utah Division of Wildlife Resources (UDWR) has been conducting an on-going post impoundment reservoir study focusing mainly on the fisheries of Lake Powell. The goal of sustaining a healthy fishery and promoting a great angling experience can be challenging as changing angler expectations as well as changing fish assemblages can make goals a moving target. The 50-year dataset has provided an unprecedented look into this unique fishery and the impact that UDWR regulatory actions have had on guiding and development of the fishery.

In terms of popularity and productivity, Lake Powell continues to be one of Utah's more important fisheries. Although fishing pressure is highly variable, a peak estimate of 1.95 million angler hours was generated during the 2006 season with an estimated total catch of 3.37 million fishes. Superb Striped Bass *Morone saxatilis* and Smallmouth Bass *Micropterus dolomieui* populations are what currently drive the fishery. In the early days Largemouth Bass *Micropterus salmoides,* Black Crappie *Pomoxis nigromaculatus* and Walleye *Stizostedion vitreum* were the main drivers. According to estimates from the latest angler survey conducted in 2018 fishing has never been better on Lake Powell in terms of angler success and the Utah Division of Wildlife Resources (UDWR) continues to explore management options to make it even better.

Species introductions, both planned and inadvertent have shaped the fishery in unique ways. The early introduction of Threadfin Shad *Dorosoma petenense* in 1963 has largely fueled the fishery to this day. Meanwhile, the inadvertent introduction of Gizzard Shad *Dorosoma cepedianum* in 2000 has greatly changed the forage dynamic, and mostly in a positive way. The recovery of Walleye in 2004 has largely been attributed to the presence of Gizzard Shad and currently both Striped Bass and Walleye have no creel limits. The planned introduction of Smallmouth Bass in 1982 was another highly successful introduction that quickly developed into a fantastic fishery, replacing the Largemouth Bass stock that had declined due to the loss of brushy habitat as a result of reservoir aging.

The inadvertent introduction of both the Tamarisk Beetle *Diorhabda carinulata* and Quagga Mussels *Dreissena rostriformis bugensis* was initially very alarming and, although still concerning, has not had the dire effects on the fishery as was initially predicted. However, preventing the spread of Quagga Mussels from Lake Powell to other bodies of water remains a priority for the state of Utah and rightly so as their effect on other waters in the state may be devastating. The advantage of long-term sampling and data trend lines becomes apparent when assessing possible impacts that these introductions are having on the system.

This report is similar to the previous one and is unconventional in some ways. It is broken down to reflect our major fisheries, areas of concern and special interest. It is more integrated and less repetitive than previous reports and deviates from a formal scientific journal style. Introductions, materials and methods described, in many cases, were copied from previous Lake Powell completion reports for efficiency, as was most of the study area and hydrological overview portion of the report that, although updated here, basically remains unchanged from the previous report. There is necessarily some data overlap between jobs and we have attempted to eliminate redundancies as much as possible but with this format a certain amount was unavoidable.

STUDY AREA AND HYDROLOGICAL OVERVIEW

Lake Powell is the second largest reservoir by volume in the United States. The reservoir was impounded by construction of the Glen Canyon dam, which began in 1958. Storage began in March of 1963 and initial filling was completed by June of 1980. With over 1,900 miles of shoreline, Lake Powell has a full pool capacity of 27 million acre feet with 163,000 surface acres. Full pool elevation is 3700 ft with a maximum water depth at the dam of 560 ft.

Sampling areas are generally standardized, but water elevation changes occasionally dictate temporary site changes. There are currently 4 marinas and 5 launching access areas that serve the lake. Down-lake marinas/ramps are at Wahweap, Stateline Ramp and Antelope Point. Mid-lake marinas are at Bullfrog and Hall's Crossing. The up-lake marina was historically at Hite but access has been somewhat limited at this site due to the receding water levels and silt accumulation problems. Ramps at these marinas constitute the main lake access points and angler surveys are conducted here. Primitive launches occur at a few locations but use is limited compared to the main access ramps.

Mid-water trawl transects, to sample pelagic shad, are conducted at Wahweap Bay, Bullfrog Bay, Good Hope Bay, and on the San Juan arm by Piute Canyon. Larval shad are sampled in meter net tows with down-lake sites at Wahweap Creek, Warm Creek and Navajo Canyon. Mid-lake sites are at Ticaboo Canyon, Bullfrog Creek and Halls Creek while up-lake sites are at Red Canyon and Trachyte.

Electrofishing stations are at Wahweap Bay/Warm Creek Bay, Bullfrog Bay at Stanton Creek, Rincon Bay, Good Hope Bay at Red Canyon, and the San Juan near Piute Canyon. Meanwhile, the gill net survey stations are at Wahweap Bay, Rincon Bay, San Juan at Piute Canyon, and Good Hope Bay at Red Canyon (Figure 1).

Four major tributaries empty into the reservoir. The two most important in terms of volume are the Colorado River with 10.6 million acre feet and the San Juan at 2.1 million acre feet. Of lesser importance are the Dirty Devil and the Escalante rivers. Inflows from these sources are responsible for rising water levels from May to July each year.

The reservoir stratifies in the summer months with an inflow current overflowing a denser bottom layer. Stratification typically breaks down in October due to convective mixing and advective currents. Due to the great depth (560 ft – full pool) at the lower end of the lake, the water below the penstocks remains homogenous and separate from the water above. During the winter a cold dense inflowing current moves along the bottom and over time displaces this layer up and through the penstocks. Average water retention time for the reservoir is two years although it is only 8 months for the upper portion of the lake above Bullfrog. This is due, not only to shallower water depth, which is more susceptible to convective mixing, but also the close proximity to the Colorado River, which allows for more lateral circulation (Potter and Drake 1989).

Lake Powell is classified as oligotrophic although productivity increases closer to the inflows and in the backs of most side canyons. Maximum surface water temperatures reach 26^0 – 28^0C. Zooplankton densities in the mainstem are in the 20-27 plankters/liter range but can increase greatly in near-shore areas.

Since reaching full pool in 1980 (3700 ft elevation) 2 major droughts have affected the reservoir since 1983. The first began in the mid-1980's and lasted until 1993, the second began in 1999 and ended in 2005 (Figure 2). This second drought, in particular, appears to have had a profound effect on the water chemistry of the lake: affecting productivity and the fishery itself. In recent years the region has been experiencing a third drought that has not been totally reflected in peak yearly lake levels and is being masked somewhat by water level manipulations. Recently, water levels peaked in 2011 at 3660 (MSL) then declined in 2012 and 2013, reaching a low in April 2014 at 3574.21 ft before recovering later in the season and increasing again in 2015. However, new regulations put in place to address declining water levels now require an equalization flow to be released downstream to Lake Mead when surface elevation at Lake Powell meets or exceeds 3640 (MSL) during September of any given year. The annual requirement of releasing 8.23 maf is increased in years when equalization flows are mandated. Declining water levels again in 2018 and 2020/2021 suggest that the latest drought is still in effect with long-term projections for the Colorado River system dire.

Lake elevation increases can have a profound impact on the fishery. Declining lake elevation allows for the establishment of terrestrial plant species as they follow the declining shoreline. As water levels increase over the previous year this flooded vegetation becomes vital nursery habitat for YOY fishes, especially Centrarchid species, as well as providing sites for macrophyte attachment.

Water temperatures typically peak in July but occasionally in August. Peak surface water temperatures usually exceed 26.7^{0}C (80^{0}F) in the open water. In 2019 they were recorded at 89.4^0 F at the open water site at Trachyte, a new record. A distinct thermocline typically sets up in July around 8 meters and migrates downward through August to a depth around 15-20m. Near-shore sampling sites are usually much warmer than open-water sites with peak summer surface water temperatures often exceeding 29.4^{0}C (85^{0}F). These temperatures exceed adult Striped Bass tolerances and prevent them from accessing forage in the backs of many canyons during the summer months.

Lake Powell rarely has ice conditions, and then only in the mid and uppermost areas. The only species in Lake Powell that are susceptible to cold water temperatures is Threadfin Shad. High mortality was noted by Parson and Kimsey (1954) at 7.2^{0}C (45^{0}F) while Strawn (1965) observed 50% mortality at 6.1^{0}C (43^{0}F). Winter shad die-offs are rare with the last one reported in 1992 from the Hite/North Wash area with reports also from the White and Farley Canyon areas. The die-off was typically of only limited magnitude (Blommer and Gustaveson 2002). Historical winter shad die-offs were usually in isolated canyons up-lake and have not been reported in the last two decades.

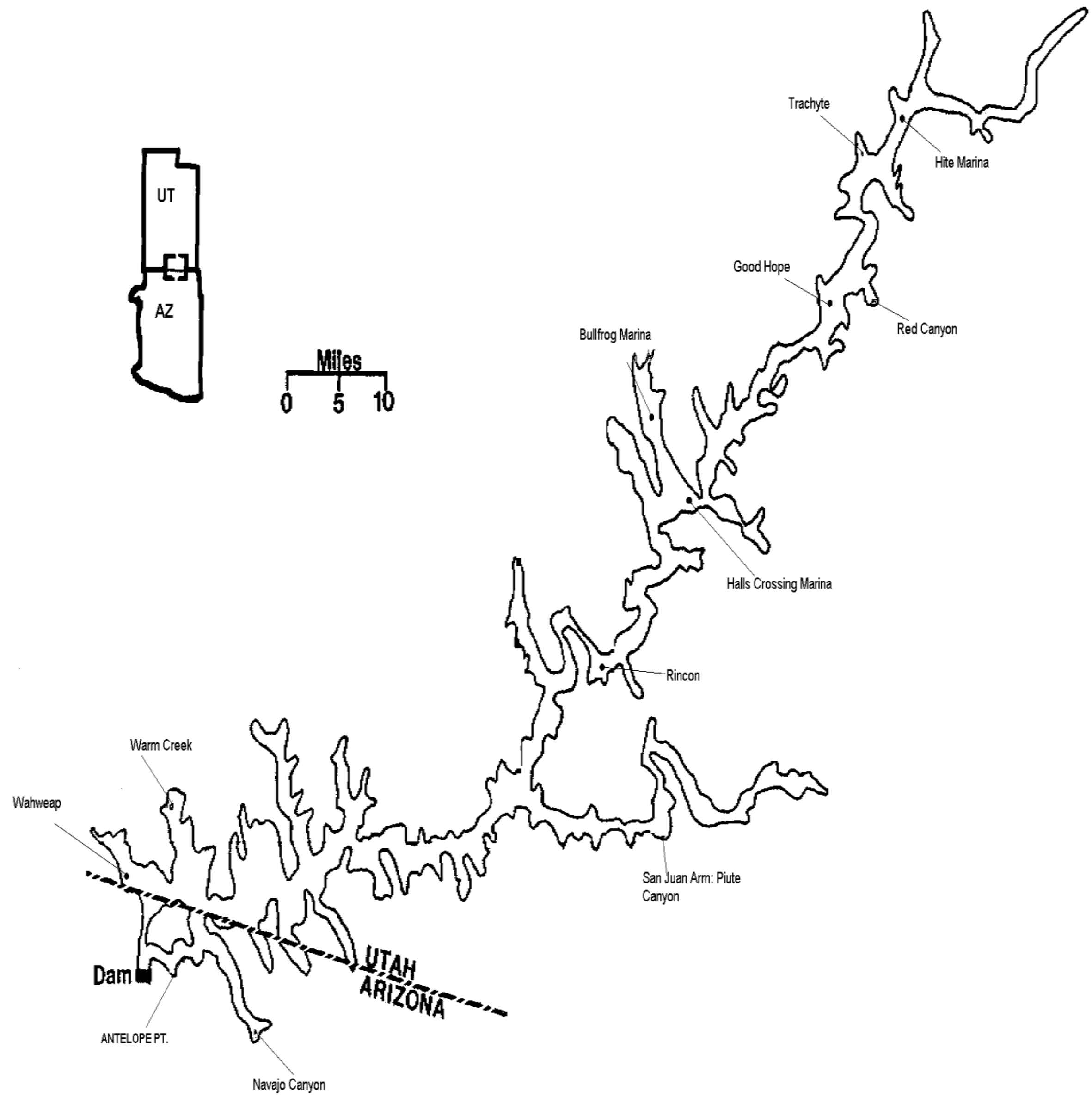


Figure 1. Map of Lake Powell with major sampling areas.

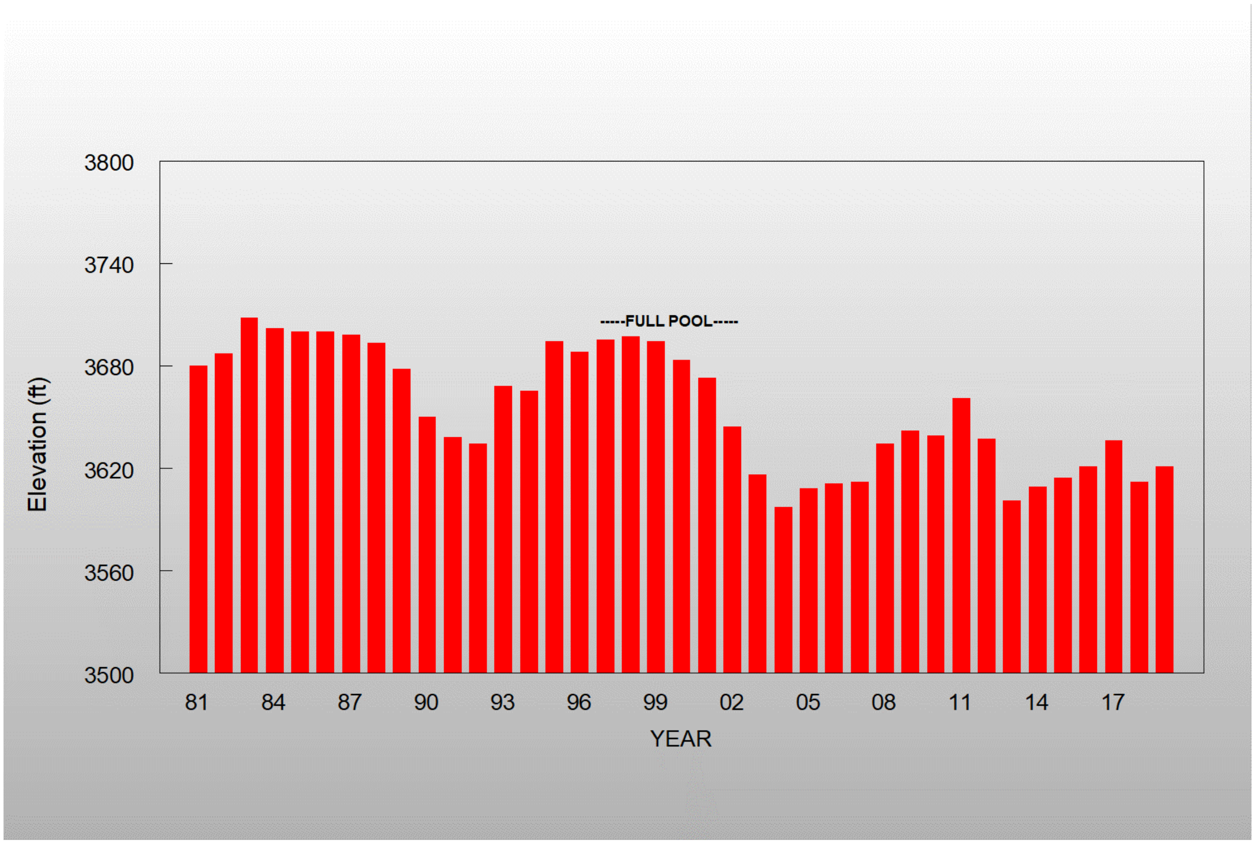
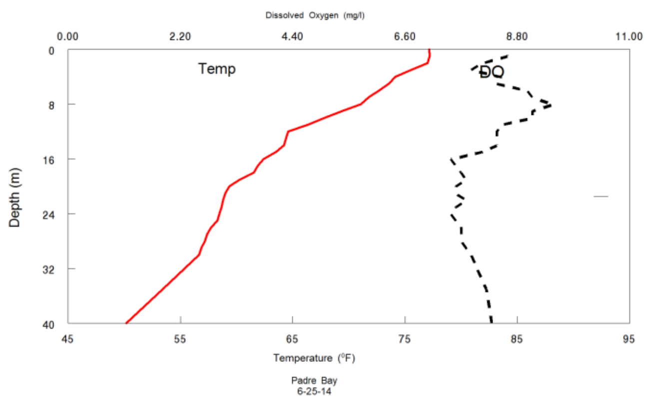


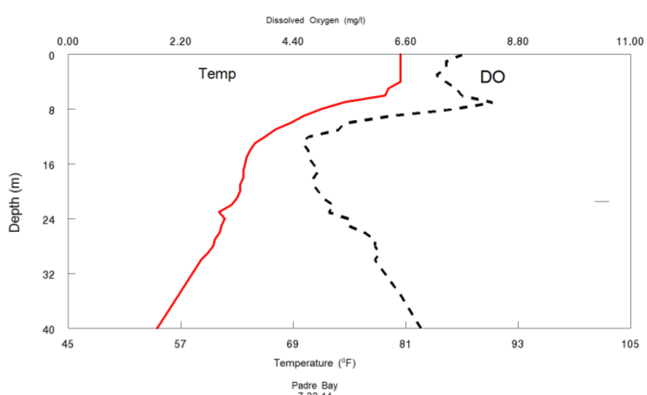
Figure 2. Maximum pool elevations, 1981-2019, Lake Powell, UT/AZ.

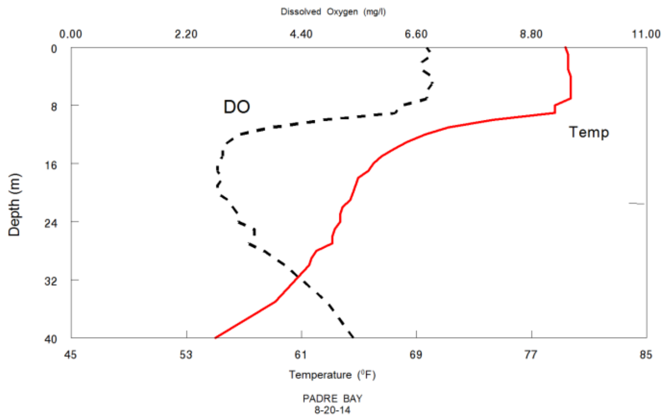
Historically, Lake Powell oxygen profiles in the lacustrian zone showed a minimum depletion in the metalimnion (Gloss et al. 1974): this situation has continued up to the present. Usually this phenomenon began in July and continued through September before breaking down in October (Figure 3). However, the intensity of the depletion varied yearly and between sites. The upper most sampling station at Trachyte Canyon did not show the classical mid-water depletion since it was heavily under the influence of the river water which moved along the bottom at this site, creating a noticeable current when sampling sondes were at depth. Most years the depletion developed and intensified up-lake first before appearing at mid and down-lake locations, while other years the depletion was detected almost simultaneously across sampling stations throughout the lake. This metalimnetic depletion is not uncommon in deep reservoirs and is also observed upstream in Flaming Gorge Reservoir and downstream in Lake Mead. In the case of Lake Powell, the depletion develops just downstream of the inflows during spring runoff and is transported by advective currents downstream towards the dam (Williams 2007). Bolke (1979) attributed the depletion in Flaming Gorge Reservoir to similar interflow currents while respiratory activity was suspected in Lake Mead (Baker et al. 1977). Meanwhile, lower lake stations at Wahweap and Padre Bay often display an oxygen spike at 5m – 8m during the spring and early summer months, probably the result of phytoplankton oxygen production (Figure 3).

In 2014 the depletion was observed lake-wide after beginning in July. The duration was longer than usual with the depletion observed through October before breaking down at lake turn over in November. Most years the depletion persists only into September than breaks down in October as was the case in 2015. Also, in 2015 the depletion did not set up until August and was not well defined at the Good Hope or Wahweap stations. Sampling from 2016-2019 showed the typical depletion patterns.

Intuitively, fishes should be avoiding depths where the depletion occurs and this may be the case. Acoustical sampling in September shows that forage species are centered about the 10-11m depth range, which is almost in all cases just above the depletion. Larger fishes appear to remain just below the mass of forage and also above the depletion. However, a few targets are occasionally in the depletion zone which is often below 4 mg/l of dissolved oxygen, and can go below 2.0 mg/l in the worse affected zones. These depletion zones usually extend 10m of vertical depth but can, in some years and locations, extend to the bottom.







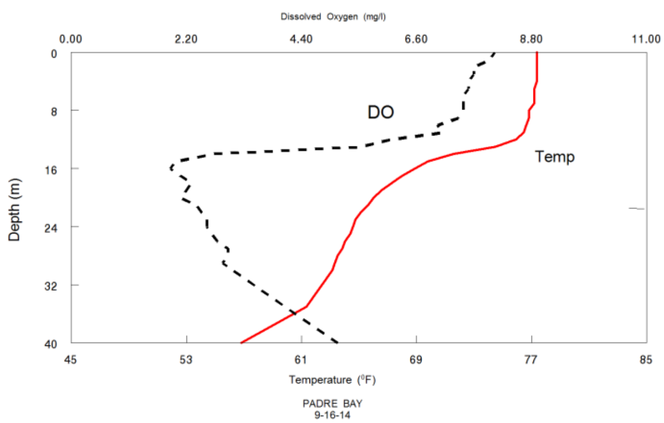


Figure 3. Typical oxygen and temperature profiles from the Padre Bay station, Lake Powell, UT. June-September, 2014.

Global warming concerns have garnered an inordinate amount of attention in recent fishery publications. We looked at mean surface water temperatures recorded at the 4 gill-net survey stations during the first 2-weeks in November which suggest that the fall heat budget may be warming on Lake Powell. Although surface water temperatures can be highly variable, and data were not collected with an eye towards statistical analysis, the long-term nature of the data set provided an interesting first look at possible warming water temperatures on Lake Powell. Temperatures at the higher end appear not to be following a particular trend, however the number of years where lower temperatures were recorded appears to be diminishing over the past 15-years. The lowest 2 mean temperature years recorded in the 1981-2000 period with 13.30C $(56)^0$ F and 13.9C (57^0F) in 1985 and 2000 respectively. Additional low temperature years that were equal or less than 15.6^0C (60^0F) occurred in 1985, 1989, and 1990. By comparison, in the latest 15-year span from 2001 – 2019 there was only a single year (2013) when the mean surface water temperature was less than 15.6^{0}C (60^{0}F) (Figure 4).

Higher fall water temperatures have the potential to affect the fishery in profound ways. We know that the gill net catch was suppressed in years with low water temperatures (see Trend Sampling Overview – gill-net survey section). Most likely, lower water temperatures decreased fish activity thus decreasing the effectiveness of the sampling gear. A longer grow season has the potential to effect growth and survival of both predators and prey. Many of the effects may be subtle yet resonate throughout the fishery in ways too complicated and speculative to address in this report.

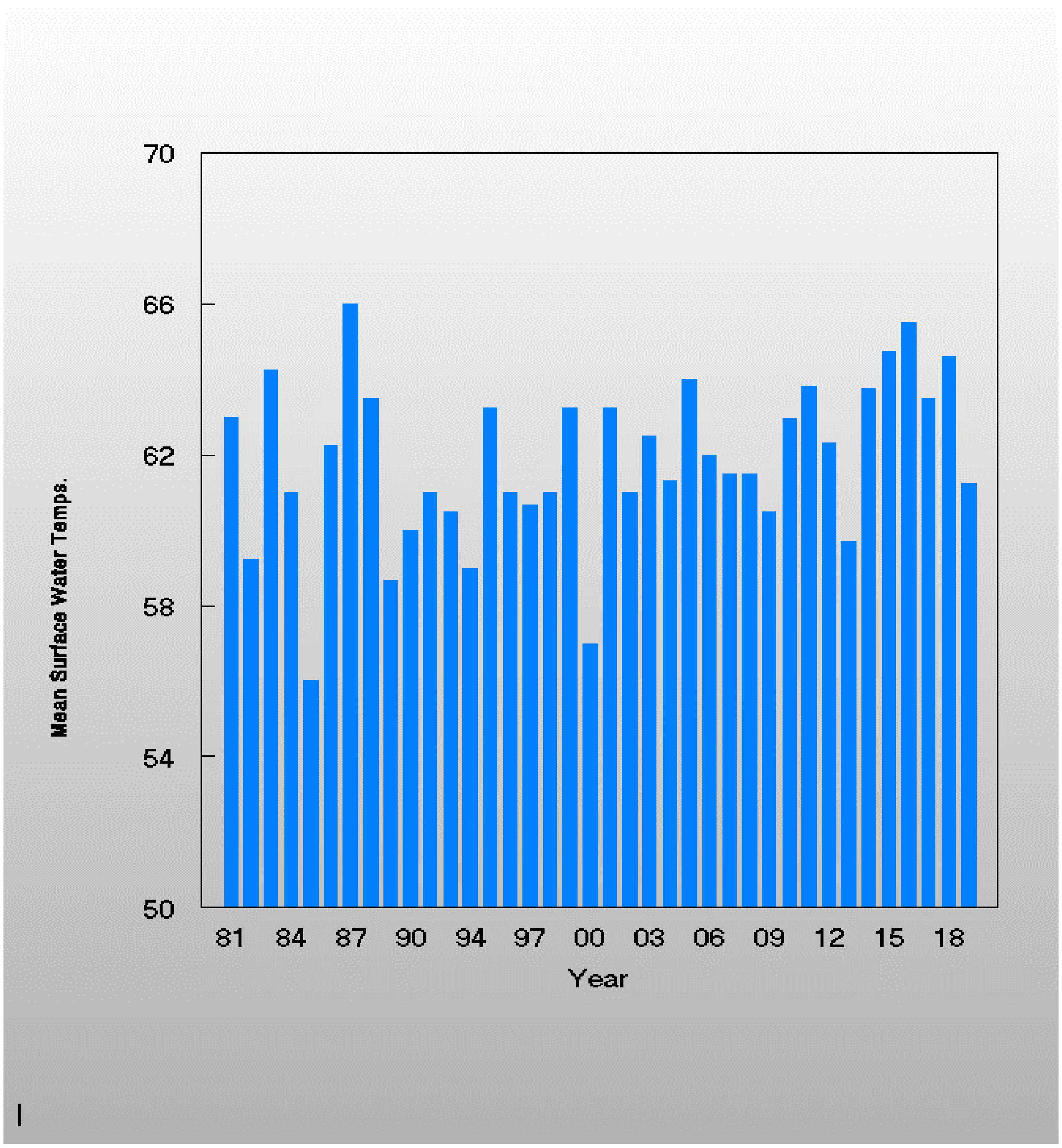


Figure 4. Mean surface water temperatures taken yearly during the first 2-weeks of November from the annual gill net survey standard sampling sites, Lake Powell, UT. 1981-2019.

PRODUCTIVITY AND ZOOPLANKTON STATUS

UDWR began its ongoing zooplankton sampling in 1999. Previous studies sampled zooplankton from open-water sites only, whether in the open bays or deep canyon sites. Our sampling was geared toward quantifying the responses of pelagic forage fishes as well as littoral dwelling YOY fishes to zooplankton densities and included a near-shore (<= 3 m) sampling component along with the traditional open-water sites. This long term sampling has been fortunate in providing historic zooplankton levels prior to the establishment of Gizzard Shad in the early 2000's and the subsequent Quagga Mussel invasion that began in earnest in 2012. Both of these invasions could potentially have a profound effect on the planktonic community.

All sampling was done using a 30 cm diameter, 80 micron mesh, simple style plankton net. Open-water tows were pulled vertically from 40 m to the surface unless depth was insufficient, in which case the tow was from the bottom to the surface. The Trachyte station was the only open water site that consistently was sampled at less than 40 m. Near-shore samples were pulled vertically from the bottom to the surface with a maximum depth of 3 m. Two samples were taken at each site through 2014 when a single sample was pulled.

All samples were preserved in completely denatured ethyl alcohol with the biological stain Phloxine B added to aid in identification and enumeration. In the lab, the sample was brought to a set volume and three separate 1 ml subsamples placed on a Sedwick-Rafter cell to be counted and identified. All species were identified to size based groups that included the categories: Rotifer, Nauplii Copopodes, adult Copopodes, Cladocerans, Bosmina, Other. The "other" category became "veligers" starting in 2014.

Sampling sites evolved over time but sites were standardized by 2003. Down-lake open-water sites were at Wahweap Bay and Padre Bay. Mid-lake sites were at Rincon and Bullfrog Bays while up-lake sites were at Good Hope Bay and in the main channel by Trachyte Canyon. Near-shore sites were down-lake at Wahweap Creek, Warm Creek and Navajo Canyon inflow areas. Mid-lake sites were at Rincon (near shore), Bullfrog Creek and Bullfrog near shore at Stanton Creek. Up-lake near-shore sites were at Good Hope Bay (near-shore), Red Canyon Creek and Trachyte Creek.

In conjunction with our zooplankton sampling, monthly temperature and dissolved oxygen profiles were obtained at open-water sites using an YSI Model 58 dissolved oxygen meter. Additionally, a secchi disk reading and surface water temperatures were taken at all sites. Starting in 2007 sampling began at all sites for turbidity and chlorophyll a. A Turner Designs *Aqua*fluor™ was used to measure turbidity and *in vivo chlorophyll a*. Samples were taken at all near-shore and open-water sites where zooplankton samples were taken. Turbidity was measured in Nephelometric Turbidity Units (NTU) and chlorophyll *a* in Relative Fluorescent Units (RFU): due to the semi-quantitative nature of the detection process. Near-shore samples were taken at a depth of .305 m (1 ft). Open-water samples were taken at a depth of .305 m (1 ft) and also a tube sampler was used to take a sample from the surface to a depth of 15.24 m (50 ft) for a limited number of years. Turbidity was also sampled with a secchi disk and reported to the nearest ¼ m.

Productivity:

Although classified as oligotrophic, a productivity gradient on Lake Powell has long since been recognized with nutrients increasing as you approach the tributaries and in the backs of most side canyons, especially those with inflows (Paulson and Baker 1983; Potter and Drake 1989; Wurtsbaugh et al. 1992, 1994; Sollberger et al. 1989). The up-lake portion of the reservoir is generally more productive than the down-lake portion as measured by mean Relative Fluorescent Units, plankton counts as well as numerous fish indices. However, productivity can decrease directly near inflow areas where the sediment load decreases light penetration (Wurtsbaugh and Steinhart 1995).

Lake-wide mean open-water RFU's collected the previous 4-years were 3.55 (SD = 0.46). Compared with mean chl *a* of 2.25 from data generated by Glen Canyon Environmental Studies (GCES) from 1991-2004 (Bill Verneau personal communication) and from UDWR data collected from 2008-2015 of 2.48 (SD = 0.64), the open-water portions of the lake would appear to be increasing in productivity (Table 1).

Table 1. Mean Relative Fluorescent Units measured from open-water (OW) sites, Lake Powell 2008-2019.

	WW_OW	PB_OW	RN_OW	BF_OW	GH_OW	TC_OW	SJ_OW	**MEAN**
2008	0.97	1.14	2.53	2.55	3.51	4.39	1.62	**2.39**
2009	1.20	1.43	1.79	3.52	6.55	4.97	1.18	**2.95**
2010	0.60	1.19	1.71	2.04	2.05	2.69		**1.71**
2011	0.83	1.49	2.80	2.61	2.55	3.31	4.38	**2.57**
2012	1.64	0.76	1.17	1.52	2.50	1.82	1.36	**1.54**
2013	1.22	1.23	3.92	3.69	2.85	5.52	1.78	**2.89**
2014	1.32	1.81	2.94	2.79	3.42	5.57	2.86	**2.96**
2015	1.55	2.42	3.00	2.92	4.48	5.80	4.34	**3.50**
2016	0.84	1.27	3.66	4.22	4.63	6.74	3.06	**3.49**
2017	1.82	2.15	2.10	2.49	4.15	5.73		**3.07**
2018	0.77	0.82	2.69	3.88	5.16	8.18	1.90	**3.34**
2019	1.75	2.47	3.35	4.31	6.18	8.85	3.20	**4.30**
Mean	**1.21**	**1.51**	**2.64**	**3.04**	**4.00**	**5.30**	**2.56**	

Note: WW = Wahweap, PB = Padre Bay, RN = Rincon, BF = Bullfrog, GH = Good Hope, TC = Trachyte, SJ = San Juan

Lake-wide mean near-shore RFU's also increased when the previous 4-years (2016-2019) were compared with 2012-2015 from 4.90 (SD = 1.83) to 6.41 (SD = 1.49) (Table 2). Near-shore productivity "hotspots" occur down-lake at Navajo Canyon (NC_IS) and up-lake at Red Canyon (RDC_IS) and Ticaboo Canyon (TC_IS). All of these sites have an inflowing stream that runs for a good portion of the year. Furthermore, mean lake-wide RFU's were at historically high levels for both open-water (RFU = 4.30, SD = 2.27) and near-shore (RFU = 8.34, SD = 8.22) samples in 2019. However, variability in near-shore estimates has been high over the previous 4 years with sites at Red Canyon Creek, Ticaboo and Navajo Canyon spiking in recent years (Figure 5).

Table 2. Mean Relative Fluorescent Units measured from near-shore (IS) sites, Lake Powell 2008-2019.

YEAR	WW_IS	WC_IS	NC_IS	RN_IS	BF_IS	BFC_IS	GH_IS	RDC_IS	TC_IS	SJ_IS	**Mean**
2008	1.34	1.88	3.07	2.16	3.10		4.66	7.23	7.4	1.71	**3.62**
2009	4.27	3.72	7.93	1.66	3.28		2.42		4.08		**3.91**
2010	1.22	1.65	6.80	1.38	2.01	2.45	2.09	4.11	4.59		**2.92**
2011	1.61	2.62	8.24	3.15	2.77	3.19	2.77	6.49	7.06	2.71	**4.06**
2012	2.21	2.28	19.57								**8.02**
2013	2.08	1.92	4.50	2.65	2.26	4.18	2.62	6.69	5.86		**3.64**
2014	1.54	2.30	6.47	2.97	2.49	3.19	4.41		5.73	2.65	**3.53**
2015	3.14	3.33	7.18	2.96	2.64	5.02	5.07		4.96	5.55	**4.43**
2016	2.97	4.14	6.9	3.71	4.19	5.39	6.00	5.88	28.02	5.34	**7.25**
2017	4.45	6.78	13.21	1.49	2.84	2.44	3.11	10.13	8.60	2.71	**5.58**
2018	2.11	2.20	8.24	2.36	2.92	5.98	4.06	3.20	10.84	2.79	**4.47**
2019	3.06	3.95	18.03	3.20	3.61	4.46	5.06	10.14	29.0	2.85	**8.34**
Mean	**2.50**	**3.06**	**9.18**	**2.52**	**2.92**	**4.03**	**3.84**	**6.73**	**10.56**	**3.29**	

Note: WW = Wahweap, WC= Warm Creek, NC= Navajo Canyon, RN = Rincon, BF = Bullfrog, BFC = Bullfrog Creek, GH = Good Hope, RDC = Red Canyon Creek, TC = Trachyte, SJ = San Juan

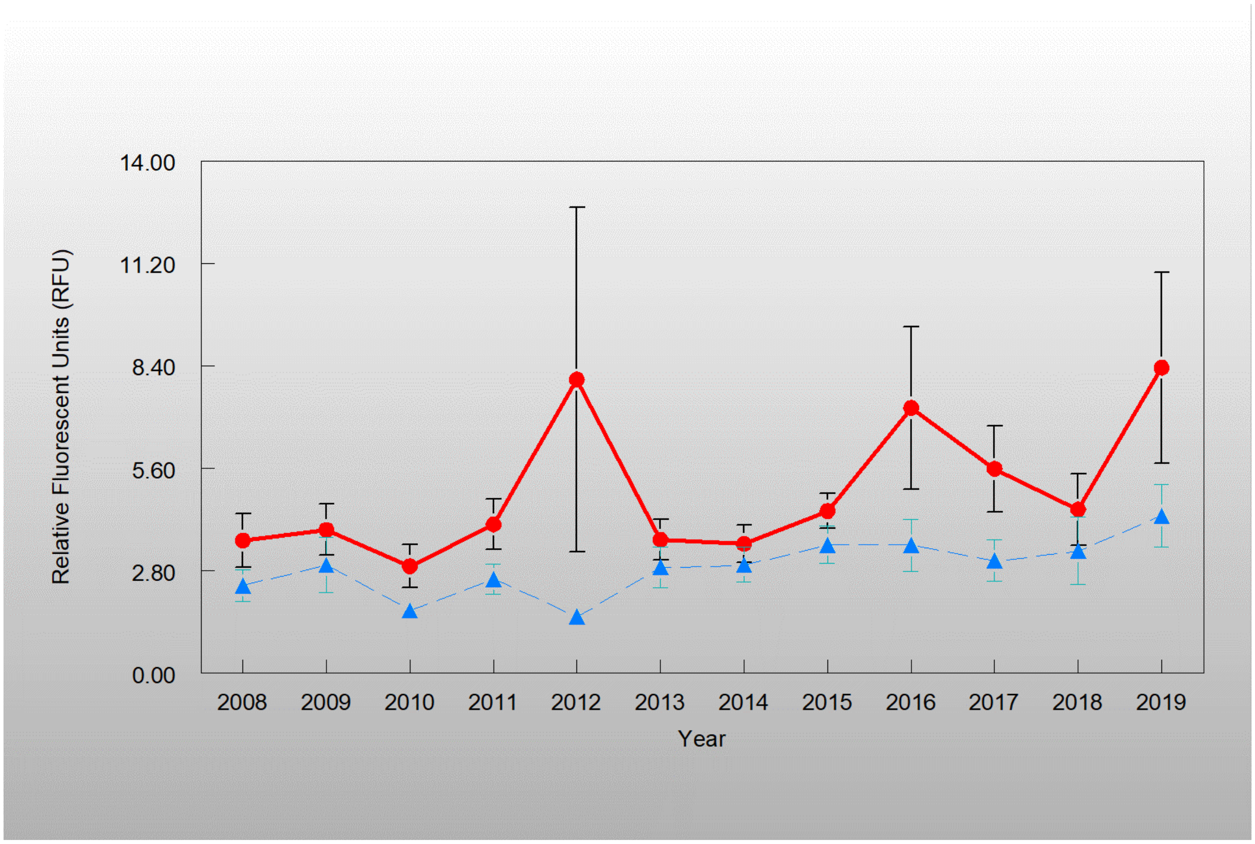


Figure 5. Mean Relative Fluorescent Units (RFU) measured lake-wide at near-shore (red line) and open-water (blue line) sampling sites with SE, Lake Powell, UT. 2008-2019.

Lake-wide near-shore RFU's increased steadily, peaking in July before declining through November. This compares with historical data (2008-2015) where mean RFU's peaked in August but at much lower values. Open-water values were more variable during the latest 4-year period compared with historically. Open-water RFU's peaked sharply in July after an early season slump in May than paralleled the near-shore sample with a sharp decline through September. Recovery occurred in October before bottoming out in November (Figure 6). As with near-shore sampling overall productivity was higher during the 2016-2019 period compared with historical values (2008-2015).

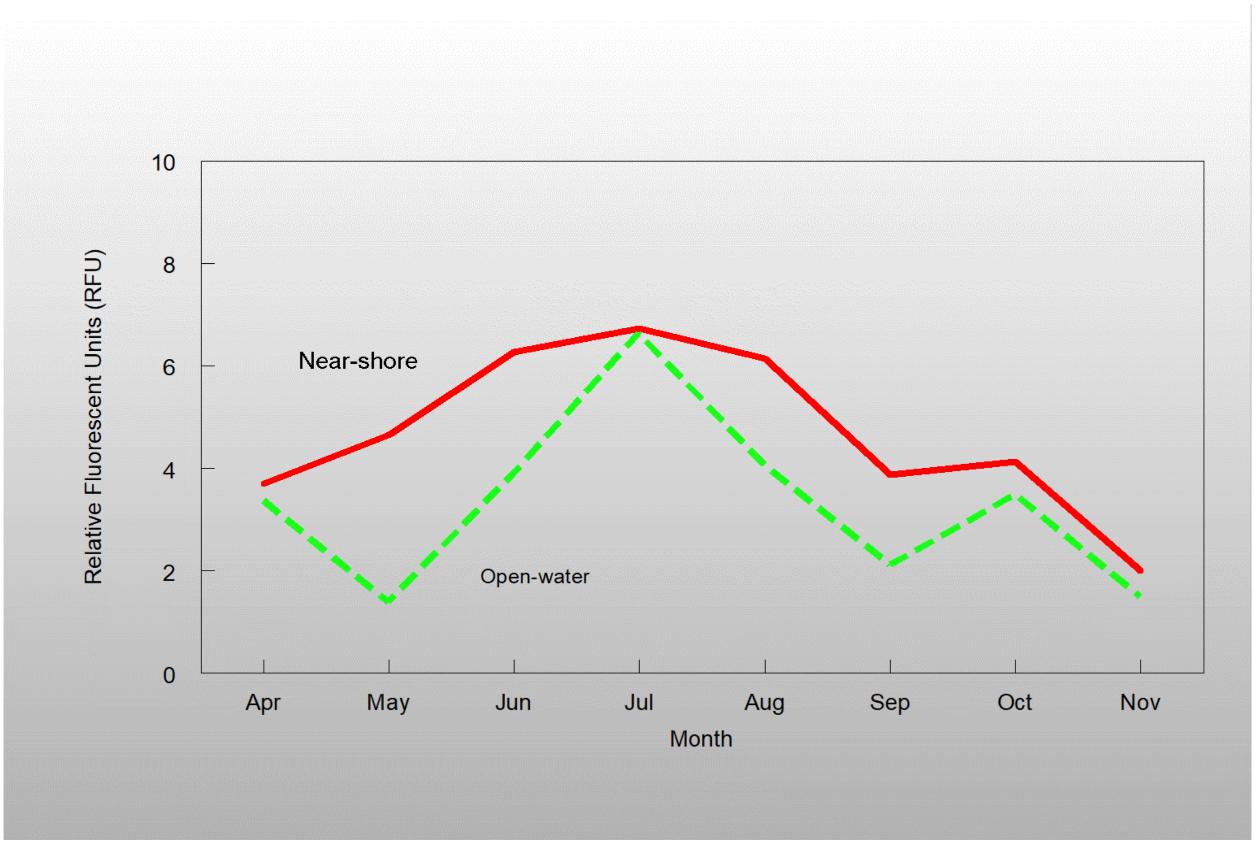


Figure 6. Mean Relative Fluorescent Units (RFU) measured lake-wide at near-shore and open-water sampling sites, combined data from 2016-2019, Lake Powell.

Zooplankton Status:

Open-water zooplankton densities have historically been modest in Lake Powell. Early studies including those of Stone and Rathburn (1969) estimated zooplankton densities at 10-22/liter for the top 30m. Likewise, Sollberger et al. (1989) concluded that zooplankton samples were low and normally less than 20/liter and rarely exceeding 50/liter in the upper 20m. Furthermore, they reported that average densities in the upper 40m of the water column varied between 3 and 26/liter.

By comparison, mean open-water zooplankton counts over the previous 4-year period were 24/liter which was quite similar to the historical mean and does not reflect the modest uptick in productivity values. With the exception of 2010, where open-water sampling estimated mean zooplankton values at 51/liter, estimates have been remarkably similar averaging 22 plankters/liter (SD = 3.3) since 2005 (Figure 7).

Open-water zooplankton estimates (all species) have not been a good predictor of pelagic shad abundance or size. This would suggest that forage in the open water portions of the lake may not be a limiting factor regulating the shad population. We also explored relationships between shad densities and large bodied cladoceran densities but also failed to find a significant relationship. Mueller and Horn

(1999) reported similar findings when analyzing data from their 2.5 year study. Likewise, no relationships existed between pelagic shad TL and cladoceran densities in the open water bays at Wahweap, Bullfrog and Good Hope. Although, Mueller and Horn (1999) detected a diel vertical zooplankton migration that they speculated may have been driven by predation as particular large bodied zooplankter's attempted to avoid predation. However, Sollberger et al. (1989) did not detect any sizable diel vertical zooplankton migration. Consequently, there existed a sizable pelagic Threadfin Shad population for most of the Muller and Horn study in 1996 and 1997 that was virtually non-existent during the years that Sollberger et al. (1989) conducted their study in 1987 and 1988.

The composition of open-water samples remained surprisingly stable over the course of this survey from 1999-2015. Typically, open water samples were dominated by Nauplii Copepods (45%), followed by adult Copepods (31%), Rotifers (14%), adult Cladocerans (7%) and others. Quagga veligers began showing up in 2013 but at less than 1% in both near-shore and open-water samples. However, in 2015 2% of the open water samples consisted of Quagga Mussel veligers which increased to 8%, 12%, 23%, and 16% for the following years 2016-2019 respectively. Pooling % composition zooplankton data for the years 2015-2019 lake-wide open water samples consisted of 20% Rotifers, 26% adult Copepods, 28% Nauplii Copepods, 10% Cladocerans, 4% Bosmina, and 12% Quagga Mussel veligers.

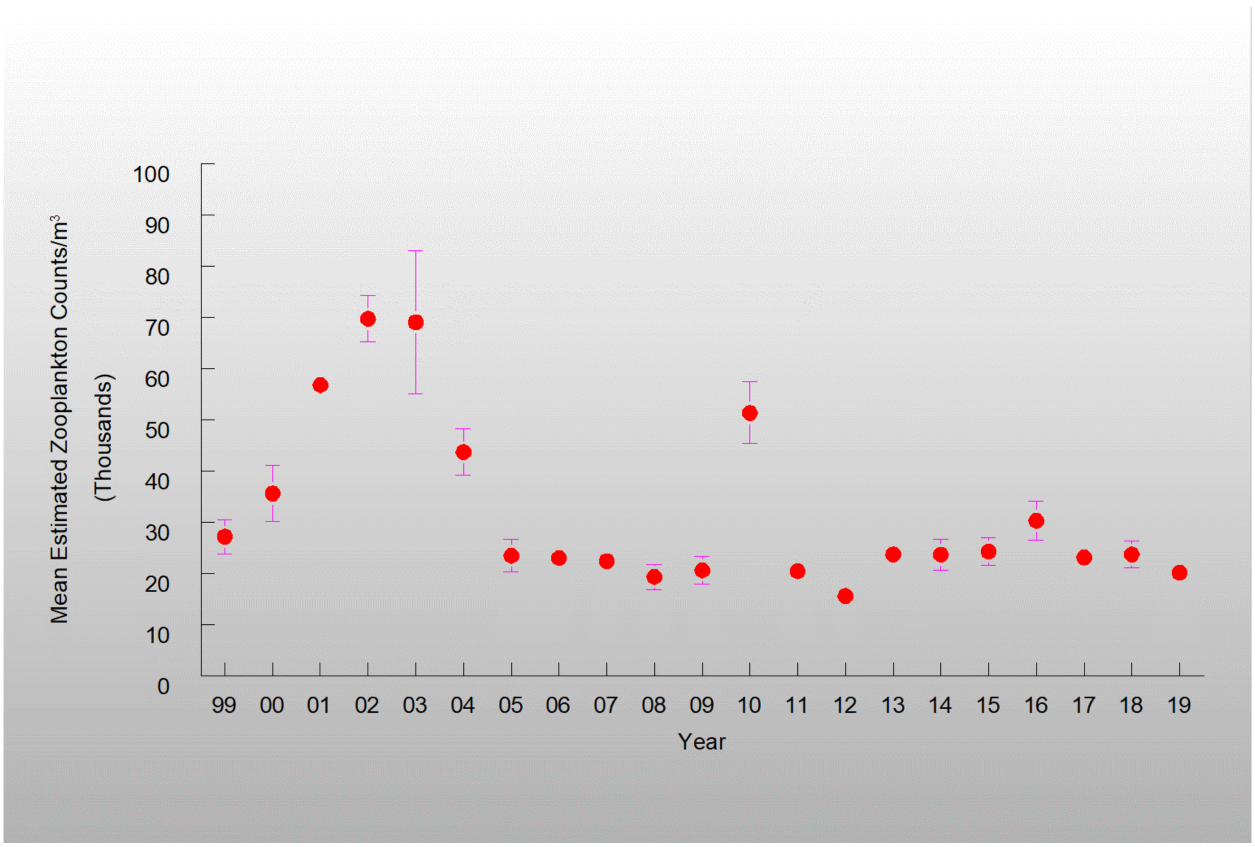


Figure 7. Mean lake-wide total open-water zooplankton estimates with SE, Lake Powell, 1999-2019.

Historical studies focused on open-water plankton populations, but in many ways the near-shore populations and those in the backs of canyons are just as important. Young of year (YOY) of all species spend most of their early life in close proximity to the shore where protective habitat is more readily available. Furthermore, the current study shows that zooplankton densities were, on the average, 5X higher at near-shore sampling sites when compared to open-water sites and densities ranged from 2X to 11X higher per liter. Near-shore densities typically increase throughout the spring before crashing by mid-July, about the time larval shad were no longer captured in the meter net tow samples (Blommer and Gustaveson 2017).

Lake-wide near-shore estimates which had declined in 2012 and remained low through the 2015 sampling season were originally thought to possibly be associated with the rise in Quagga Mussel densities. However, lake-wide zooplankton estimates recovered in 2016 and with the exception of another decline in 2018 were back in the 200+ zooplankton/liter range (Figure 8).

Historically (1999-2015), lake-wide near-shore samples were dominated by Rotifers (72%) followed by Naupulii Copepods (16%) with adult Copepods and Bosmina at 5%. Cladocerans accounted for only 1.5% of near-shore samples possibly due to intense predation. Recent sampling 2016-2019 had Rotifers still dominating but at 52%, Naupulii Copepods were estimated at 19%, adult Copepods at 11% with Cladocerans 5%, Bosmina 6% and Quagga Mussel veligers at 7%.

As with open-water samples, no relationship exists between lake-wide near-shore zooplankton estimates and lake-wide near-shore productivity (RDU) values. Correlation analysis (Pearson) also failed to detect any relationship between water elevations and changes in water levels between years and estimated mean lake-wide near-shore zooplankton densities. The higher variability in lake-wide estimates appears due more too local water conditions at the various sample sites, and due to the limited number of sites does not lend itself well to lake-wide analysis.

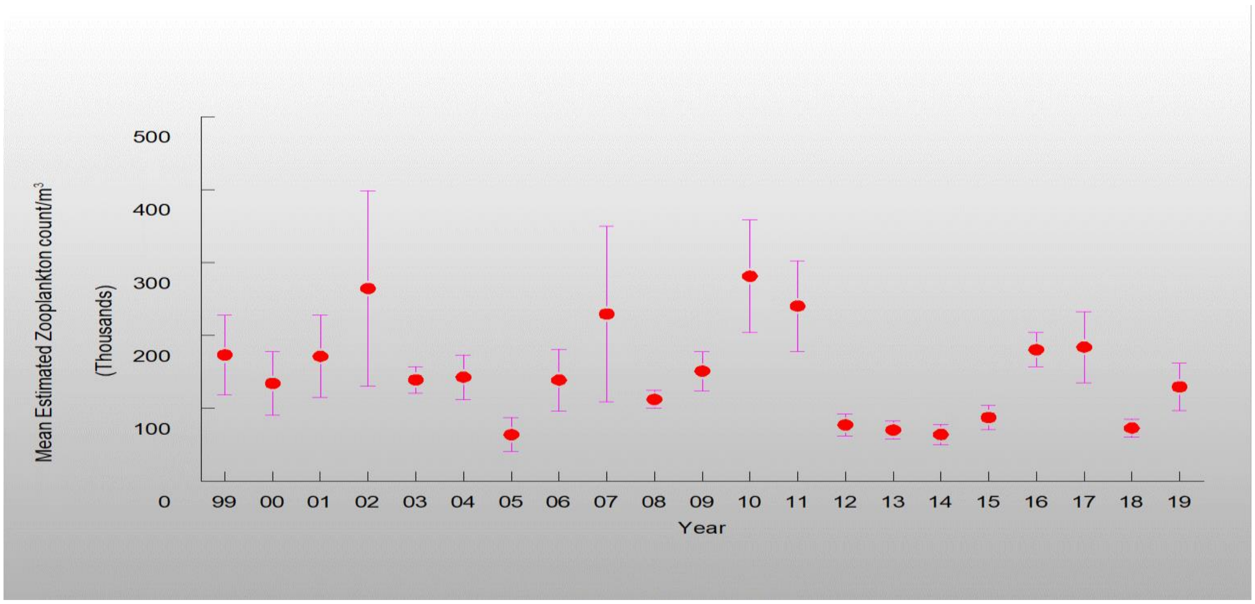


Figure 8. Mean lake-wide total near-shore zooplankton estimates with SE, Lake Powell, UT, 1999-2019.

Quagga Mussel Invasion:

Quagga Mussel veligers were first discovered in Lake Powell in 2012 and adults were confirmed in 2013. By 2015 the extreme down-lake areas including the Wahweap, Warm Creek and Navajo Canyon areas were heavily infested and up-lake movement had been detected as far as mid-lake. Reservoir-wide distribution of adult Quagga Mussels were confirmed in 2016. UDWR began detecting suspected Quagga veligers in the weekly plankton samples in 2013, and by 2014 they were prevalent in many down-lake samples and were also appearing in some up-lake samples as well (Blommer and Gustaveson 2017).

Veligers continue to represent a larger portion of the open-water zooplankton samples compared to the near-shore samples. The % composition of veligers in the open-water and near-shore samples peaked in 2018 with veligers accounting for, on average, 23% of the open-water zooplankton samples and 14% of the near-shore samples. Surprisingly, the % composition of veligers declined in both open-water and near-shore sampling in 2019 at 16% and 5% respectively (Table 3). Total zooplankton densities have remained relatively stable in recent years with veligers accounting for a larger % composition of the samples.

Table 3. Mean percent of veligers in the plankton samples across sampling sites for open and near- shore locations, Lake Powell, 2014-2019.

YEAR	OPEN WATER SITES	NEAR SHORE SITES
2014	**1%**	**<1%**
2015	**2%**	**2%**
2016	**8%**	**3%**
2017	**12%**	**5%**
2018	**23%**	**14%**
2019	**16%**	**5%**

Ascertaining the effects of the Quagga Mussel invasion will be an ongoing endeavor for many years to come. To date no RFU response to the presence of Quagga Mussels has yet to be detected at the current invasion level at nearshore or open-water sampling locations. Likewise, to date, no detectable response in open-water zooplankton densities have been recorded. Near-shore total zooplankton densities declined in 2013 and remained low through 2015 but recovered in 2016 and although variable are back to normal.

Fish response to the establishment of Quagga Mussels has been limited to a few casual observations and at this point are not statistically quantifiable. Both YOY Bluegill Sunfish *Lipomis macrochirus* and to a lesser extent YOY Green Sunfish *Lepomis cyanellus* have returned stronger to the annual fall electrofishing survey since the establishment of Quagga Mussels and this bears watching. Additionally, mean TL of YOY Bluegill Sunfish (TL <61mm) declined slightly (1mm) following the establishment of Quagga Mussels. The return of Bluegills to the creel was also improved in 2018. UDWR and other researchers have verified the presence of Quagga Mussels, both adult and veligers, in the stomachs of adult Bluegills and perhaps the older fishes are benefiting from the presence of adult mussels. Although Quagga Mussel's impact on the system is now better known, continued research and monitoring would be advised. However, we do not expect a catastrophic loss of any of the fisheries. Most species have shown to be extremely resilient and perhaps through foraging are utilizing veligers and adult mussels to their advantage.

TREND SAMPLING OVERVIEW

Gill-Net Survey:

Gillnetting has been conducted on Lake Powell since before impoundment. However, early standardized efforts were begun in 1972, mainly centered on an annual spring survey that was conducted in March. This survey utilized ten 100 ft experimental sinking gill nets that were attached to and set perpendicular to shore following the bottom contour. The nets used in the spring survey differed from those later used in the annual fall survey in that their mesh sizes were 1", 1.5", 2", and 3" bar mesh size. Water temperatures during the spring survey were in the 49-55^{0}F range. This survey was discontinued in 1997 when changing fish assemblages limited CPUE. The early fishery consisted mainly of Largemouth Bass, Black Crappie and Walleye, species that were active early in the spring. A put-grow and take Rainbow Trout *Oncorhynchus mykiss* fishery was attempted lake-wide but was only moderately successful in the lower reservoir and was discontinued. The later fishery was dominated by Striped Bass and Smallmouth Bass that became active at higher water temperatures making the fall gill-net survey a far better choice. Walleye, which have staged a comeback in later years, was successfully sampled in both the spring and fall survey.

The annual fall gill-netting survey has been conducted each November since 1981. The survey sites included 4 stations at Warm Creek / Wahweap Bay (down-lake), Rincon (mid-lake), Red Canyon at Good Hope Bay (up-lake), and the Piute Canyon/Neskahi Canyon area on the San Juan arm. Nets were deployed for 2 consecutive nights at each location and were checked, with fish being removed and processed each morning. Total length and weight were obtained from each fish. Additional information was obtained on certain target species including: sex, stomach contents (% occurrence), fat index, parasite index, and scale samples for aging.

Similar to the spring survey 10 experimental, sinking style gill nets were set at each location. Each net consisted of 4 panels with progressively increasing bar mesh sizes of 0.75", 1.0", 1.5", and 2.0" respectively. Nets were attached to the shore, alternating large and small mesh sizes on the nearshore side. Nets were set in a perpendicular orientation to shore with the terminal end usually set at a 20-60 ft depth range. Water temperatures ranged from 56^{0}F to 74^{0}F throughout the survey.

The overall catch from the fall survey remains similar to previous years since the inadvertent introduction of Gizzard Shad into the fishery. Fish returns averaged 340 fishes/station (SD = 30) for the years 2016-2019 compared with 374 fishes/station (SD = 99) for the previous post Gizzard Shad years (2003-2015; Figure 8).

The percentage of the catch from each station when combined over the previous 4-years had Good Hope and the San Juan stations accounting for 37% and 36% of the total survey catch respectively. Rincon followed with 17% and Wahweap was last with 10% (Figure 9). The catch closely follows the Lake Powell productivity gradient with up-lake and major inflows harboring greater numbers of fishes than their counterparts lower in the reservoir. Pooling data over the last 4-years had the composition of the lake-wide catch dominated by Gizzard Shad (38%) followed by Striped Bass (24%), Smallmouth Bass (14%) and Walleye at 11% (Figure 10).

Historically, the total catch of fishes has been lowest but most consistent at the Wahweap station. The influx of Gizzard Shad has been the least pronounced at this station averaging only 46 fishes/survey since 2003 and 38 fishes/survey over the previous 4-years. Striped Bass are the most collected species at Wahweap followed by Gizzard Shad, Smallmouth Bass and then Walleye. Reduced primary productivity and the resultant weaker food chain in the lower lake regions was probably to blame. Mean estimates of pelagic shad sampled in both the mid-water trawl and acoustical surveys have historically been lowest at this station. The mean total catch from the annual gill-net survey was 205 fishes (SD = 52) since 2003 with the previous 4-years recording a mean total catch of 183 fishes/survey (SD = 24; Figure 11).

The mid-lake station at the Rincon is similar to Wahweap, in that, fish captures were below those at the San Juan and Good Hope stations. The water clarity at this station was almost always high during the annual fall gill-net survey as particulate matter that is migrating down-lake falls out before entering the area. The low turbidity makes the gill nets highly visible and fish are better able to avoid capture. The mean number of fishes captured was 114/survey (SD = 118) before the establishment of Gizzard Shad but rose to 218/survey (SD = 88) following establishment. The mean capture the previous 4-years was 167/fishes (SD = 64; Figure 11). Gizzard Shad are the most caught species at the Rincon station in the annual fall gill-net survey followed by Smallmouth Bass and Striped Bass that have both averaged 30 fishes/survey over the previous 4-years. The condition of Striped Bass and Smallmouth Bass is usually less than what is seen at the other stations although the condition of Smallmouth Bass collected from the San Juan station can be slightly worse.

The San Juan station represented an inflow environment that is more riverine than lacustrine. The total gill-net catch improved greatly following the establishment of Gizzard Shad. The mean pre-Gizzard Shad survey catch (1981-2001) was 129 fishes/survey (SD = 56) compared with 350 fishes/survey (SD = 84) following establishment. The mean capture (all species) over the previous 4-years was 371 fishes/survey (SD = 89) with the 2019 survey having the highest total number of fishes captured historically at the San Juan station at 518 fishes/survey (Figure 11). When the gill net catches were combined over the last 4-years Gizzard Shad accounted for 49% of the catch followed by Striped Bass (18%), Smallmouth Bass (16%) than Walleye at 4%. The San Juan area appears to harbor good numbers of fishes although condition of the major sport fish was often lower, especially for Smallmouth Bass, and the incidence of

Bass Tapeworm *Proteocephalus ambloplitis* was more apt to be higher than at the other stations, with the exception of the Rincon, and the condition and fat index was the lowest for all stations.

The station at Good Hope Bay has historically collected more fishes than any other station. Being the furthest up-lake station in the gill-net survey it benefits from being the most productive in terms of not only primary productivity, but throughout the food web. As with most other stations the establishment of Gizzard Shad greatly increased the gill-net catch from the Good Hope area. The mean total (all species) catch/station was 225 fishes/survey (SD = 88) before Gizzard Shad compared with 609 fishes/survey (SD = 225) afterwards. The previous 4-years recorded 638 fishes/survey (SD = 81; Figure 11). Gizzard Shad represented 39% of the catch when pooling the catch over the previous 4-years, followed by Striped Bass (28%), Walleye (17%) and Smallmouth Bass (11%). Condition indices were usually the highest for the various sport fishes that were collected from this station with productivity and forage fishes also sampled at high levels. The Walleye resurgence has been attributed mainly to sampling in this up-lake area of the lake.

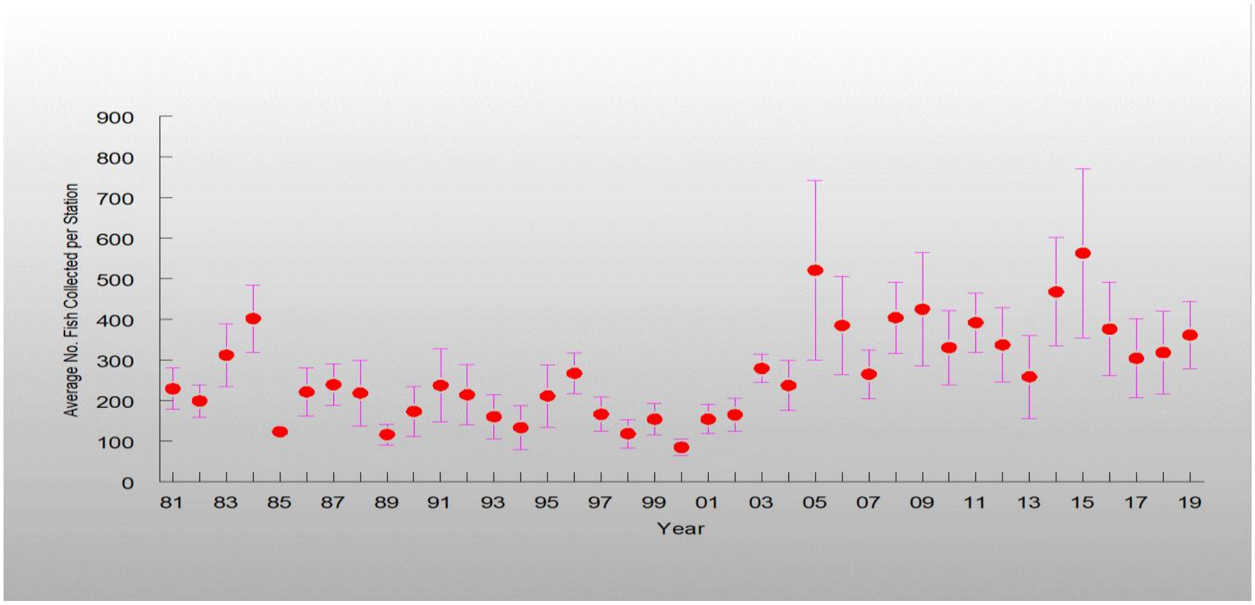


Figure 8. Average catch (all species) per station with SE from the annual fall gill-net survey, Lake Powell, 1986-2019.

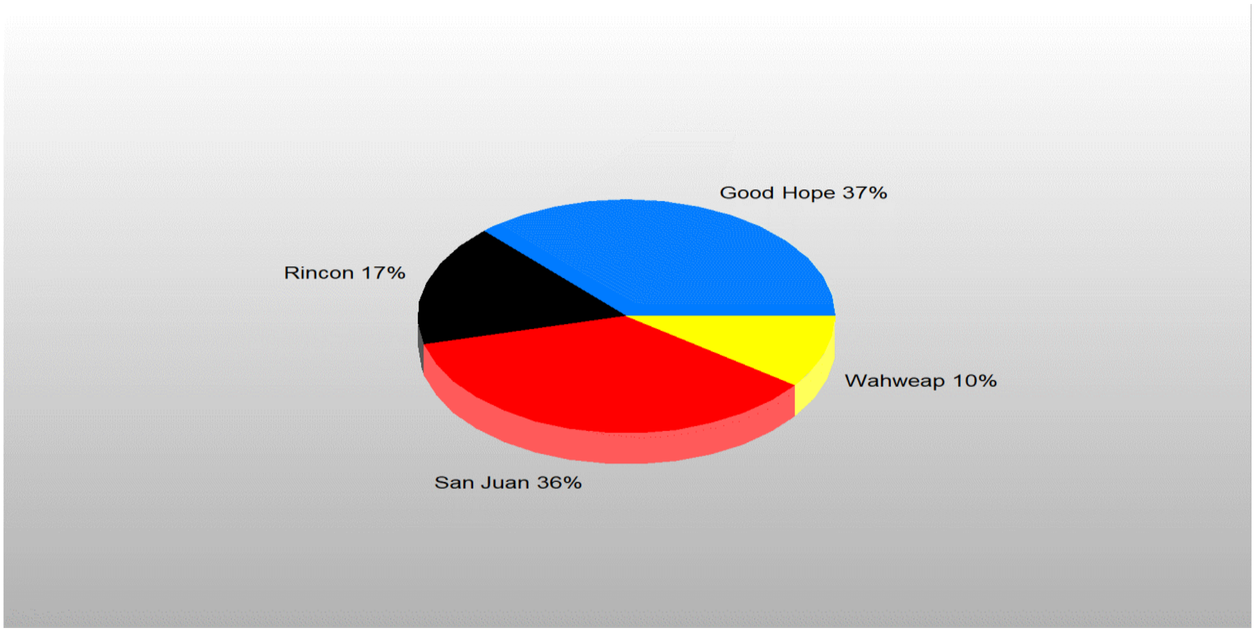


Figure 9. Percentage of the catch at each location from the annual fall gill-net survey, Lake Powell, combined data from 2016-2019.

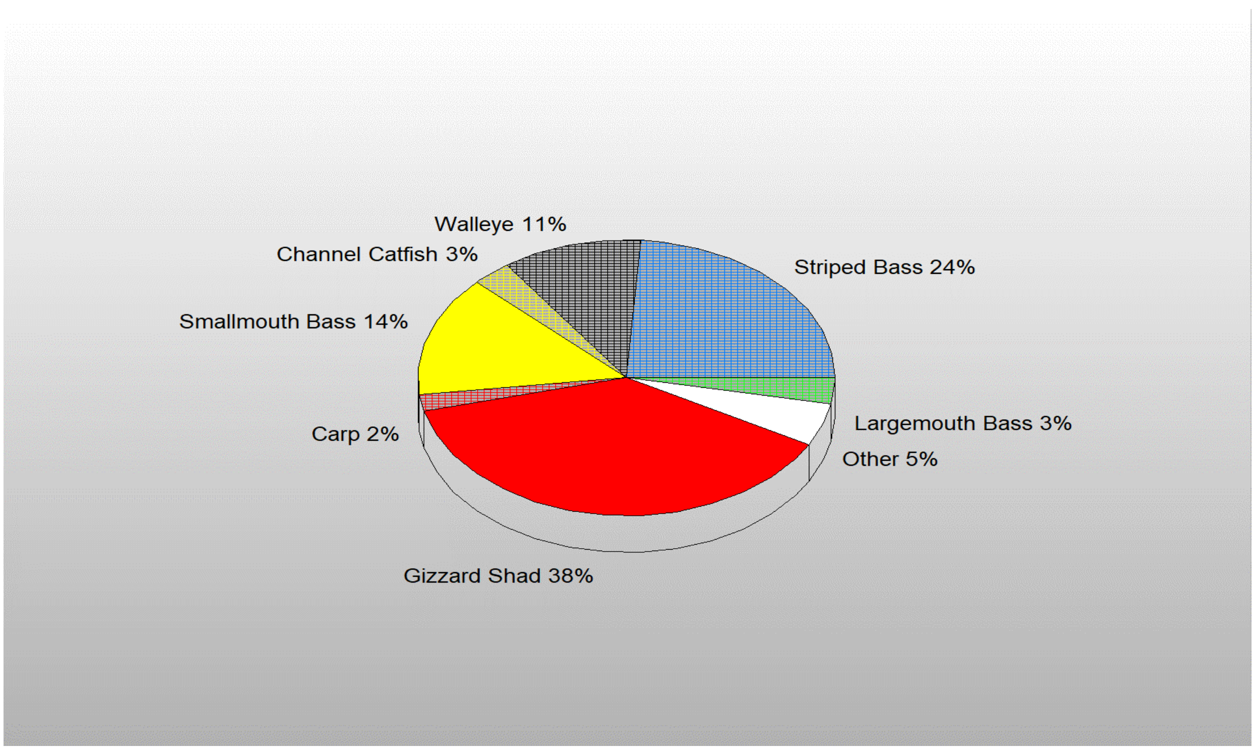


Figure 10. Percent occurrence of various species collected from the annual fall gill-net survey at Lake Powell, combined data from 2016-2019.

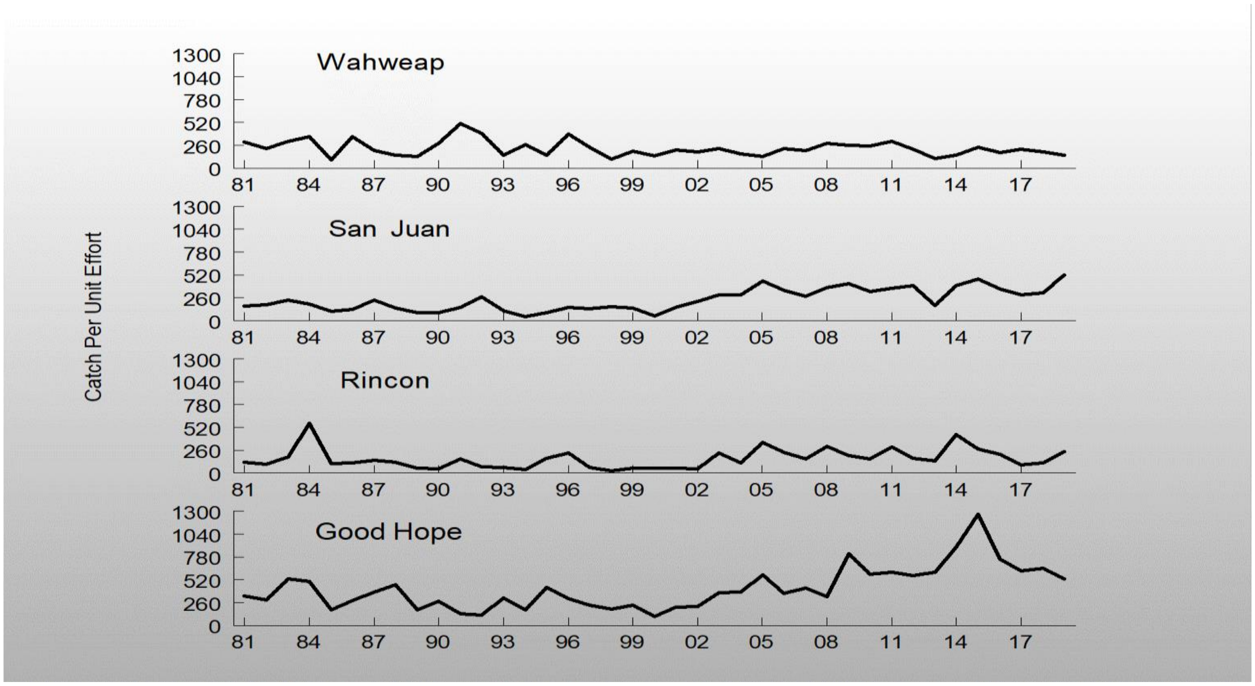


Figure 11. Total catch (standard sample) from the annual fall gill-net survey, Lake Powell, 1981-2019.

The annual fall gill-net survey continues to be UDWRs most important survey in terms of quality and quantity of data collected. It has been a great tool in tracking the changes in fish assemblages over time and is a main driver in management decisions. Information such as relative abundance, health (condition, parasite, fat indices) and age & growth data are some of the data obtained that have allowed UDWR to assess the status of various species and effect changes necessary to maintain and improve the reservoir sport fisheries (Blommer and Gustaveson 2017).

As important as the gill-net survey has been in managing the fishery at Lake Powell it has limitations that need to be accounted for. First and foremost we run the survey around the first two weeks in November and spend only 2-nights at each of only 4 locations. What we produce is a snapshot that we try to use to generalize the status of the fishery lake-wide for the entire year. Water temperatures can have a marked effect on gill-net catches as catch efficiencies rise with rising temperatures (Figure 12). The presence, absence, amount and type of forage species, in our case shad species, can also have a statistically significant effect on the rate of capture of select sport fishes in the gill-net survey. The type of habitat that the gill nets are set over will also affect their capture efficiencies, and this can increase or decrease randomly, up or down, with changing water levels. Rising water levels over time will flood newly established brush, increasing nursery habitat for many of the lakes Centrarchid species increasing cohort strength. Turbidity also has the ability to greatly affect gillnetting efficiency with clear water areas like the Rincon and Wahweap producing far fewer fishes than the more turbid areas closer to the major inflows. Species morphology can also have a large effect on the catchability of any given species. Adult Gizzard Shad, for example, have a large body on the vertical axis’s that allows for their capture in the larger mesh sizes while retaining a small head and gill area that allows the same fish to be caught throughout the range of mesh sizes. For this and other reasons Gizzard Shad are captured at a higher rate than most other species on Lake Powell and can be over represented in the gill-net survey. All of these factors and others make population comparisons between sections of the lake, or between different lakes, a tenuous exercise at best and fraught with pitfalls.

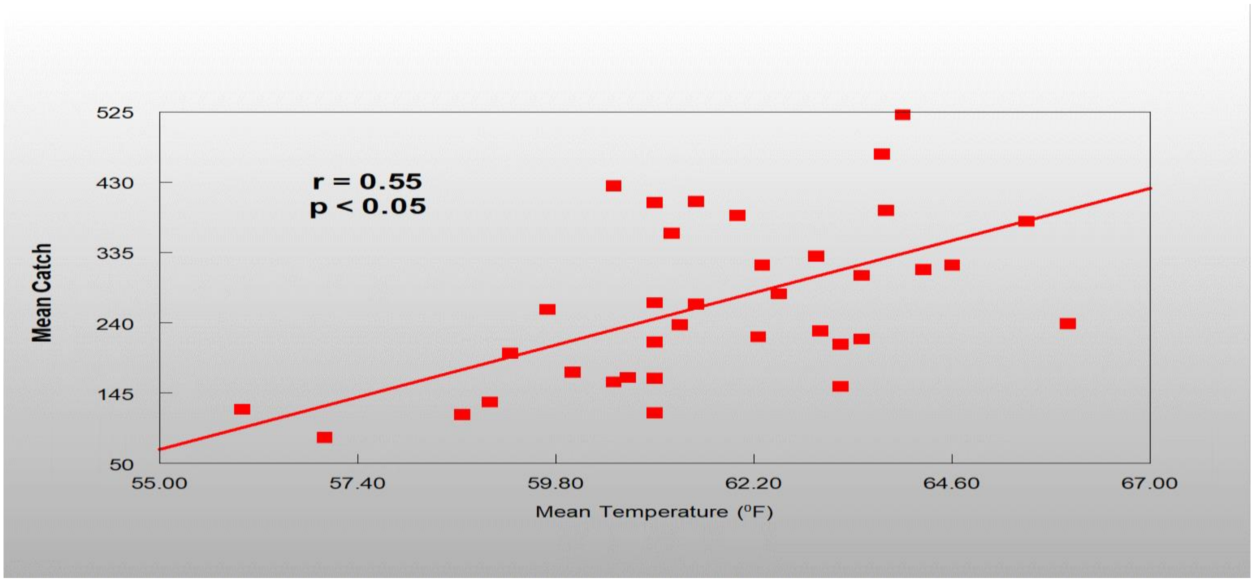


Figure 12. Relationship between mean surface water temperatures and the mean catch of all species per station from the annual fall gill-net survey, Lake Powell, 1981-2019.

Electrofishing Survey:

The annual fall electrofishing survey was initiated in 1977 and was designed primarily as a tool for sampling young of year (YOY) centrarchids. Early on Bluegill Sunfish, Green Sunfish and Largemouth Bass were the main targets with YOY Smallmouth Bass also becoming important following their introduction in 1982. The steeply sloping shoreline and minimal littoral vegetation provides rapid access to deeper water, and allows for most of the larger fishes to avoid capture by the gear. Non-centrarchid YOY sport fishes such as Striped Bass, Channel Catfish *Ictalurus punctatus* and Walleyes are sampled only incidentally with this gear but data collected can be used, in some cases, as a gross index in predicting peak species abundance.

The current electrofishing setup has been in use since 1994. An aluminum Jon boat was equipped with a Honda model EM5000SX generator. Output was run as DC-pulse through a Coffelt model VVP-15. Pulse width was set between 20%-50% and the frequency between 60-80 pulses/sec. The terminal end of the gear (anode) consisted of a 43cm diameter stainless steel sphere set just below the surface. The boat hull served as the cathode.

Standard electrofishing sampling sites were located at Warm Creek/Wahweap Bay, Rincon, Piute Canyon on the San Juan arm, Good Hope Bay, and Stanton Creek in Bullfrog Bay (In 2012 the Bullfrog survey was changed to the Hall's Crossing buoy field and discontinue all together after the 2013 season).

Four shoreline transects were run at each site. Transects consisted of 15 min of pedal time and were selected on the basis of habitat, water depth, and likelihood of capture, so individual transect sites varied yearly. The survey was historically run the first two weeks of September, although coordinating the electrofishing survey with the hydroacoustical survey to run during the September new moon phase began in 2001.

Many factors in addition to fish abundance can influence the capture rate of this survey including: wind, turbidity, netting efficiency, and available habitat. Lake elevation can have a profound effect on available habitat as rising water levels flood areas that revegetated when water levels were lower. However, regression analysis of historical electrofishing catch (all species combined) against maximum lake water level elevations as well as against the yearly change in elevation failed to show a statistical relationship at the alpha = .05 level. On an individual species level, YOY Bluegill ($r = .35$, $p = .03$) and YOY Green Sunfish ($r = .46$, $p = .008$) are the only species whose catch was positively correlated with maximum yearly water levels but not with the change in water levels over the previous year. Meanwhile, YOY Largemouth Bass are the only species that showed a positive relationship with the change in elevation over the previous year ($r = .62$, $p = .005$; Figure 13). Intuitively, habitat availability, which changes with water levels, is a factor which should effect YOY catch particularly in regards to YOY nursery habitat. Meanwhile, Gizzard Shad, typically the most collected species in the survey show no long-term relationship between water levels and presence in the annual electrofishing survey probably due to their more generalist habitat usage.

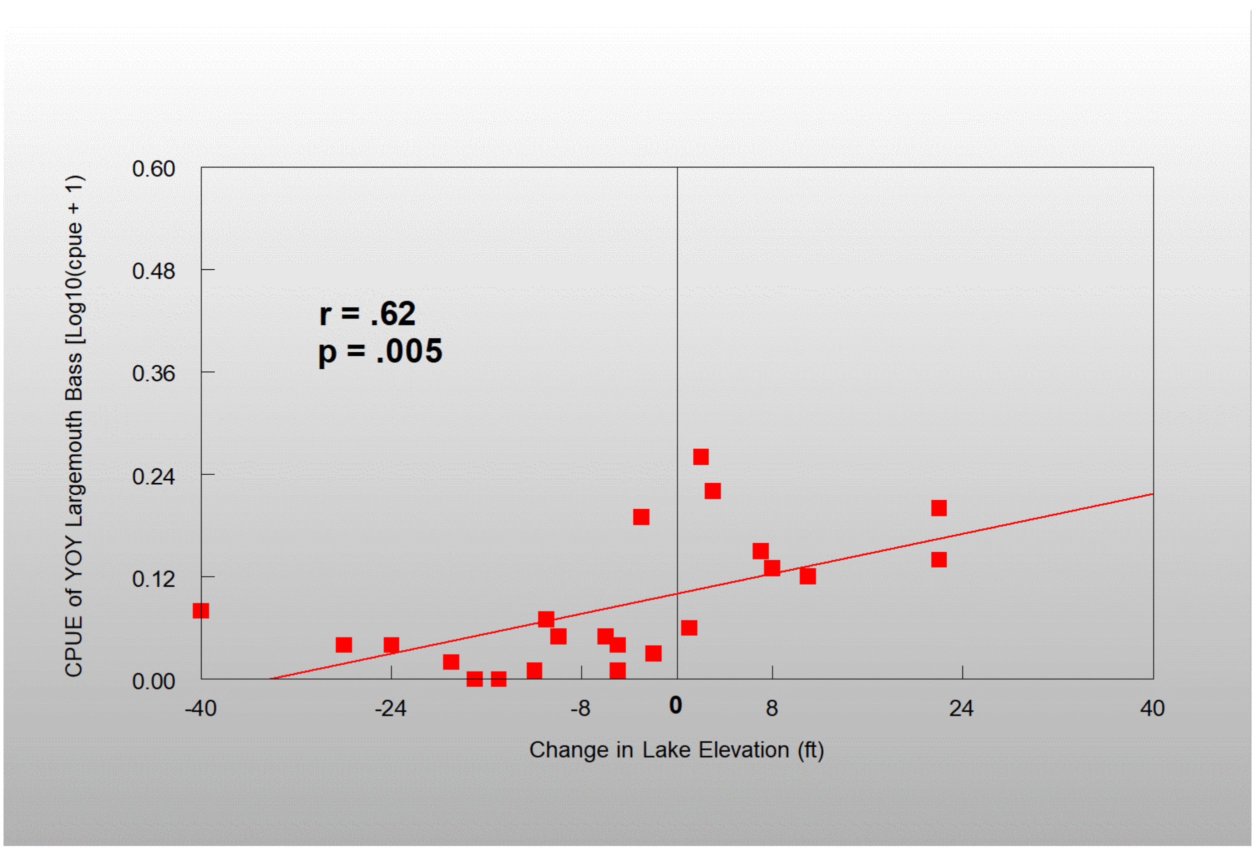


Figure 13. Relationship (Pearson) between the yearly change in maximum water levels and the catch of YOY Largemouth Bass from the annual fall electrofishing survey, Lake Powell, 1988-2018.

Long term analysis of electrofishing catch data spanning the last 35 years show a mean catch/hour (all species) of 503 fishes (SD = 250). Some of the highest catch rates have occurred since 2011, and have largely been due to the increased presence of Gizzard Shad at the Good Hope station which also accounted for the high standard error obtained from the estimates (Figure 14). Overall catch/hour for the last 4-years had typical catch rates of 327, 454 and 443 for the years 2016-2018 respectively: just below the historical average. However, the mean catch of all species in 2019 was a record high for the survey of 1162 fishes/hour. The large number of Gizzard Shad collected from the Good Hope station of 515 fishes/hr were largely responsible, although Bluegill Sunfish also returned strongly.

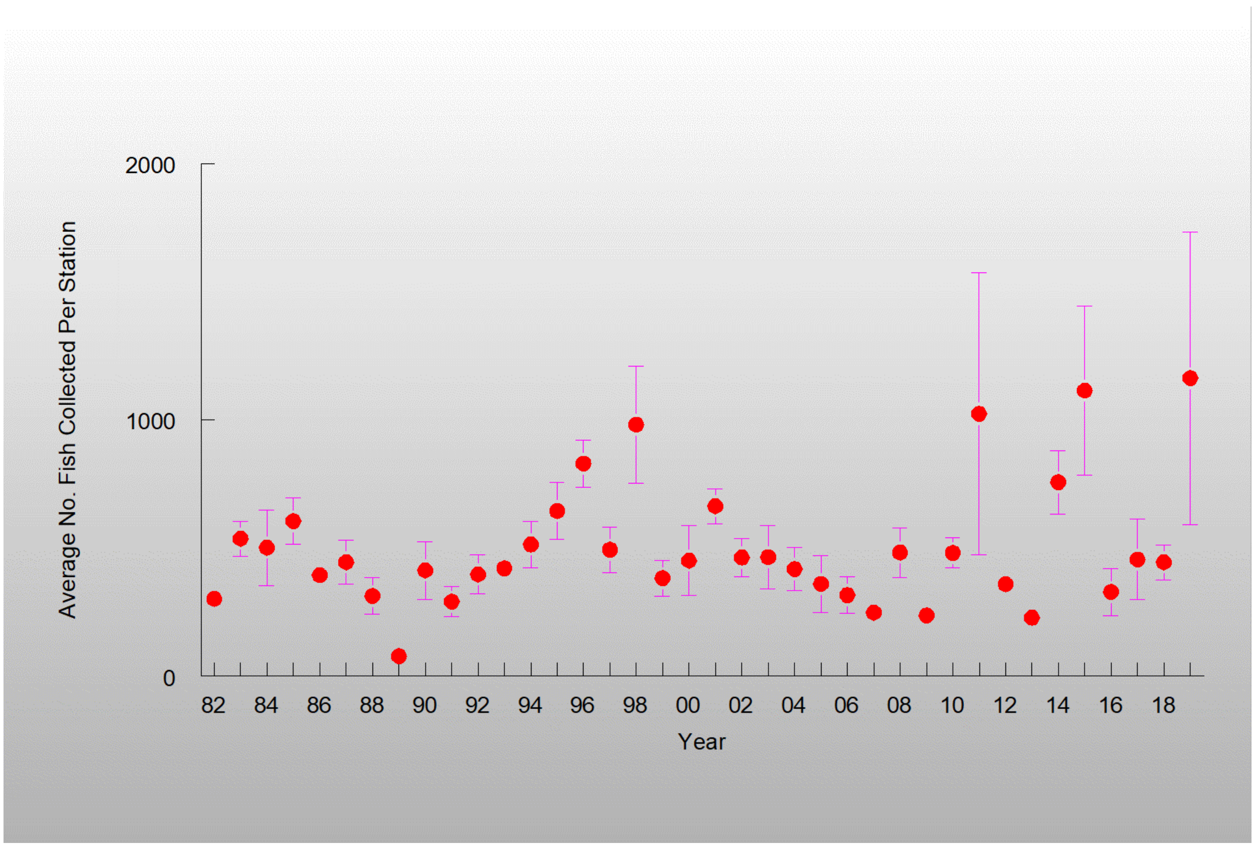


Figure 14. Mean catch per hour with SE of fish collected from the annual electrofishing survey at Lake Powell, (1982-1993 excludes Threadfin Shad, 1994-2019 includes all species).

Historical analysis (1982-2019) of electrofishing survey data (excluding shad and Carp) show the mean catch/hr was highest at the Good Hope Station (578 fishes/hr, SD = 313) followed by San Juan (456 fishes/hr, SD = 192), Bullfrog (433 fishes/hr, SD = 331), Rincon (397 fishes/hr, SD = 223), and Wahweap (291 fishes/hr, SD = 161; Figure 15). The historical catch has basically followed the reservoir productivity gradient. However, analysis of variance (ANOVA) computed on yearly mean catch from the various sampling stations suggest that the San Juan was the only station that differed significantly from the other stations (alpha = .05). Catch appears to be a function of available habitat, which changes with water levels, and factors such as turbidly, wind velocity, temperature and netting efficiency. The San Juan station at Piute Canyon differs from our other stations in that it exhibits characteristics found in both riverine and lacustrine areas. Because of these hydrological and chemical differences, the San Juan station rarely fits the norm in aquatic sampling on Lake Powell.

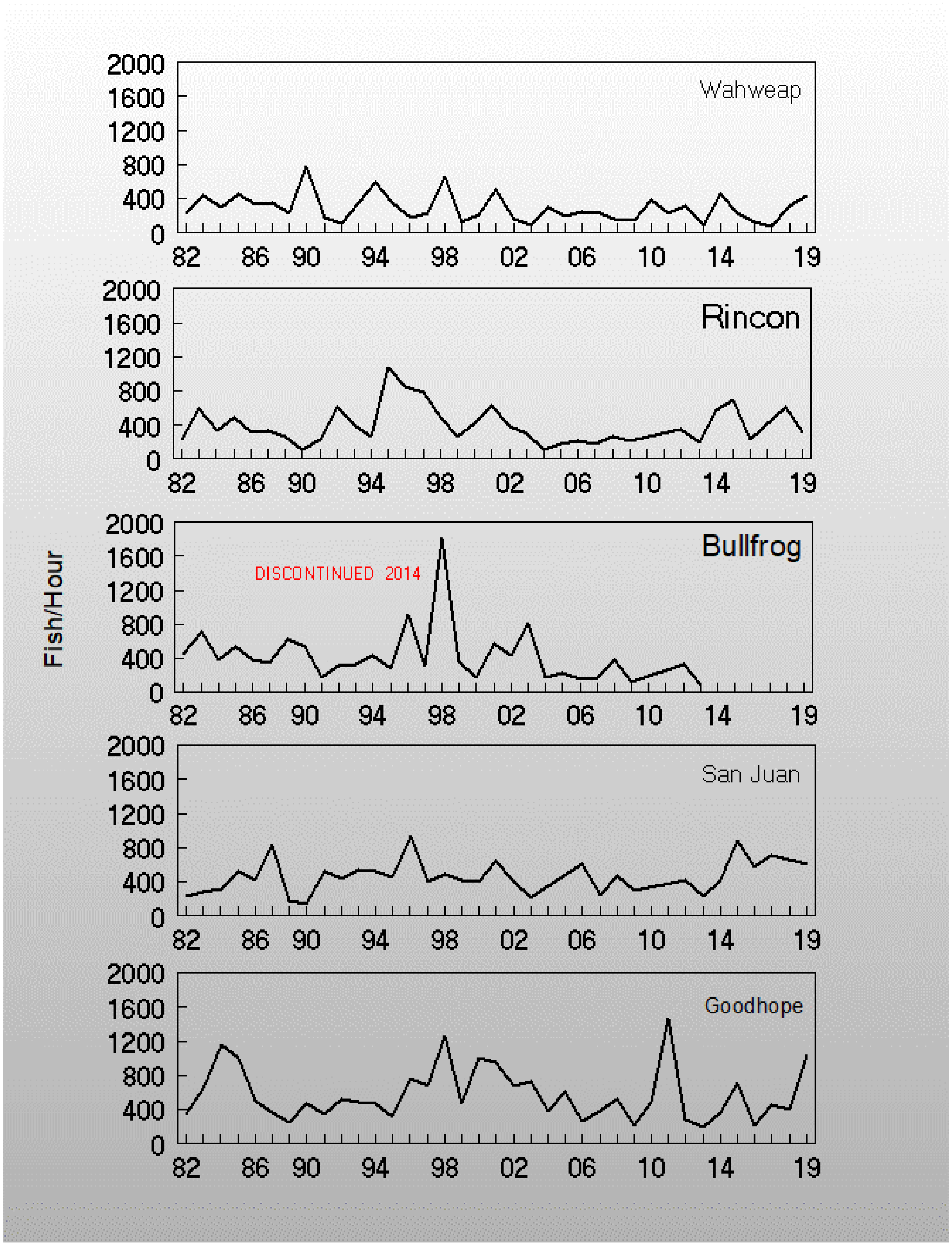


Figure 15. Total catch/hr of all species (excluding shad and carp) from the fall electrofishing survey by location, Lake Powell, 1982-2019.

Species composition averaged over the past 4-years was typical with Bluegill Sunfish comprising 46% of the catch followed by Gizzard Shad and Green Sunfish at 16% and 15% respectively. Smallmouth Bass made up 8% and Largemouth Bass at 4% of the catch followed by Threadfin Shad (4%) and Black Crappie (3%). Other species accounted for 4% of the catch and were sampled only occasionally, consisting of Striped Bass, Common Carp, Channel Catfish, Yellow Bullhead, and Walleye (Figure 16).

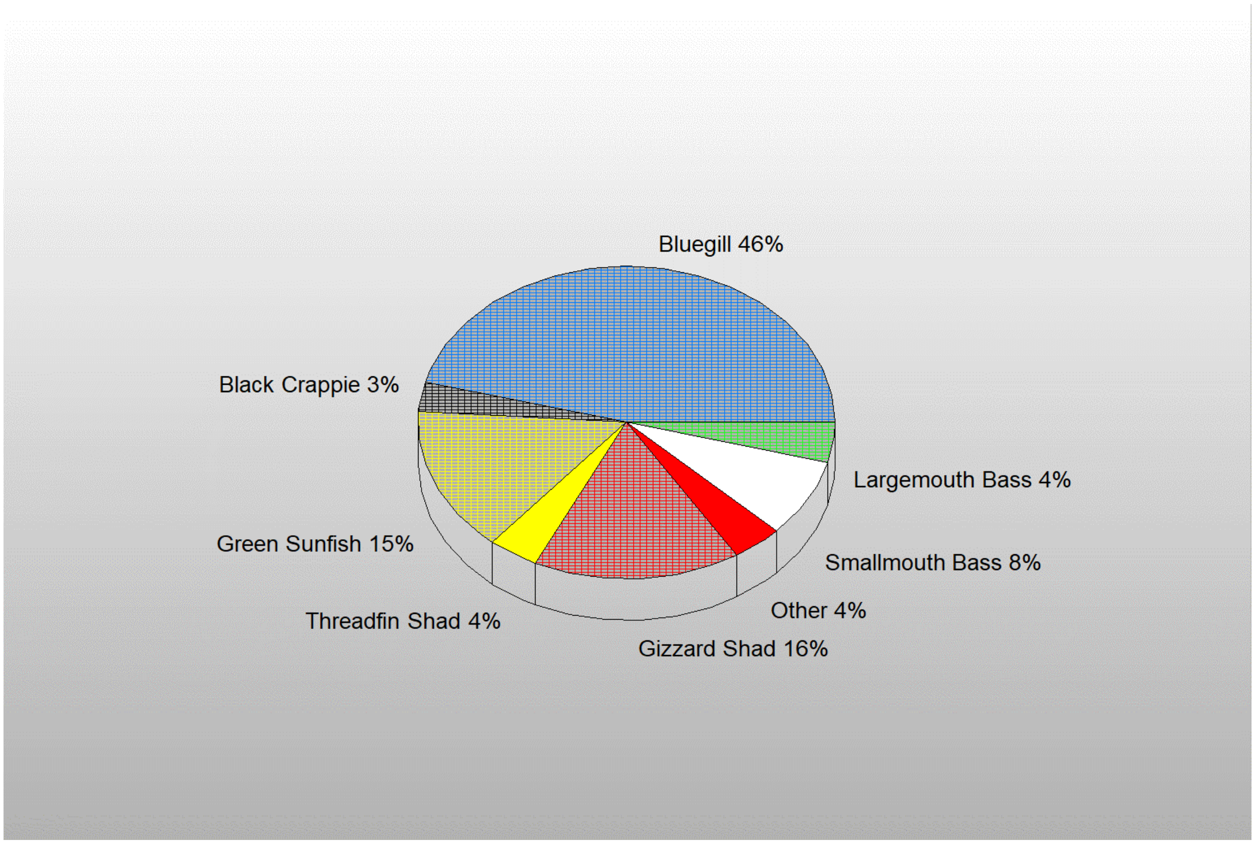


Figure 16. Percent composition of various species collected from the annual fall electrofishing survey, 2016-2019 data combined, Lake Powell.

A subtle shift in the electrofishing survey catch towards Bluegill Sunfish and Gizzard Shad has occurred over the last decade. Young of Year Bluegill Sunfish have increased in the survey over the last 5-years particularly in the San Juan and Good Hope areas (Figure 17). Higher relative lake elevations may be responsible in part but perhaps Gizzard Shad and Quagga Mussels may also be a factor. Meanwhile, Green Sunfish recruitment which apparently crashed in 2004 following the initial expansion of Gizzard Shad has been struggling to regain its dominance in the survey (Figure 18). Like Bluegill Sunfish, their dynamic with both Gizzard Shad and Quagga Mussels is little understood but both centrarchids have been observed with Quagga mussels in their guts.

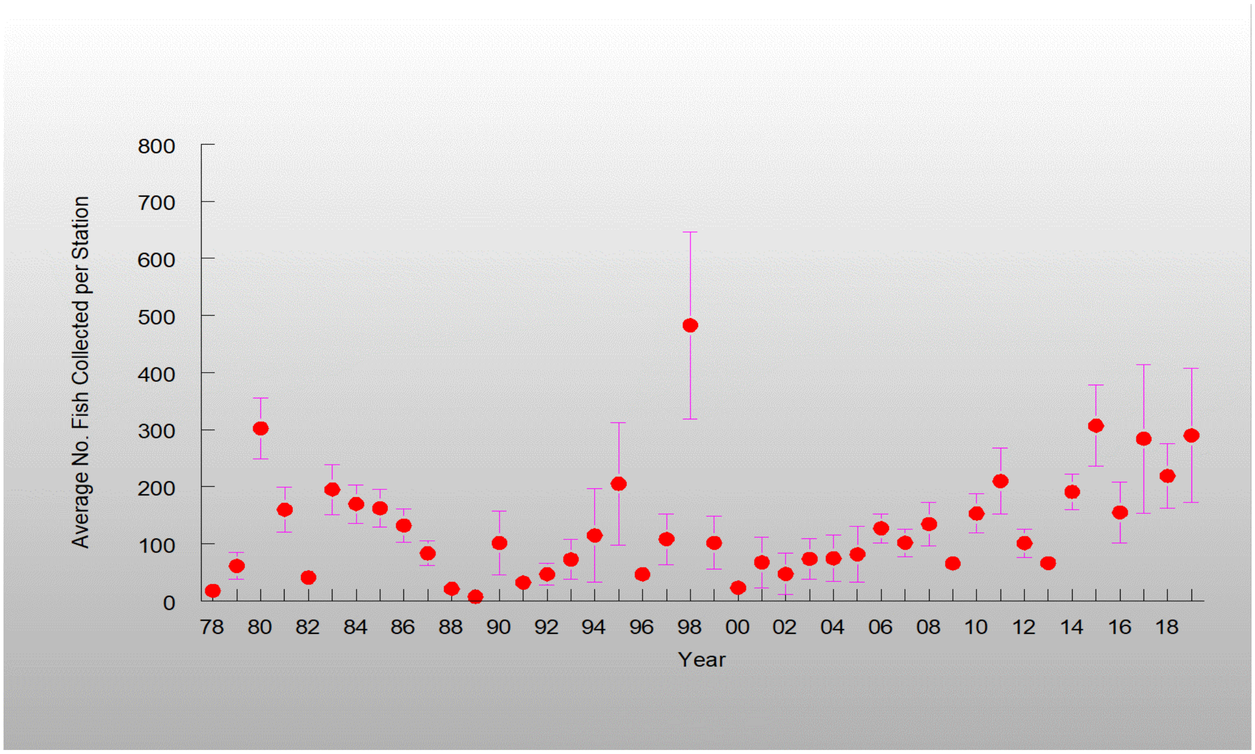


Figure 17. Mean catch of Bluegill Sunfish per station from the annual fall electrofishing survey with SE, Lake Powell, 1978-2019.

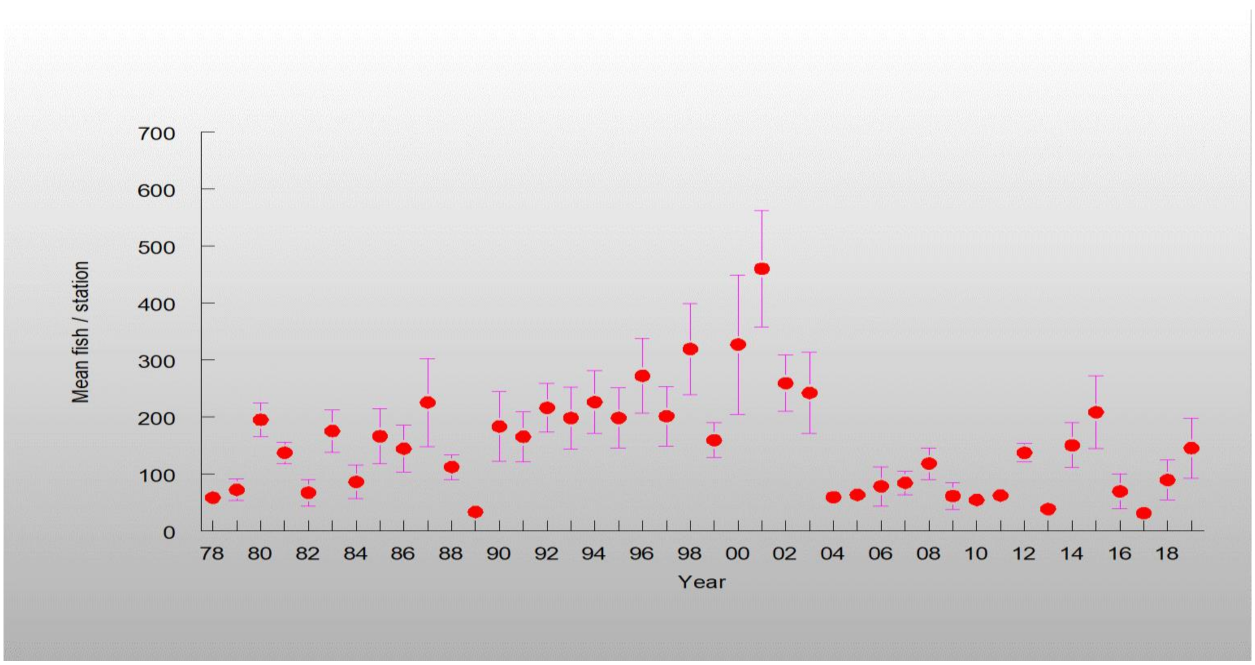


Figure 18. Mean catch of Green Sunfish per station from the annual fall electrofishing survey, with SE, Lake Powell, 1978-2019.

Angler Survey:

The angler survey is probably the most important of all of the sampling that UDWR does on Lake Powell. In many ways the creel survey, in regards to our major sport fishes, is more sensitive to population change than even the gill net survey. Additionally, the survey informs us on how our anglers are experiencing the fishery. You can have what appears to be a great fishery based on various sampling methods but if the anglers are not catching fish you have a problem.

The angling survey on Lake Powell was first initiated in 1975 and has continued until the present. The survey was run yearly until 1986 when it was switched to every three years. The logistics of conducting a survey on a reservoir of such a large size can be daunting; requiring additional seasonal workers and vehicles, and oftentimes assistance from other agencies in the form of trailer counts, boat rental counts, airplane flights, and housing.

The creel survey program used to analyze the 2018 survey data continues to be the one developed under contract for UDWR in 2000. Due to the great expanse of Lake Powell and limited shore access an access type survey using point-of-access design with completed trip interviews was developed using formulas based largely on those reported by Bernard et al. (1998) and used by the Alaska Fish and Game Department.

Five marinas, operated by the U. S. National Park Service concessionaire ARAMARK were used to obtain the angler and recreational boater interviews (Figure 19). The two down-lake marinas at Wahweap and Antelope Point were combined for survey purposes due to their close proximity to each other and the fact that anglers using these marinas had ready access to the same fishing areas. Similarly, up-lake marinas were represented by Bullfrog Marina and Halls' Crossing Marina and were also combined for survey purposes. Hite Marina, the upper-most marina, provided limited access to anglers in 2018 due to extremely low water levels leaving the public launch ramp a long way from the water, and was not surveyed.

The survey was conducted from April 1 until October 31. Historical data show that low boating pressure during the off-survey months results in limited interview opportunities so no angler information was collected during this time (Blommer et al. 2004). Stratification was by month and marina (either down-lake or up-lake). Four interview days were selected in each stratum. The creel day began at 11 am and continued until dusk. An attempt was made to interview all boaters exiting the fishery.

Marina specific trailer counts were made, usually at the start of the daily survey. Daily boat counts were calculated from the trailer counts while ARAMARK provided boat rental counts, boats out of slip and boats out of dry storage for each marina. All catch and harvest estimates, total hours, along with catch and harvest rates were generated per stratum from the computer creel program and combined for the seven months of the creel.

Similar to the previous survey in 2015, a total of 1,560 interviews were conducted during the 2018 angler survey, not including "previous day" interviews. Parties fishing at least a single day accounted for 38% of the interviews with the remaining 62% reported boating only. Thirteen states (USA) and a single foreign country were represented in the survey. Demographics continued to remain virtually unchanged over the life of the survey (1964-2018). Residents of Utah accounted for 38% of anglers interviewed followed by Arizona (33%), Colorado (19%) and California (3%) (Table 4). Typically, anglers from Arizona are strongly represented at the down-lake marinas while Utah anglers dominate mid-lake at Bullfrog with a strong presence at Hall's Crossing and up-lake at Hite. Colorado anglers have a strong presence at Hall's Crossing and to a lesser extent at the Hite primitive launch area although both of these access points are not used to the extent of Bullfrog and Wahweap marinas (Blommer and Gustaveson, 2011). As stated previously, Hite Marina had very limited access in 2018 due to low water levels and no interviews were conducted at this location.

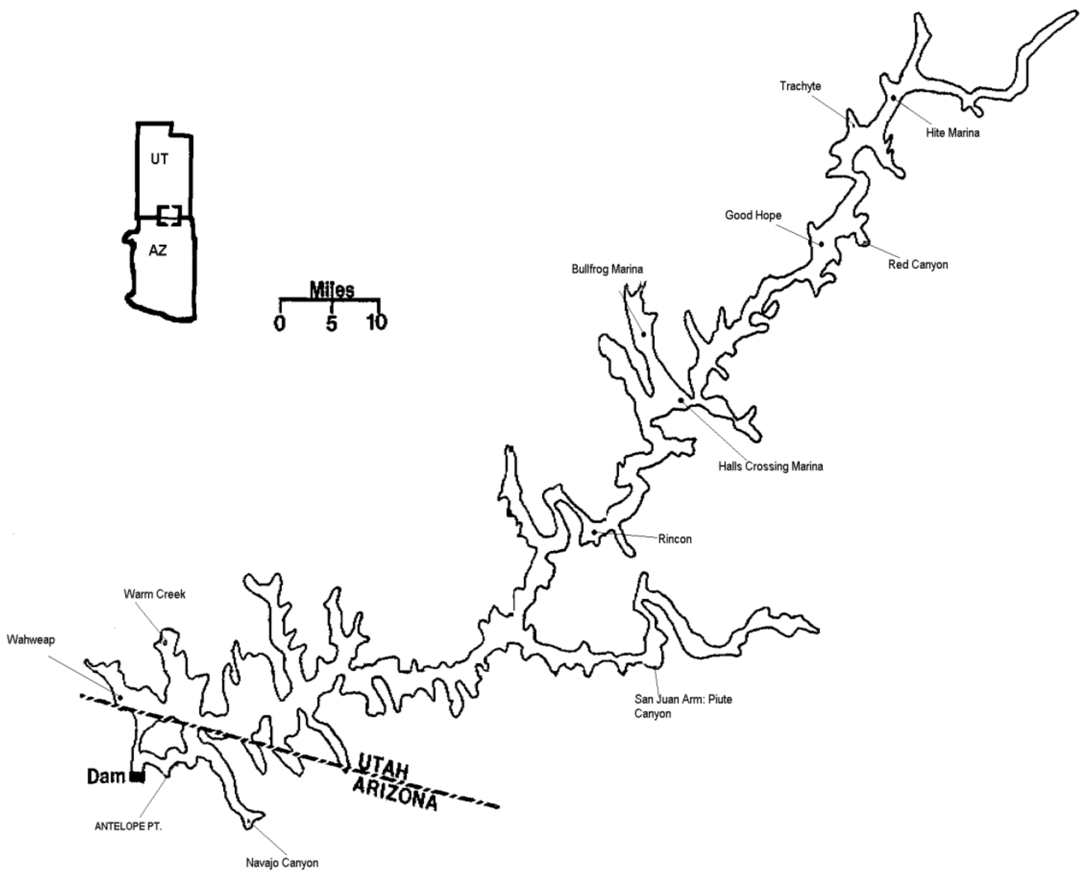


Figure 19. Map of Lake Powell showing major sampling areas.

Table 4. Residence of anglers based on boat registration, collected from creel surveys at Lake Powell, 1975-2018.

	Year												
Residence	64-79	80-84	1988	1991	1996	1997	2000	2003	2006	2009	2012	2015	2018
Utah	30	30	31	33	35	42	34	40	41	42	40	38	38
Arizona	21	27	28	30	32	23	31	21	20	20	25	28	33
Colorado	28	29	21	22	18	24	21	29	27	25	20	19	19
California	8	5	13	8	7	3	4	3	4	4	5	6	3
Other	13	9	7	7	8	8	10	7	8	9	10	9	7

Total angling pressure for the 7-month survey was at a 40 year low with an estimated 732,501 hrs (SE = 73,805) expended. This estimate stands in stark contrast to the previous (2015) survey which recorded an estimated 1,630,521 (SE = 103,835) angling hrs, but more closely resembled the estimate from the 2012 survey (Figure 20). Although numerous metrics contributed to the significant reduction in angler hours the most telling was the decline in the percentage of boat days that were spent angling. Only 23% of boat days were angling days in 2018 and the lowest recorded since surveys started in 1966. This compares to 39% from the previous survey (2015) and the 35.5% average over the previous 10 surveys dating back to 1988 (Figure 21).

Other factors that contributed to the reduction in total angler hours include the number of anglers per boat (2.3), days fishing per trip (2.1) and the number of angler hours per angling day (4.0). All of these metrics were below the estimates derived from the previous survey in 2015 and below the historical survey averages.

The distribution of angling pressure was atypical with 56% (409,911 hrs) of total angler hours generated at down-lake marinas and only 44% (322,509 hrs) at up-lake marinas. The previous survey (2015) recorded 68% of total angler hours originating from up-lake marinas and 32% down-lake. Angler hours peaked down-lake in June and up-lake in August (Table 5).

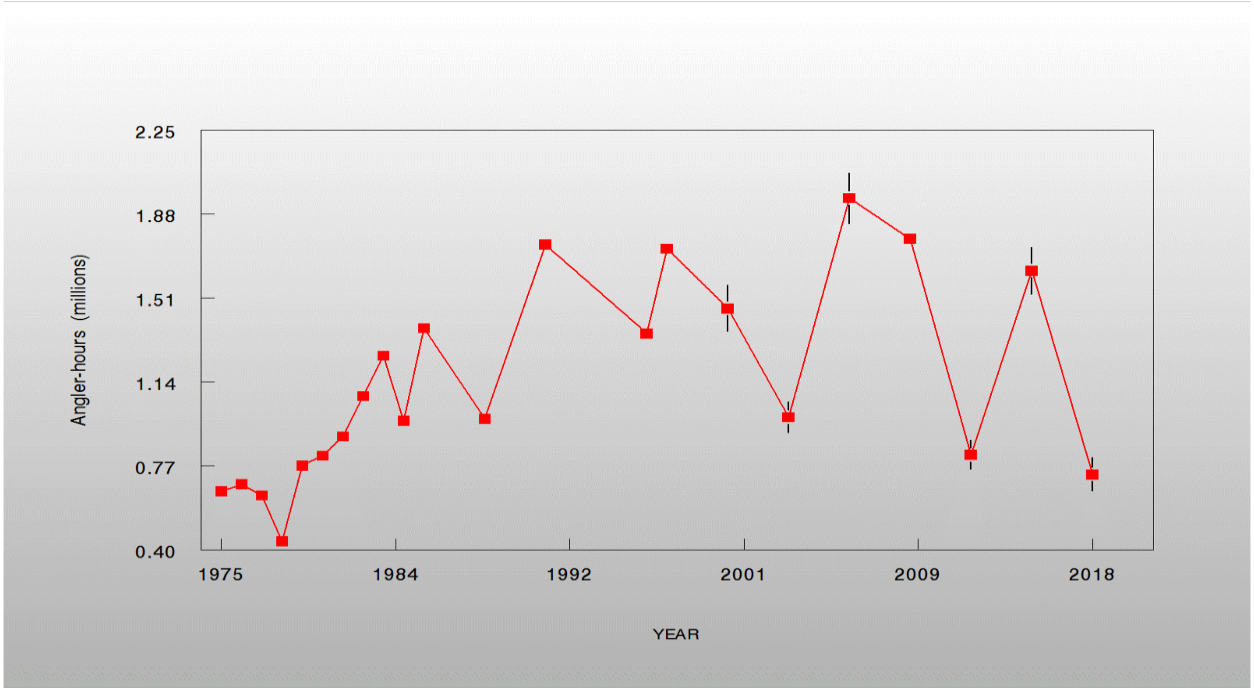


Figure 20. Total hours spent angling. Estimate for 12-months (1975-1997). 2000-2018 data with SE are for 7-month only.

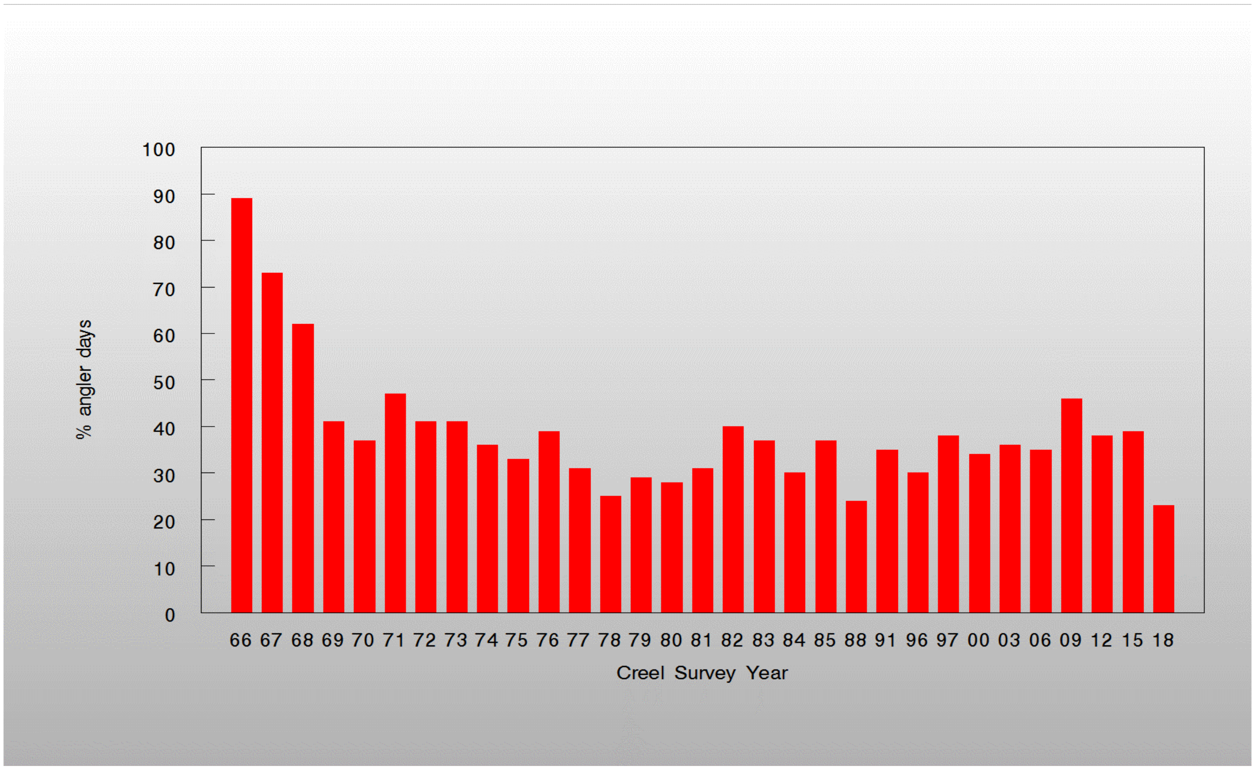


Figure 21. Percentage of recreational boat days that were angler days, 1966-2018, Lake Powell UT/AZ.

Table 5. Total estimated angler hours, Lake Powell, Utah / Arizona, 2018.

Location	Month							Totals
	Apr	May	Jun	Jul	Aug	Sep	Oct	
Down-lake	25,998	75,835	100,271	43,961	54,192	60,079	49,575	409,911 (56%)
Up-lake	35,685	25,176	55,724	51,509	86,339	51,050	17,107	322,590 (44%)
Totals	61,683	101,011	155,995	95,470	140,531	111,129	66,682	732,501
%	9	14	21	13	19	15	9	

The majority of anglers (36%) were non-specific when asked their target species preference. This is typical and compares favorably with the 34% of anglers who were not targeting any specific species reported in the 2015 creel, but was a large decrease over the 53% of non-specific anglers from the 2012 survey. Striped Bass were the most popular target species pursued by anglers in 2018 at 33%. Black bass (Largemouth and Smallmouth Bass) were the next most popular species: targeted 24% of the time, followed by Walleye (5%) then Channel Catfish (0.7%) and Bluegill Sunfish (0.4%) (Table 6).

Down-lake anglers were more apt to select a target species (76%) opposed to up-lake anglers (44%). Up-lake anglers were more likely to fish for Walleye (9%) than down-lake fishers (3%), which was typical. Black bass were targeted by 33% of down-lake anglers but only 10% of those originating up-lake. Striped Bass were the favored species sought after at both locations with 39% of anglers targeting them down-lake and 23% up-lake. This differs from the previous creel (2015) where black bass were slightly favored at both locations over Striped Bass (Blommer and Gustaveson 2017).

Table 6. Percentage of anglers that target select species, Lake Powell, 1985-2018.

	Year											
Species	1985	1988	1991	1996	1997	2000	2003	2006	2009	2012	2015	2018
Any Fish	39	45	53	31	37	32	57	46	52	53	34	36
Black Bass	14	14	18	44	32	31	20	14	21	19	31	24
Striped Bass	41	37	22	17	25	34	18	37	24	25	28	33
C.Catfish	1	3	3	5	3	2	3	<1	1	<1	1	<1
Walleye	3	2	3	<1	1	<1	<1	2	1	2	5	5
Bluegill	<1	1	<1	1	<1	<1	<1	<1	0	<1	<1	<1
Black Crappie	2	<1	<1	1	<1	1	<1	<1	1	<1	<1	<1

Due to the reduced fishing pressure from the 2018 angler survey, the total catch estimate for the 7-month survey was only 1,634,972 (SE = 190,464) fishes. This contrasts sharply with the previous survey (2015) where total catch was 2,713,965 (SE = 185,198) fishes and the pressure was considerably higher. Consistent with pressure estimates more fishes were caught at down-lake sites (54%) than up-lake sites (46%) with June and August being the most productive (Table 6b). This differs from the previous survey where up-lake sites produced more fishes than down-lake with September and October recording the highest total catch (Blommer and Gustaveson 2017).

Table 6b. Total number caught of all species by area and month estimated from the 2018 angler survey at Lake Powell.

Marina	Apr	May	Jun	Jul	Aug	Sep	Oct	Totals
Down-lake	43,835	163,034	174,611	75,841	166,744	126,621	133,602	884,288
Up-lake	29,202	51,040	125,328	156,459	253,640	98,218	36,797	750,684
Totals	73,037	214,074	299,939	232,300	420,384	224,839	170,399	1,634,972

The composition of the catch was typical with Smallmouth Bass accounting for 43% of the total catch followed by Striped Bass at 37%. These two species generally vie for the top spot with Smallmouth Bass edging out Striped Bass for the last two creel cycles. Bluegill Sunfish and Channel Catfish were the next most caught species with each accounting for 5% of the total catch. Bluegill Sunfish have returned strongly to the creel starting in 2015, which is encouraging as they are known to consume Quagga Mussels to some extent. Largemouth Bass made up 4% of the catch and Walleye accounted for 3%, which is also fairly typical. The remainder of the catch was rounded off by Green Sunfish (1.5%) followed by Black Crappie, Common Carp *Cyprinus carpio* and Yellow Bullhead *Ameiurus natalis* with each accounting for less than 1% of the total catch.

Forty Two percent of the total catch was harvested (680,801, SE = 148,537) in 2018 (Table 7). This compares favorably to the 40% of the total catch that was harvested in 2015 but well below the 62% of the total catch that were harvested during the 2012 survey. Striped Bass continued to make up the majority of the fish that were harvested, accounting for 470,427 fishes (SE = 115,519) and representing 77% of the Striped Bass catch being harvested. Smallmouth Bass accounted for 109,874 (SE = 20,904) of the total fish harvested and 15% of the Smallmouth Bass catch. Efforts to increase the harvest of Smallmouth Bass, which included increasing the daily bag limit to 20 fishes/day in 2002 initially resulted in an increased stock density with the percent harvested increasing from 11% to 34%. Walleye accounted for 43,018 fishes (SE = 11,691) harvested with 92% of the Walleye catch being harvested. Channel Catfish contributed 33,204 fishes (SE = 10,761) to the total harvested which represented 40% of the catfish catch.

Table 7. Total fish harvested, all species, by area and month, estimated from the 2018 angler survey at Lake Powell.

Area	Apr	May	Jun	Jul	Aug	Sep	Oct	Totals
Down-lake	17,458	72,506	96,173	27,143	80,590	49,657	39,464	382,991
Up-lake	9,347	8,661	21,003	55,966	157,896	33,228	11,709	297,810
Totals	26,805	81,167	117,176	83,109	238,486	82,885	51,173	680,801

The catch rate (fish/hr) was the most exciting metric derived from the 2018 creel and was the highest recorded since the catch rate replaced the harvest rate as the main method for measuring the fishing success of the Lake Powell fishery (Table 8). The lake-wide catch rate for the 7-month creel was an impressive 2.23 fishes/hr (weighted average). As stated this was a record for the fishery and well above the statewide UDWR catch rate goal of 0.50 fishes/hr from flat-water fisheries (Gustaveson et al 1996).

The best fishing was in August (2.99 fishes/hr) and October (2.55 fishes/hr) which is comparable with the historical average for the best fishing months (1996-present), (Table 8). Catch rates were the same at both up-lake and down-lake locations with Smallmouth Bass providing the best lake-wide fishing (0.97 fishes/hr) followed by Striped Bass (0.83), Bluegill Sunfish and Channel Catfish both at 0.11 fishes/hr, followed by Largemouth Bass at 0.09 fishes/hr and Walleye at 0.06 fishes/hr.

Table 8. Comparison of catch rates for all species, April-October, Lake Powell, 1996-2018.

Year	Apr	May	Jun	Jul	Aug	Sep	Oct	Wt/Avg
1996	0.73	1.25	0.82	0.71	0.97	0.76	0.59	0.29
1997	1.14	1.85	0.77	0.76	0.96	1.40	1.73	1.18
2000	0.06	0.69	0.82	1.00	1.14	1.00	0.67	0.79
2003	0.56	0.42	0.41	0.33	0.67	0.63	1.01	0.53
2006	1.20	1.47	0.59	1.62	2.73	1.52	1.78	1.73
2009	1.00	0.92	0.77	0.92	1.34	0.78	1.03	0.96
2012	2.02	1.27	2.04	2.33	2.63	2.07	2.18	2.13
2015	1.57	1.51	1.44	1.32	1.24	1.48	3.44	1.66
2018	1.19	2.12	1.92	2.43	2.99	2.02	2.55	2.23
Avg.	1.05	1.28	1.06	1.27	1.63	1.29	1.66	1.32

The 2018 creel was “atypical” in many respects. It was ironic that in the face of some of the best fishing ever recorded at Lake Powell, fishing pressure was the lowest recorded in the last 40-years. Fishing pressure typically is variable between surveys and although trailer counts (total boaters) were above the previous survey, that didn’t equate to higher fishing pressure as the percentage of boaters that were angling was at a historical low. This coupled with anglers spending less days per trip, less anglers per boat and less hours/day angling created the “perfect storm” that drove fishing pressure (angler hours) to pre-1980 levels. The wide swings in fishing pressure that have occurred over the last few creel cycles are puzzling and whether they are real or a product of our survey process is unknown.

Lake Powell continues to be a phenomenal fishery with the highest catch rate ever recorded in 2018. Although most anglers are happy to catch any species, Striped Bass and Smallmouth Bass continue to be the most targeted and the most caught species on the lake. Anglers continue to harvest Walleye (92%) and Striped Bass (77%) at high rates followed by Channel Catfish (40%) and with Smallmouth Bass (15%) being largely a “catch and release” fishery. Continued promotion of the fishery is imperative as Lake Powell is one of only a few statewide lakes that can sustain greater levels of angling pressure with no current limits on the catch and harvest of Striped Bass and Walleye and the generous harvest limit on Smallmouth Bass (20 fishes/day). Additional species specific angler survey information is contained in the individual species portion of this report.

STATUS OF FORAGE SPECIES

Introduction:

Lake Powell has a varied forage base consisting primarily of Threadfin and Gizzard Shad, YOY of all fish species and crayfish. This assemblage has increased and shifted to varying degrees over time and has supported a dynamic sport fishery. However, Threadfin Shad and Gizzard Shad make up an integral part of the forage base in Lake Powell whose importance to the sport fishery and especially Striped Bass cannot be overestimated, and are the main focus of this section.

Threadfin Shad were first introduced into Lake Powell in June of 1968. This original stocking consisted of 1500 fingerlings from Lake Mead which were released into Wahweap Bay (Utah F & G 1968). These Lake Mead shad were believed to have originated originally from fish obtained from the Tennessee River at Watts Bar, TN (Kimsey et al. 1957). Additional stocking of eggs placed on excelsior mats by Arizona Game and Fish Department personnel occurred down-lake in May and June of 1969. These eggs were produced from Threadfin Shad residing in Lake Pleasant, Arizona (Riney and Essbach 1971). The rational for the introduction of Threadfin Shad into Lake Powell was to provide additional forage for existing sport fishes and in anticipation of later stocking of Striped Bass which occurred in 1974 (Gloss et al. 1971). By July 1970 distribution and reproduction of Threadfin Shad was documented reservoir-wide (Gloss et al. 1970).

The effect of Threadfin Shad introduction on the growth of various sport fishes was positive and almost immediate with Threadfin Shad becoming the predominant food item in the stomachs of Largemouth Bass, Black Crappie, Green Sunfish and Bluegills (May et al. 1975). Subsequent studies showed increased growth for Largemouth Bass and Black Crappie following shad introduction (Hepworth and Pettengill 1980). A pre and post Threadfin Shad introduction study also examined the food habits and growth for Walleyes, and similar to other major sport fishes of the time a drastic shift in the diet from centrarchids to Threadfin Shad was noted. However, growth of Walleye following shad introduction failed to show the improvements seen in other sport fishes (Hepworth and Gloss 1976). Although no growth improvements were noted during this study, shad continue to account for 70% occurrence of food items in the stomachs of Walleyes captured in the annual fall gill-net survey (see Walleye section).

Because Threadfin Shad throughout their lifetime, and Gizzard Shad for the early portion of their lives, occupy the pelagic zone they are integral in maintaining the Striped Bass fishery on Lake Powell. Following the introduction of Striped Bass in 1974 and their establishment as a self-sustaining population by 1979 (Gustaveson et al. 1984) intense predatory pressure was exerted on the Threadfin Shad forage base. Gustaveson et al. (1980) reported rapid growth, approaching record levels for a landlocked Striped Bass population shortly following the initial introductions. However, the successful Striped Bass reproduction and recruitment resulted in a Threadfin Shad population crash in 1980 (Gustaveson 1999). A cyclical “boom & bust” dynamic set up with pelagic shad populations peaking every 2-7 years followed by periods of severely limited populations of shad in the pelagic zones. This dynamic continued until after Gizzard Shad, which were discovered in-lake in 2000, became established in 2003 and provided an alternate forage species for Striped Bass. This forage introduction appears to have relieved predatory pressure on the hard pressed Threadfin Shad population.

In June of 2000 a United States Geological Survey (USGS) team collected the first Gizzard Shad in the San Juan arm of Lake Powell in a trammel net at Piute Farms (RM-52). It is believed that these original shad migrated out of Morgan Lake, an impoundment upstream on the San Juan River near Farmington, New Mexico. Apparently, these fishes were inadvertently included along with several other non-target species in an earlier Fish and Wildlife Service (USFWS) stocking, and became firmly established in that reservoir (Mueller et al. 2001). Similar to the Threadfin Shad introduction, expansion in Lake Powell was rapid with adult Gizzard Shad being collected at all of the stations in the annual fall gill-net survey by 2003 (Blommer and Gustaveson 2007). Due to their rapid growth in Lake Powell, Gizzard Shad remain as viable sized forage for the majority of the Striped Bass population for only the first 1.5 years of life (Vatland 2006).

***Larval Sampling*:**

Sampling for larval Threadfin Shad, and later Gizzard Shad, in the backs of selected canyon began in 1981 utilizing icthyoplankton nets. Sampling generally began in late April and canyons were selected that had some inflow during the spawning months and were in close proximity to mid-water trawling sites. Larval shad tow gear consisted of a 500-micron mesh net with a 1-meter circular opening tapering to 76.2mm diameter at the cod-end. Overall net length was 3 meters with a detachable cup to facilitate fish removal at the terminal end. The net was towed for 2 minutes at a speed that allowed it to suspend just below the water surface with approximately 102m^3 of water sampled in each tow. Generally, 3 tows were pulled at each station. All fishes were preserved in a 10% formalin solution that transitioned to a 140 proof pure ethanol solution in later years. In the lab fishes were identified, enumerated and a subsample was measured to total length (TL). Additional data were collected on zooplankton, secchi, turbidity (NTU), and chlorophyll *a* (relative fluorescence). Sampling sites were more numerous early in the study but were paired down in later years. The most consistent down-lake sampling sites were located at Wahweap Creek, Warm Creek and Navajo Canyon. Mid and up-lake sites were located at Bullfrog Creek, Red Canyon and Trachyte Canyon. Due to logistical constraints, mid and up-lake sites were sampled at lower frequencies than down-lake sites.

Because the spawn can vary in intensity and duration, and is oftentimes bimodal, a production index (PI) was developed to measure the strength of the spawn at each site that would be comparable between sites and years. This index multiplies the mean number of shad collected by the number of days in the spawn. The length of the spawn was measured from the day the mean number of shad collected reached 10 larval shad/tow until less than 10 larval shad/tow were collected for two consecutive sample dates. For bimodal spawns the PI was calculated by summing the PI for each spawning event. If the mean number of larval shad/tow only reached or exceeded 10 fish on a single date then the PI was calculated by multiplying this number by 7 (days/week). If sampling at a site was inconsistent or extremely limited in scope no PI was calculated.

Larval shad spawning usually begins in May but the earliest recorded spawn was on 4/28/2019 at Trachyte Canyon (Figure 22). Mean lake-wide water temperatures were 68° F at the start of the spawn with no significant differences between sites (ANOVA; SAS Institute 1987) for data collected from 1981-2019. Up-lake sites typically had earlier spawns than their counterpart's down-lake (Gustaveson et al 1980), which was consistent with other studies (Netsch et al 1971). The median first spawn date was 5/20 and the spawn was usually completed by early August but could continue into September. The latest larval shad ever collected from the meter net tows was in the first week of October. On the average, spawning lasted 46 days (SD = 21) but was highly variable with at least 3 years at the Wahweap Creek sampling site when no spawn occurred (Table 9). Consistent with other studies (Johnson 1971; Kilambi and Baglin 1969; Kimesey et al. 1957) the spawn could be bimodal but this was rare in Lake Powell and occurred less than 12% of the time over the past 40 years. Some researchers suggest that spawning can also occur in the YOY population (Heidinger and Imboden 1974: Kimsey et al 1957) and could also be caused by density dependent factors (Anderson 1973). The advent of Gizzard Shad into the lake has not advanced the onset of the shad spawning season significantly or its duration as measured in the icthyoplankton sampling. However, anecdotal sightings by researchers have observed behavior consistent with spawning in Gizzard Shad as early as April (Blommer and Gustaveson 2011).

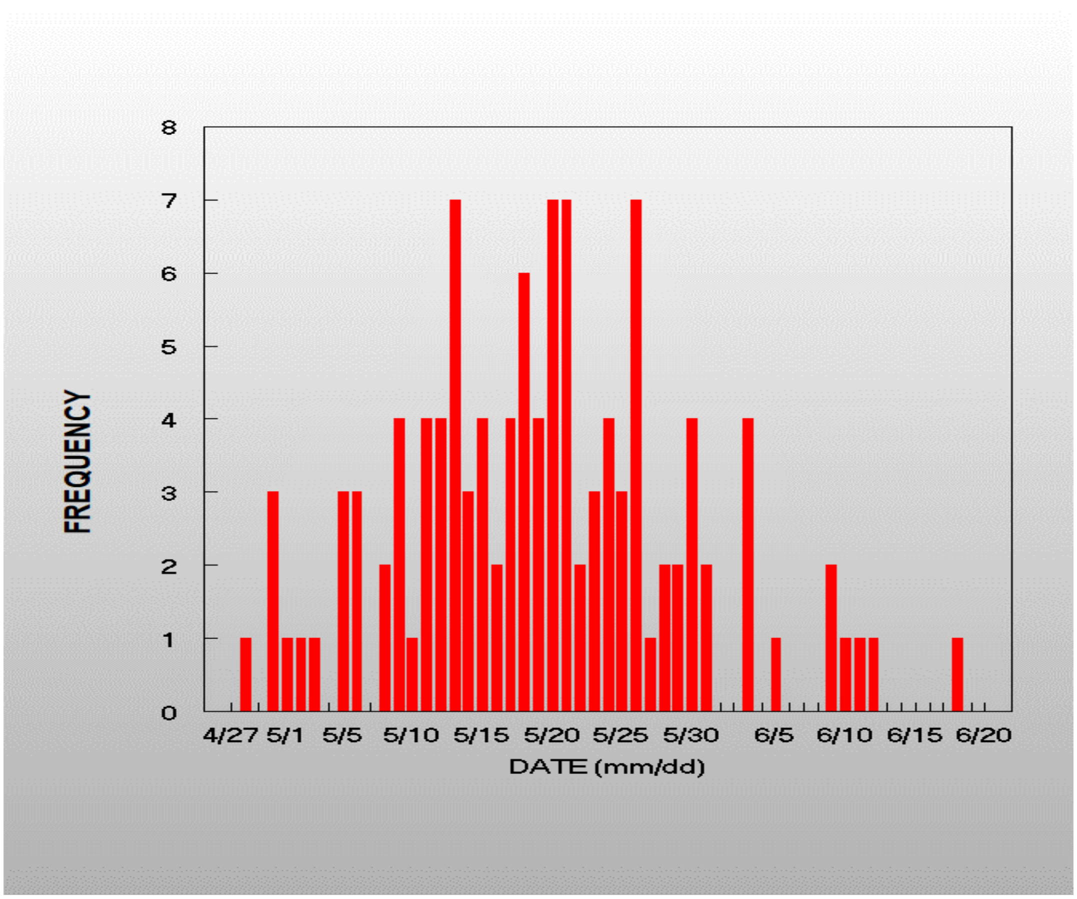


Figure 22. Date of first spawn frequency for shad species on Lake Powell, UT/AZ, 1981-2019.

Larval Threadfin Shad most likely hatched out at 3-4mm TL, but at this size were usually found gilled in the 500 micron mesh of the sampling net. Tomljanovich and Heuer (1986) found that retention of 1-d-old Threadfin and Gizzard Shad larvae (3.0-5.0mm TL) averaged less than 15% using a 500-um, square mesh, larval net similar to what was used in this study. Typically, shad were in the 6-8mm TL range when captured in their first week of life. Based on weekly down-lake larval sampling, larval shad growth approaches 1mm/day.

Table 9. Duration of spawn (days) recorded at various larval sampling sites, Lake Powell 1981-2019.

Location	Site	Mean No. Days	SD	n	Range	Years
Down-lake	Wahweap Creek	46	21	33	0 – 82	1981-2019
	Warm Creek	57	22	38	18–105	1981-2019
	Navajo Canyon	58	18	33	29-104	1981-2019
Mid-Lake	Bullfrog Creek	49	21	17	21-85	1981-2012
	Halls Creek	67	23	10	33-114	1981-2001
Up-Lake	Red Canyon	48	20	10	13-80	1981-2019
	Ticaboo Canyon	28	16	3	7-47	1981-2001
	Trachyte Canyon	65	15	7	51-99	2003-2019
San Juan	Piute Red Wall	47	22	5	20-56	1981-1988
Totals:		**52**	**11**	**9**	**28-67**	**1981-2019**

Down-lake larval sampling recorded strong numbers at Wahweap Creek in 3 of the last 4-years with 2017, 2018 and 2019 all producing catches resulting in PI values above the historical average of 9341. Likewise, strong spawn years were recorded at Navajo Canyon where all but the 2017 PI values were above the 24,763 historical average. Warm Creek sampling only managed 1-yrear (2016) where the PI value (25,155) was above the historical PI average of 24,763 (Figure 22).

Mid-lake larval sampling at Bullfrog Creek was almost nonexistent in 2016 and 2017 with a PI value of 168 and 228 respectively. This was well below the historical average of 13,076. However, larval tows in 2018 produced a PI value of 21,694 followed by 79,365 PI in 2019 which was the highest PI value ever recorded from the Bullfrog Creek station.

Up-lake larval sampling at Red Canyon suggested limited larval shad production in 2016 and 2017 with PI values below the historical average of 21,322 but rebounded in 2018 (PI = 47,534) and 2019 (47,483) with values well above the historical average. Sampling at the river/lake interface in Trachyte Canyon recorded only the 2018 spawn with a PI value above the historical average of 63,398. The 2018 PI value of 151,497 was the highest recorded historically at this site (Figure 23). As a word of caution: limited sampling at mid and up-lake sites may have contributed to lower PI values in 2016 and 2017 but estimates were consistent with later pelagic shad abundance at the Bullfrog and Good Hope Bay stations.

Various hydrological parameters were examined and their possible effects on the strength of the shad spawn as measured by meter-net tows. We looked at the positive change in lake elevation (ft) during the spring runoff versus the strength of the shad spawn (PI). Gustaveson et al. (1984) had noted a possible relationship between high inflow and increased shad reproduction in the upper lake over a limited number of years. However, Wahweap Creek was the only sampling site that showed a significant positive relationship between the magnitude of elevation change over the length of the runoff and shad production, $r = .57$, $p = .0004$ (Figure 24). All of the other sampling sites, both down-lake, mid-lake and up-lake, failed to show any significant relationship (Pearson Corr, SAS).

We also examined the day of the year that the elevation peak occurred to see if perhaps earlier or later peaks had any effect of the strength of the spawn. Again Wahweap Creek was the only site lake-wide that suggests that water levels peaking later in the runoff resulted in a larger shad spawn as measured by the PI (Pearson Correlation, $r = .51$, $p=.002$), (Figure 25).

Michaletz (1997) found that rapid elevation changes were correlated with shorter and more intense spawns of Gizzard Shad. Michaletz (1997) also found that the intensity of the spawn was greater when the spawn was of shorter duration. Our data set spanning 37 years, failed to find a significant correlation between elevation change and the duration of the shad spawn at any of the sampling sites. Furthermore, the intensity of the spawn, as measured by the peak number of larval shad collected at each site for the season, was not correlated with the duration of the spawn at all but the Bullfrog Creek site where regression analysis (Pearson Corr, SAS Institute 1987) detected a significant relationship ($r = .38$, $p = .01$). Additionally, mean PI and peak larval shad collections were slightly elevated after Gizzard Shad introduction, particularly at down-lake sampling sites. We also examined lake elevation at the start of the spawn versus the mean PI values, but failed to find a significant relationship (Reg, SAS Institute 1987).

Various dam release scenarios were also examined, but appeared to have little to no measurable effect on the production of larval shad as measured in the larval shad tow survey.

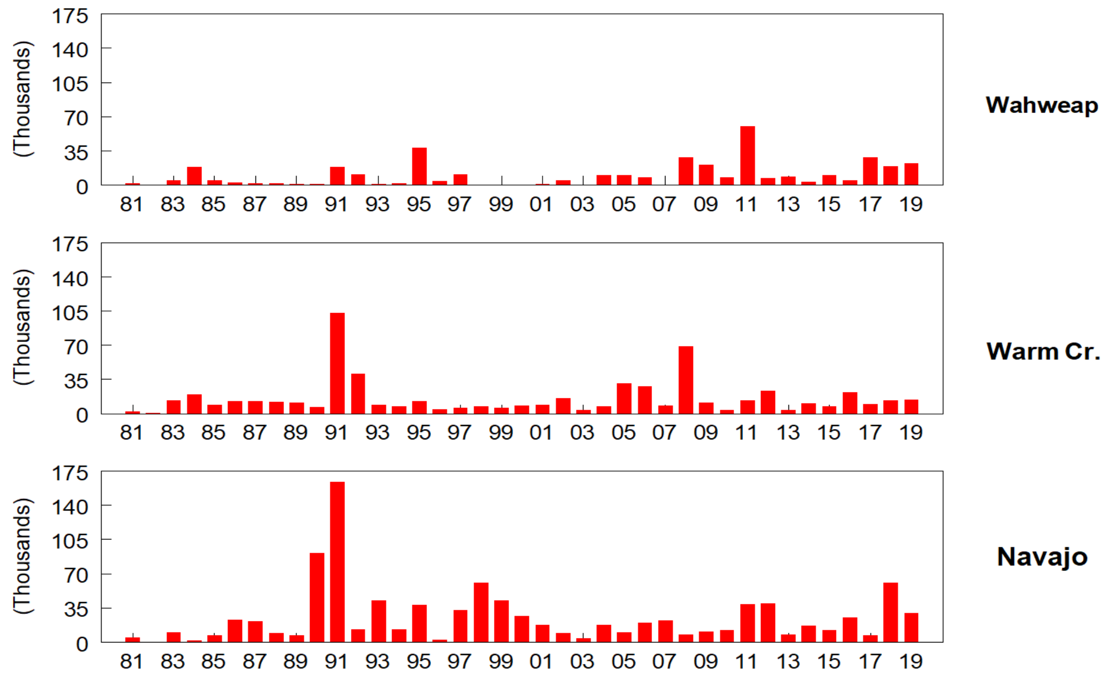


Figure 22. Larval shad production index at down-lake meter net sampling sites, Lake Powell UT/AZ 1981-2019.

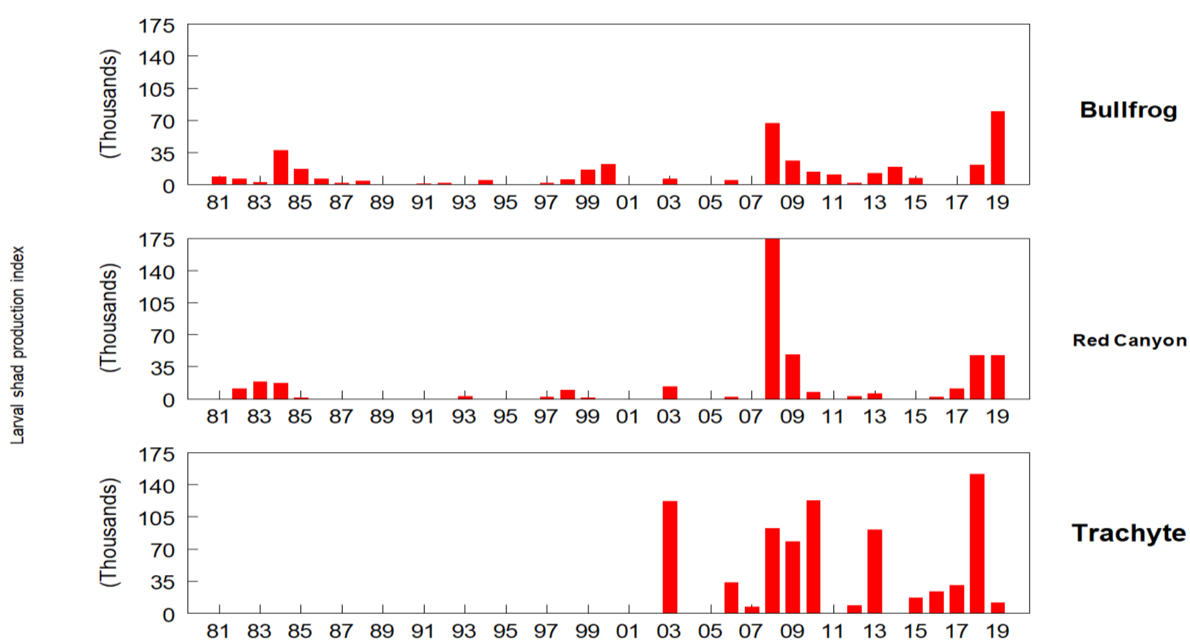


Figure 23. Larval shad production index (PI) at mid and up-lake meter net sampling sites, Lake Powell UT/AZ, 1981-2019.

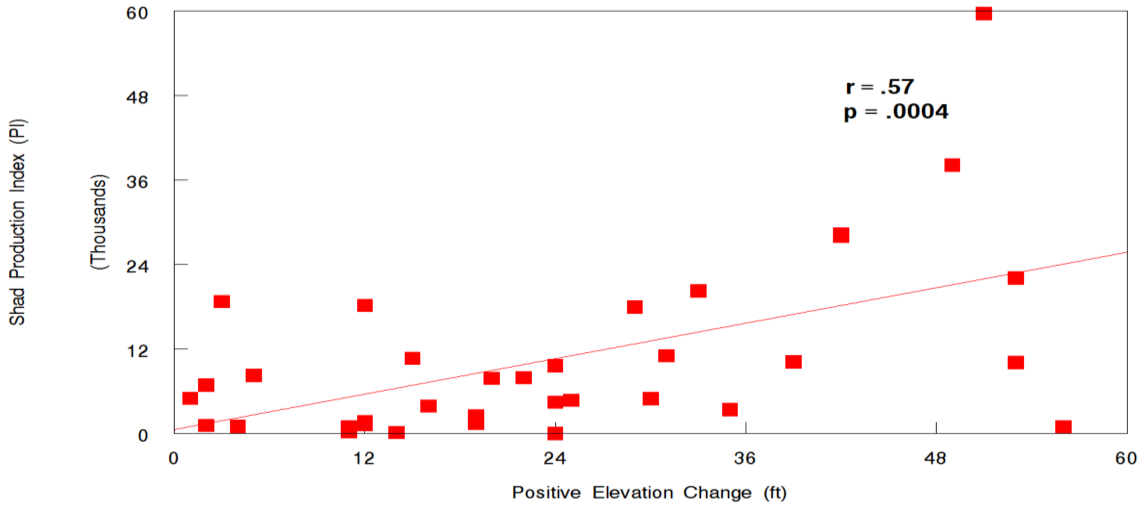


Figure 24. Relationship (Pearson Corr, SAS) between positive lake elevation change during the spawn and shad production index (PI), Wahweap Creek, Lake Powell UT/AZ, 1982-2019.

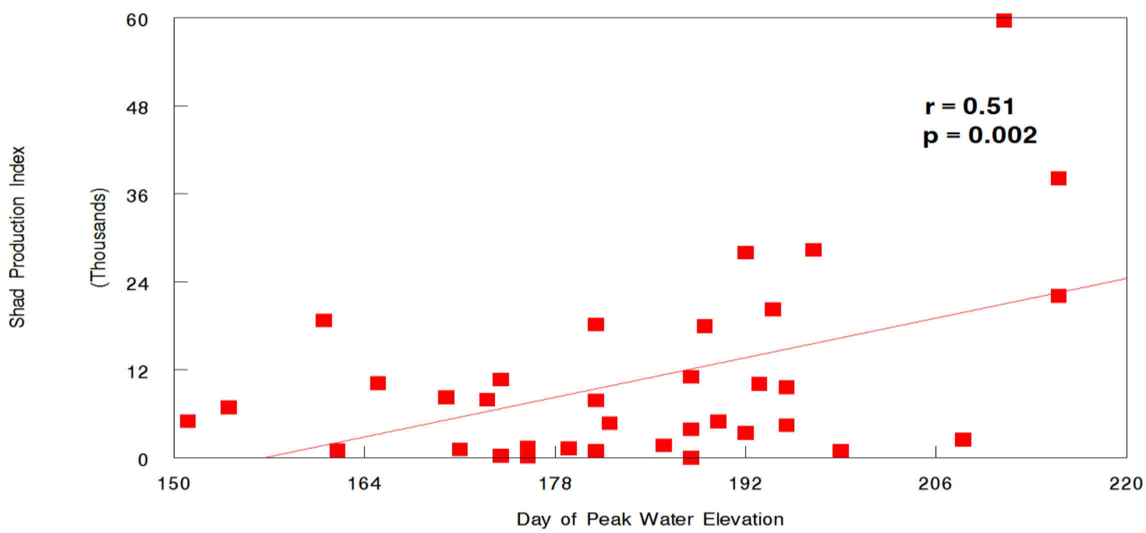


Figure 25. Relationship (Pearson Corr, SAS) between the peak water elevation day and the shad production index at Wahweap Creek, Lake Powell UT/AZ, 1982-2019.

Larval sampling down-lake was often inconclusive in predicting open-water shad populations in Wahweap Bay in July and August. This is particularly true for the larval sampling in Wahweap Creek where no significant correlation ($p > .05$, Pearson Corr, SAS) was detected using long term data sets (1981-2019). However, larval sampling at Warm Creek showed the most promise of predicting later pelagic shad populations in Wahweap Bay ($r = .44$, $p = .005$) followed by Navajo Canyon sampling at $r = .34$, $p = .04$ (Pearson Corr. SAS). Additionally, averaging the larval shad PI between all three down-lake larval sampling sites was predictive of later open-water shad populations at Wahweap Bay ($r = .40$, $P = .01$) although the model only accounted for 40% of the variability. However, comparing the PI from the combined down-lake larval sampling sites and transforming (y^3) the mid-water trawl data resulted in a model that was more convincing: accounting for 66% of the variability ($r = .66$, $p = .00001$).

Mid-lake larval sampling at Bullfrog Creek failed to correlate with pelagic shad populations as measured in the mid-water trawl sampling in Bullfrog Bay in July/August when long term data (1982-2019) were analyzed ($r > .05$, Pearson Corr, SAS). But larval sampling at both Red Canyon and Trachyte Canyon showed better predictive ability, and when combined were significantly correlated with open water shad populations at Good Hope Bay ($r = .46$, $p = .05$) for the years 1982-2019 (Pearson Corr, SAS). Although larval shad sampling utilizing meter net tows in selected canyons can show statistical significance over time in predicting the strength of the later pelagic shad population, used alone as a predictive tool and on a yearly bases it leaves much to be desired.

Pelagic Sampling:

Mid-water trawl sampling was used to sample Threadfin Shad and later Gizzard Shad that were successful in migrating from the near-shore spawning sites into the pelagic areas of Lake Powell. The standard trawl sampling began in 1976. Trawl design was based on equipment described by Von Geldern (1972). The trawl net measured 15.24 m (50 ft) in length and was 3.05 m (10 ft) square at the mouth with bar mesh tapering from 20.32 cm (8 in) at the throat to 3.17 mm (1/8 in) at the cod end. Lead weighted steel depressors were attached to the lower corners with aluminum hydrofoils with cork floats attached to the upper corners. Bridles attached each side of the net to a galvanized wire cable. The cables were spooled onto hydraulic winches mounted on either side of the trawl boat.

A standard trawl transect sampled the upper water column obliquely from the surface to a depth of 10.7 m. This was accomplished by spooling 61 m (200 ft) of cable while the boat speed was maintained at 1100 rpm. After attaining 61 m the cable was immediately retrieved while maintaining the 1100 rpm boat speed.

Because two different trawl boats were used over the course of the study slightly different depths and water volumes were sampled during a standard transect. Tows performed from 1976 – 1986 sampled 8178 m^3 of water to a depth of 10.7 m. Boat speed was 1.6 m/sec with an average tow taking 9.07 minutes (Hepworth et al. 1977). The volume of water sampled was calculated using a T.S.K. flowmeter while the maximum depth was measured using a Bendix T-1 bathykimegraph (Gustaveson et al. 1990). From 1987 through 2019 the standard tow speed was 1.27 m/sec with 7150 m^3 of water volume being sampled. Each tow took 10.1 minutes to complete and depth, although not measured, was estimated to be 11 m based on cable angle at full deployment (Blommer and Gustaveson 2002). In 1977 three standard trawl stations were established down-lake at Wahweap Bay, mid-lake at Bullfrog Bay and up-lake at Hite. The Hite station was later moved down lake to Good Hope Bay in 1981 as driftwood prevented effective sampling during the summer months (Gustaveson et al. 1981). An additional station on the San Juan arm of the lake was sampled when lake elevations and logistics permitted.

Sampling was conducted at night within 4-days of the new moon during July and August based on recommendations from Netsch et al. (1971). Originally 4 tows were made at each location but this frequency was reduced to 3 starting in 1983. A 8 min sonar transect was run in conjunction with the trawl tows at each site from 1977 until 1990 to qualitatively verify that the number of shad collected from the tows was representative of what was actually present (Hepworth et al. 1978). These sonar transects also confirmed the belief that the Threadfin Shad were evenly distributed throughout the upper water column during low light conditions (Gustaveson et al.1980). Original sonar equipment was a Simrad Skipper Sounder Model ES which was upgraded in 1983 to a Lowrance Model B and even later Model C with both units utilizing a LPT-101 transducer (Gustaveson et al. 1984).

Hydroacoustical sampling began in 2001 with the current sampling survey established in 2005. Early sampling utilized a HTI model 243 digital echo sounder. The 15^0 transducer was mounted in the down-looking position which limited the effective sampling area in the top 3 meters. However, pelagic shad were at their highest densities in the 10-12 meter range. Sites sampled were the same open-water bays where the trawl survey was run at Wahweap Bay, Bullfrog Bay, Good Hope Bay, and the San Juan arm. An additional mid-lake station at Rincon Bay was also added. The survey was performed around the new moon phase in September with 20 transects run in a zig-zag pattern. Each transect was 200 meters in length. Similar to the trawls, we started at the top end of the bay and worked toward the lower end. In 2012 we upgraded to a HTI model 241 echo sounder.

The historical predator/prey “boom / bust” cycle set up in early 1980-81 as the Striped Bass population over ran the available Threadfin Shad forage population resulting in the first population crash. The “bust” portion of the cycle typically lasted 3 or more years before peaking again. From 1988-1990 no shad were sampled in the pelagic zone and the length of time between peaks was steadily lengthening. When Gizzard Shad became established in the forage mix by 2003 the historical cycle was broken with 11 of the last 17 years showing strong pelagic shad populations (Figure 26).

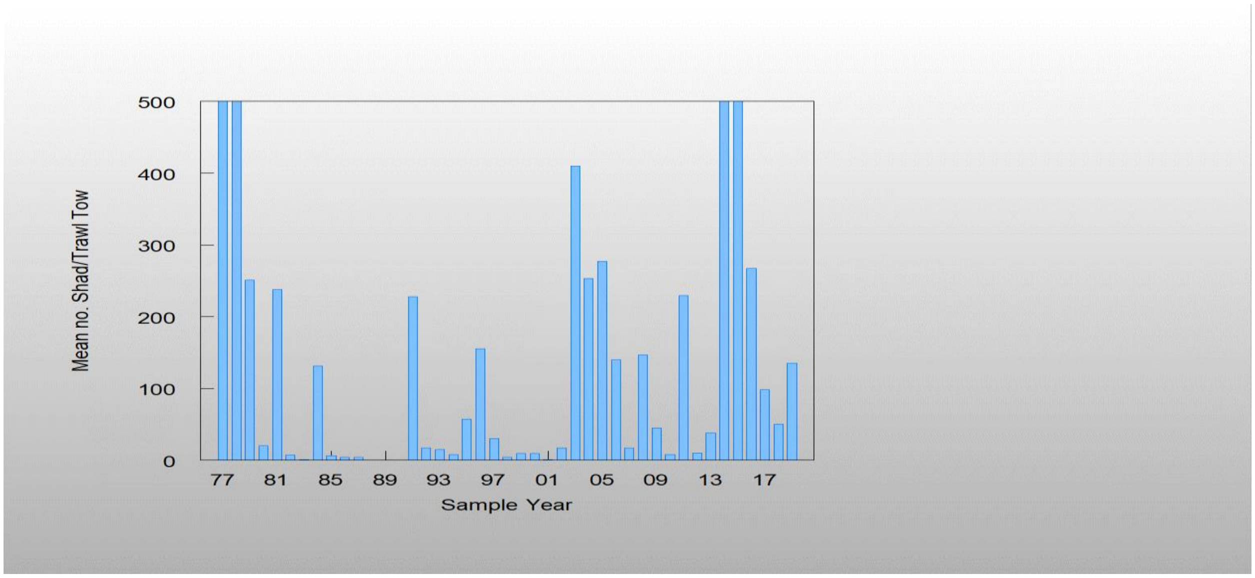


Figure (26). Mean number of shad per station collected in the mid-water trawl survey (July/August) in Lake Powell, UT/AZ, 1977-2019.

In late June to early July larval shad begin to move from near-shore areas into the open-water bays of the reservoir. This movement coincided with a decline in near-shore zooplankton abundance and an increase in water temperatures (Blommer and Gustaveson 2011). Not every year results in a measurable influx of larval shad into the pelagic areas. We speculate that these “bust” years may be the result of limited reproduction, intense predation during migration or a combination of both. Moczygemba and Morris (1977) reported that shad could be pushed into the open water areas due to intraspecific completion. However, in Lake Powell it is probable that a significant portion of the YOY population remains in the near-shore zone rather than migrating to open water. The annual fall electrofishing survey can sample large schools of juvenile and older shad in the near-shore areas well into September, this is particularly evident during “boom” shad years.

Recruitment of larval shad from the backwater spawning areas into the open-water bays is fraught with danger. Barnes (1977) found that newly hatched larval shad populations suffered natural mortality of 1/3 of the surviving population on a weekly bases for the first three weeks: and this was in excess of any predator driven mortality. Furthermore, Vatland (2006) found that the yearling Striped Bass population on Lake Powell was responsible for the majority of the predatory pressure exerted on the shad population. Data from the annual gill-net survey (1981-2019) suggests that composition of the Lake Powell Striped Bass population averages 45% yearlings, 31% age II and older and 24% YOY. In Lake Powell these yearling Striped Bass schools were often observed feeding heavily on larval shad as they migrated out of the turbid spawning areas.

Annual fall gillnetting shows a positive correlation (r = .72, p = .05; Pearson Corr) between the catch of YOY Striped Bass and the abundance of pelagic shad as measured from the mid-water trawl survey (Figure 27). Meanwhile, the catch of yearling Striped Bass showed no distinct relationship, while age II and older Striped Bass showed a weak inverse relationship between Striped Bass catch and pelagic shad abundance (r = -22, p = .05; Pearson Corr). This may suggest that survival of YOY Striped Bass is greatly enhanced during abundant pelagic shad years or that YOY are more active and/or more susceptible to the sampling gear. These YOY Striped Bass were then able to effectively decimate the shad population rapidly as they matured to yearlings setting up the classic “boom / bust” cycle.

Comparing the average lake-wide catch from mid-water trawl sites for 2016 through 2019 indicate that 2016 was the only year with above average pelagic shad abundance, although 2019 closely approached the 19-year average. Acoustical sampling, on the other hand, showed above average lake-wide pelagic shad densities every year except 2018: with 2019 having the highest mean number of forage fish/m^2 since the inception of the acoustical survey (Figure 28). Hydroacoustical sampling was sometimes at odds with mid-water trawl sampling. Some of the discrepancies may be due to timing as the trawl survey was run in summer (July and August) while the acoustical survey was run in the fall (September). It is conceivable that shad may be still migrating into the pelagic zones in September. The effects of Gizzard Shad on this dynamic is also largely unknown as their contribution to the September pelagic population of shad is unknown. Meanwhile, the condition of both adult and juvenile Striped Bass collected in the fall gill-net survey peaked sharply in 2019 while only juvenile condition peaked in 2016 (see Striped Bass section).

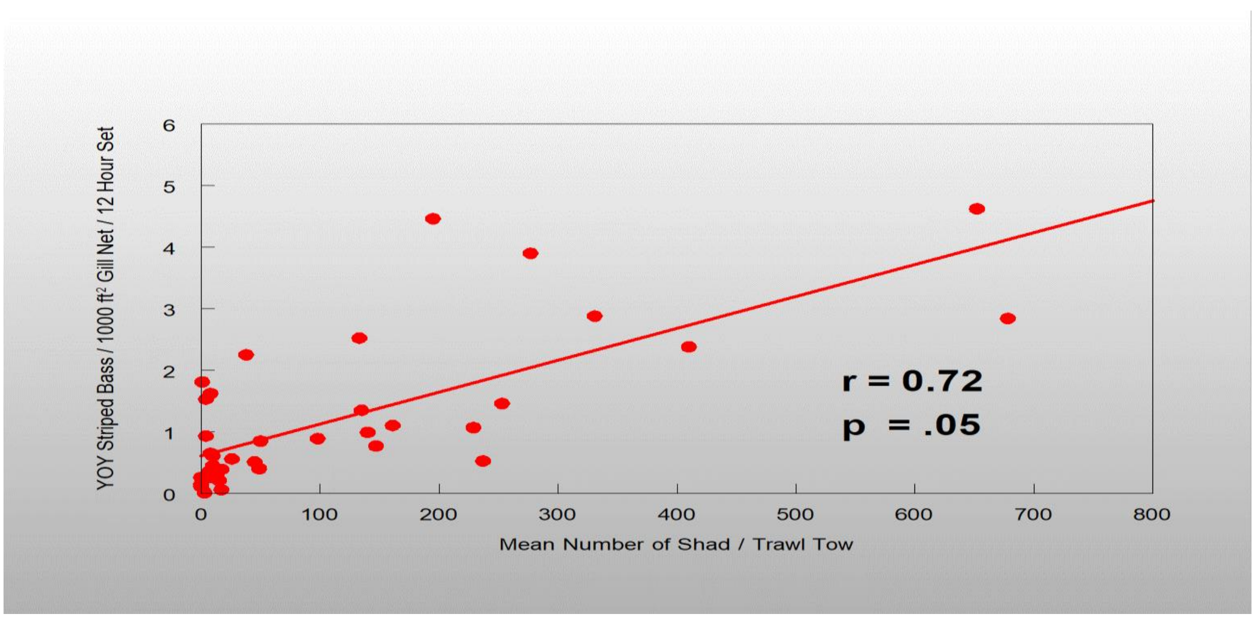


Figure 27. Relationship between the number of YOY Striped Bass collected in the annual fall gill net survey and the mean number of shad collected per trawl tow (July/August), 1981-2019, Lake Powell, UT/AZ.

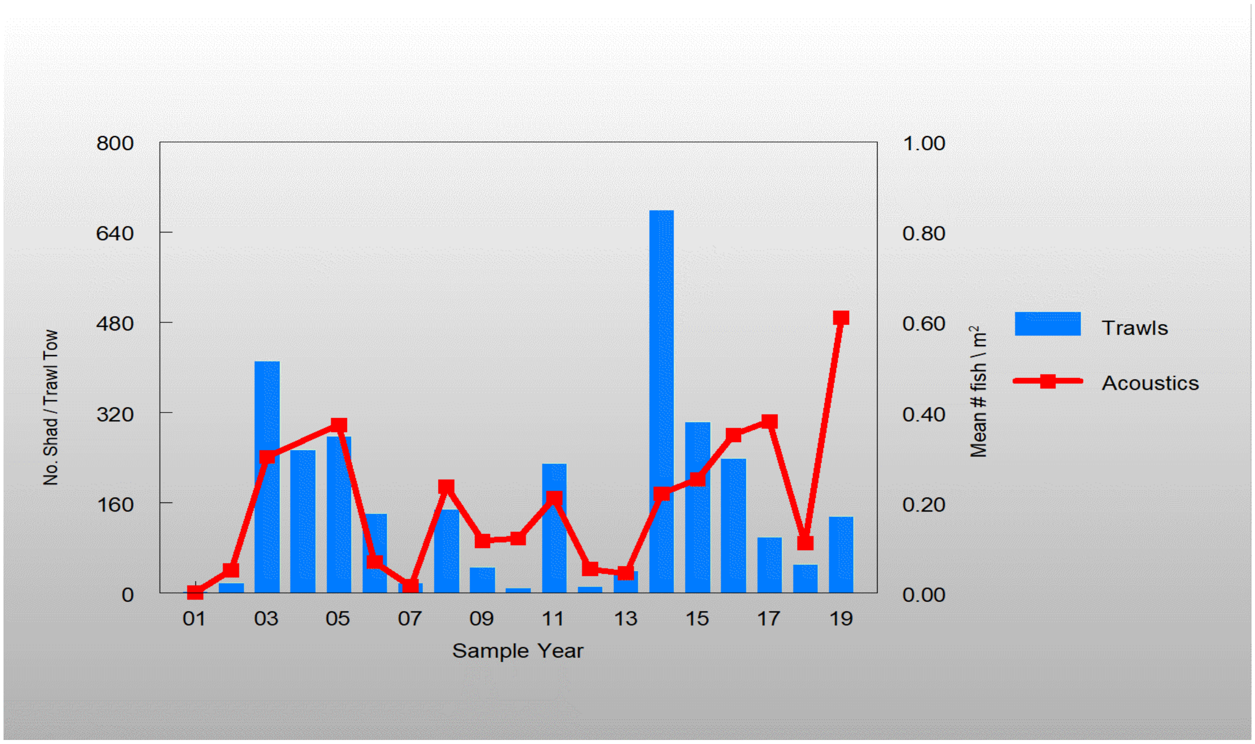


Figure 28. Comparison of mean number of shad/trawl tow (July/August) vs mean number of forage fish/m^2 (TL: 0.5" – 6.0") sampled during the hydroacoustical survey in September, lake-wide, 2001-2019, Lake Powell, UT/AZ.

Historically (1977-2000), when a shad peak occurred it tended to occur at all stations throughout the lake within a 2-year period (Figure 29). Contemporarily, shad peaks still tend to occur across all stations, especially when the hydroacoustical sampling is factored in, but occasionally peaks can occur only at isolated sites and not throughout the reservoir. Shad peaks, down-lake at Wahweap, occurred less often than at up-lake sites and with less magnitude. This was reflective of the productivity gradient that exists in Lake Powell. There was never a year when a peak occurred at Wahweap when it didn't occur at least at 3 other sites. Hydroacoustical sampling at Wahweap tended to mirror trawl sampling with the exception of 2003, 2018 and 2019 where acoustical estimates were considerably higher than the trawl samples suggested. The mean number of shad/trawl tows collected from mid-water trawls were 27, 76, 9, and 10 shad respectively for 2016-2019, while acoustical sampling also had low levels in 2016 (0.03 fish/m^2), but increasingly higher levels in 2018 (0.11 fish/m^2) and 2019 (0.18 fish/m^2).

Unfortunately, no acoustical sampling was performed in 2017 where trawl sampling suggested peak shad numbers (Figure 30). Mean historical shad densities (2003-2019) recorded from the acoustical survey at Wahweap averaged 0.11 fish/m^2 (SD = 0.11). Meanwhile, average shad densities during peak shad years at the Wahweap station averaged only 0.18 fish/m2 and were the lowest of all the stations sampled in the acoustical survey. The percentage of Gizzard Shad versus Threadfin Shad is known only from the trawl survey but not from the acoustical survey. It would be interesting to see if one of the shad species predominates in the September acoustical survey, and how that compares with the summer mid-water trawl survey.

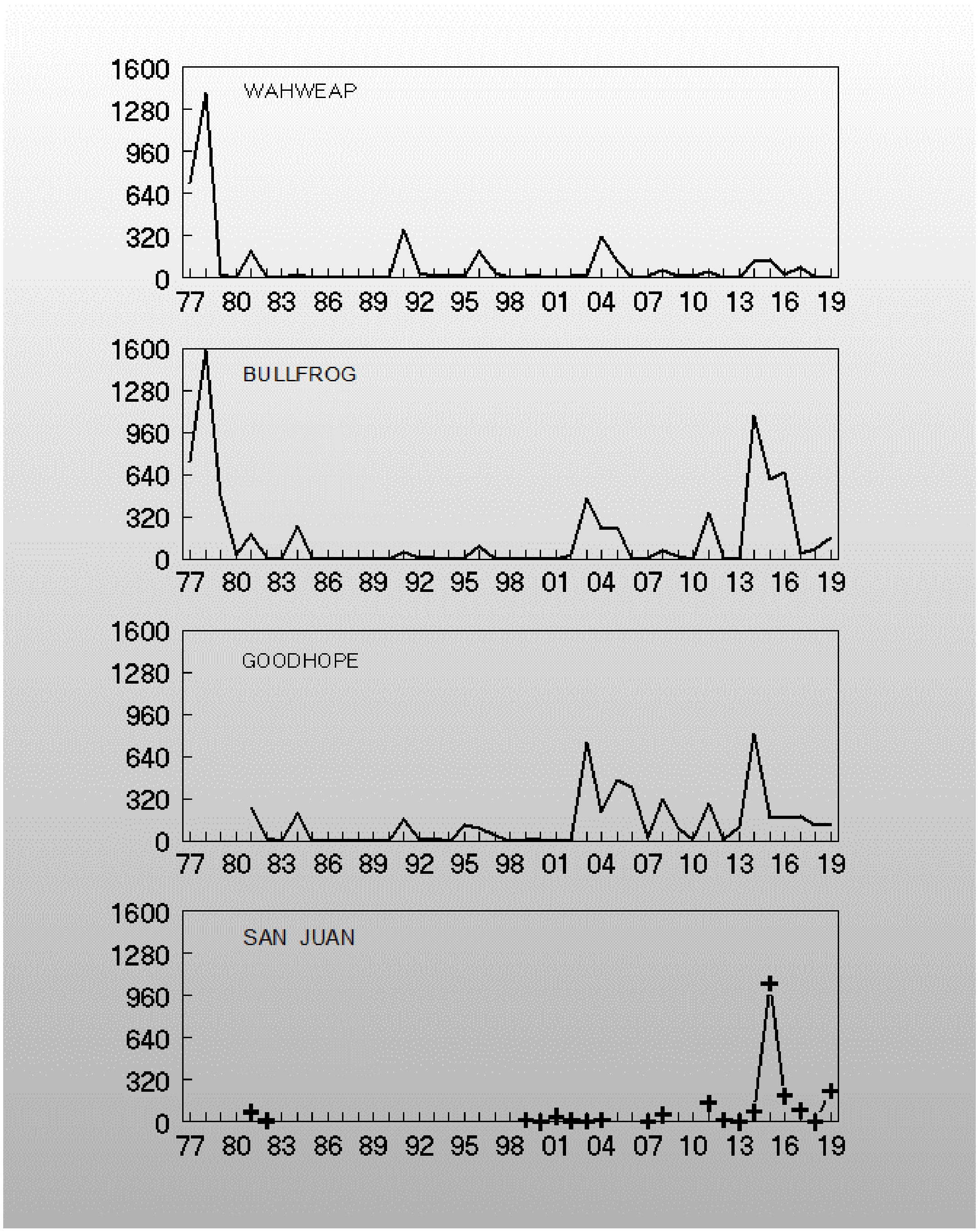


Figure 29. Average number of shad/tow collected from the mid-water trawl tows (July/August) at standard sampling sites in Lake Powell, UT/AZ, 1977-2019.

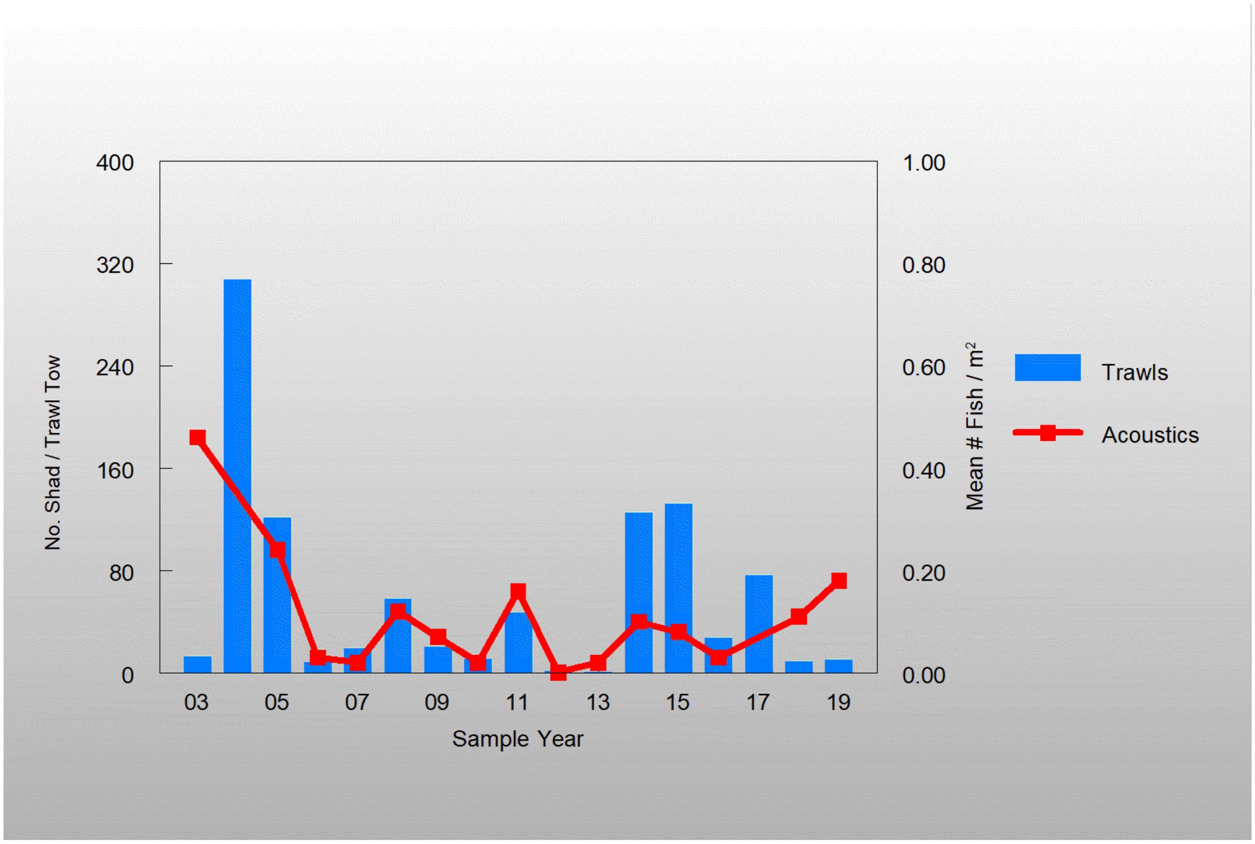


Figure 30. Comparison of mean number of shad/trawl tow (July/August) vs mean number of forage fish/m^2 (TL: 0.5" – 6.0") sampled during the hydroacoustical survey in September, Wahweap, 2001-2019, Lake Powell, UT/AZ.

Strong numbers of shad were collected from trawl sampling in the San Juan arm in 2016 at 199 shad/trawl tow and remained strong in September during the acoustical survey (0.14 fish/m^2) which was, the second highest mean density historically. Shad numbers declined in both surveys the following year (2017) and were almost non-existent in the trawl survey by 2018. No acoustical surveys were performed in either 2018 or 2019 due to logistical and equipment issues but the mid-water trawl survey recorded the second highest historical number of shad/trawl tow for the San Juan station in 2019 at 236 fish/trawl tow (Figure 31). The mean density of pelagic shad resulting from the acoustical survey from 2003-2017 was 0.11 fish/m^2 (SD = .13). Overall, shad peaks at the San Juan station averaged 0.51 fish/m^2, the highest of all the stations with acoustical estimates, suggesting higher shad densities than what the trawl survey predicts on most years. The ratio of yearly shad peaks/sample was high at 0.62 as measured by the acoustical survey but was the lowest when measured by the trawl survey at 0.21.

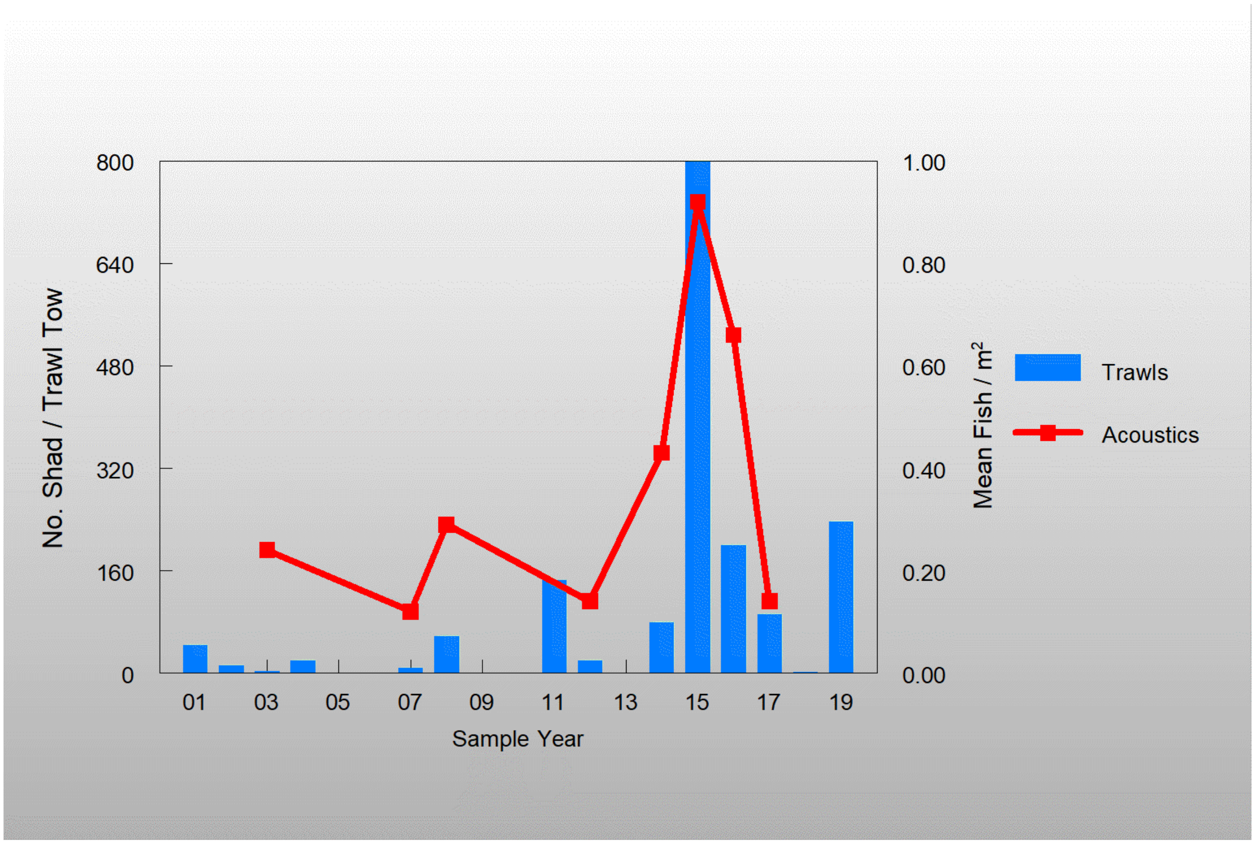


Figure 31. Comparison of mean number of shad/trawl tow (July/August) vs mean number of forage fish/m^2 (TL: 0.5" – 6.0") sampled during the hydroacoustical survey in September, San Juan arm, 2001-2019, Lake Powell, UT/AZ.

The Rincon station is only sampled in September by hydroacoustics and not trawling. To date the shad peaks occur on an every third year basis and are fairly consistent in magnitude (Figure 32). The mean shad density recorded in the acoustical survey (2003-2016) was 0.11 fish/m^2 (SD = 0.13). Meanwhile, shad peaks at the Rincon averaged 0.30 fish/m^2 (SD = 0.05) from the same period. The last September shad peak was in 2014. However, no sampling has been done at this location since 2016, when only 0.04 fish/m^2 were sampled in the pelagic area of the bay. Acoustical surveys at the Rincon station showed the lowest ratio of yearly shad peaks per number of years sampled at 0.31: lowest of all the stations.

Comparing shad densities from the acoustical survey with adult (> 499mm TL) Striped Bass condition (Kfl) from fishes collected in the annual fall gill-net survey at the Rincon station reveals a positive and significant relationship (r = .73, p = .005) and allows us to project shad densities for the years 2017-2019. Using this linear model September pelagic shad densities would be expected to be low in both 2017 and 2018 but peaking in the 0.20 fish/m^2 range in 2019.

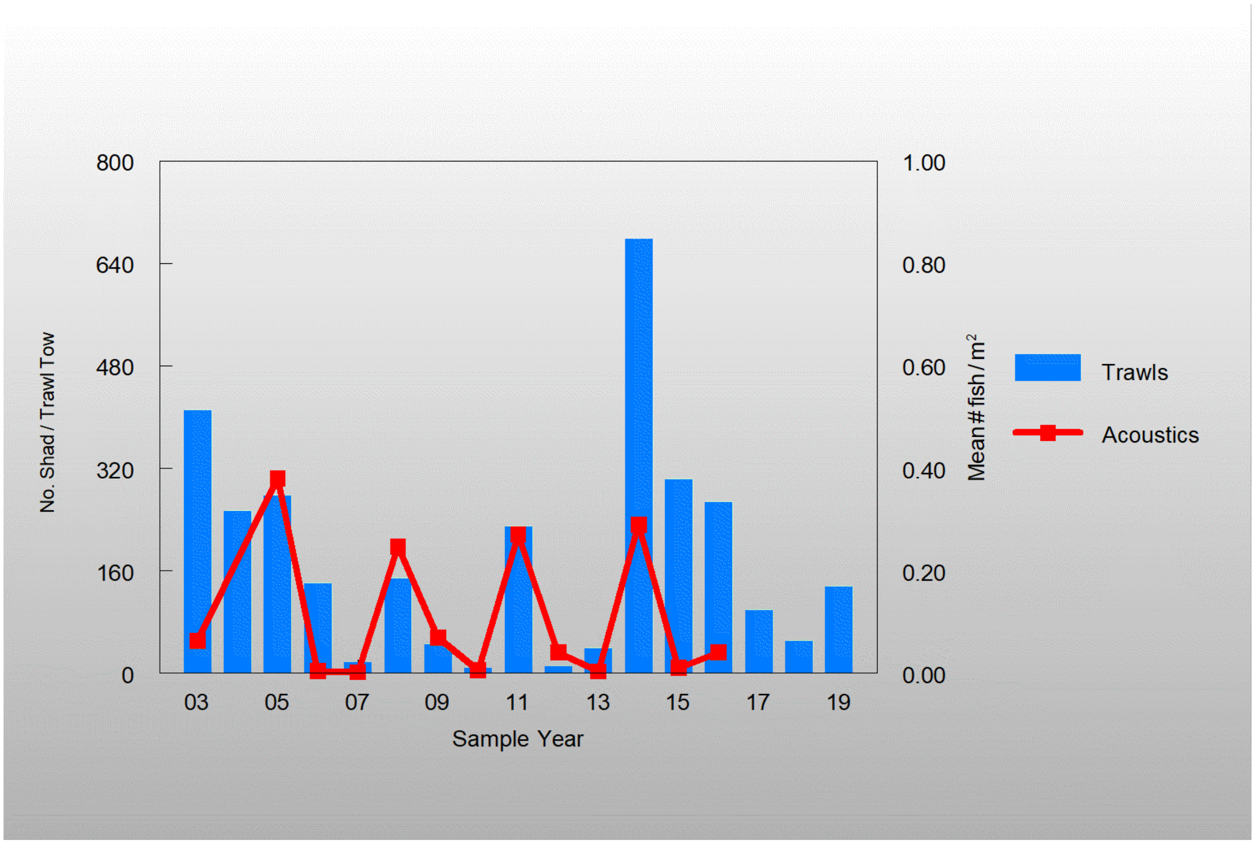


Figure 32. Comparison of mean number of shad/trawl tow (July/August) lake-wide vs mean number of forage fishes/m^2 (TL: 0.5" – 6.0") sampled during the hydroacoustical survey in September, Rincon, 2001-2019, Lake Powell, UT/AZ.

Acoustical shad peaks at Bullfrog Bay tend to agree with mid-water trawling results although the magnitude of the peaks can differ. This was most evident in 2019 where the September acoustical survey recorded a historical, all station record density of 1.09 fishes/m^2. Trawl sampling at Bullfrog Bay in July/August suggested a much more moderate peak in pelagic forage fishes (Figure 33). The mean shad density recorded in the acoustical survey (2001-2019) was 0.24 fish/m^2 (SD = 0.29). Meanwhile, the mean shad peak for the hydroacoustical survey was 0.45 fish/m^2 (SD = 0.29) for the previous 19 years. The ratio of yearly shad peaks per number of years sampled was .50: the second lowest of all of the acoustical stations. However, the ratio of the number of peak shad trawl days per sampling days was 0.47 which was the same as for the Good Hope station and higher than all other stations.

No gill netting is performed at the Bullfrog Bay station so no comparisons could be made with Striped Bass condition factors.

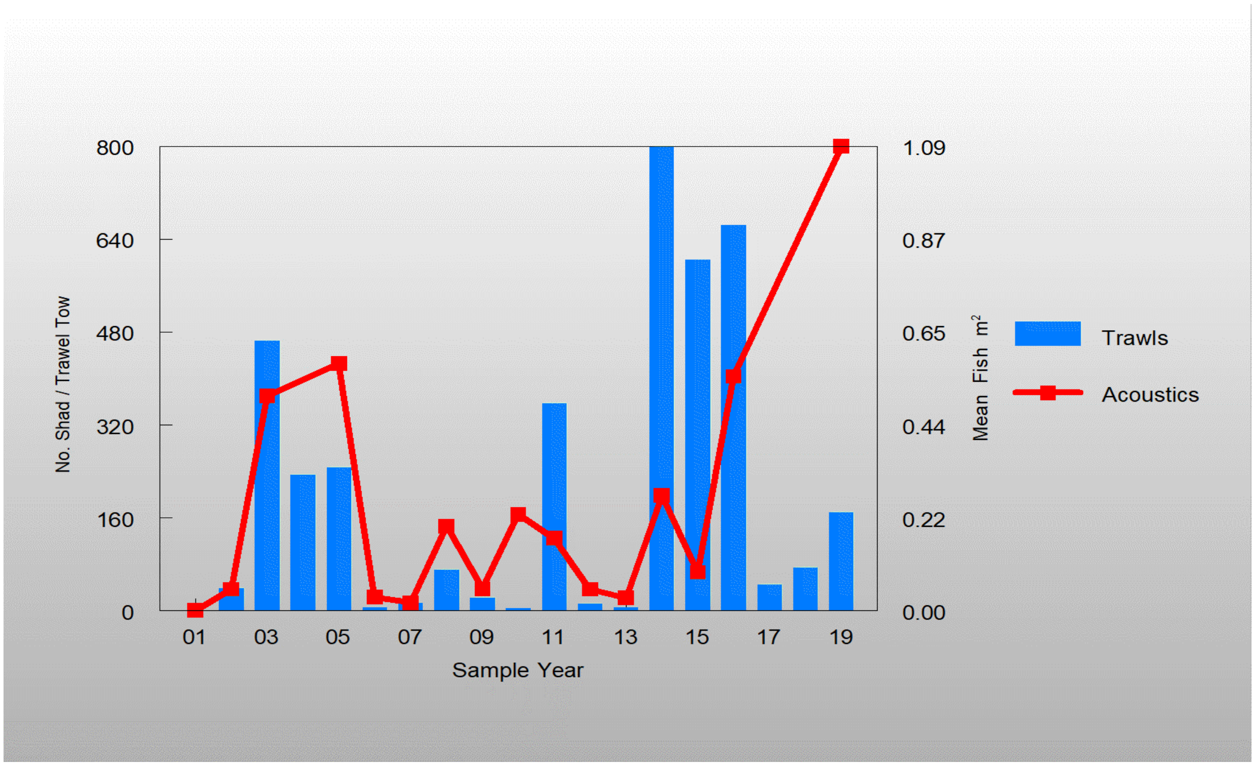


Figure 33. Comparison of mean number of shad/trawl tow (July/August) vs mean number of forage fish/m^2 (TL: 0.5" – 6.0") sampled during the hydroacoustical survey in September, Bullfrog Bay, 2001-2019, Lake Powell, UT/AZ.

The Good Hope Bay station is the farthest station sampled up-lake and the most productive. Furthermore, the acoustical survey probably mirrors the trawl survey the closest of any station. The mid-water trawl survey from 2016-2019 indicated only moderate levels of shad in the pelagic zone while the September acoustical survey showed much higher levels existed in the open water (Figure 34). November adult Striped Bass condition (Kfl) ranged from 0.88 to 1.13 in Good Hope Bay, with 2017 and 2019 being the highest values at 1.07 and 1.13 respectively. By comparison adult Striped Bass condition in 2016 and 2018 were below 1.0 level that is acceptable to anglers at 0.88 and 0.95 respectively. Unlike other stations, Striped Bass condition is not significantly correlated with estimated acoustical and trawl shad densities in Good Hope Bay (Pearson correlation, SAS).

Mean shad density in the acoustical survey from 2003 – 2019 was 0.32 fish/m^2 (SD = 0.23). This was surpassed only at the San Juan station. Meanwhile, the average acoustical shad peak at Good Hope Bay was .40 fish/m^2 (SD = .20) over 16 years. Although this mean density falls short of the San Juan and Bullfrog Bay stations, the ratio of peak sampling years to years sampled was the highest of any station at 0.75. Overall sampling suggests that shad densities follow the productivity gradient suggested by Wurstbaugh et al. 1994, with up-lake and inflow stations producing higher densities of pelagic shad than lower stations when sampled over time.

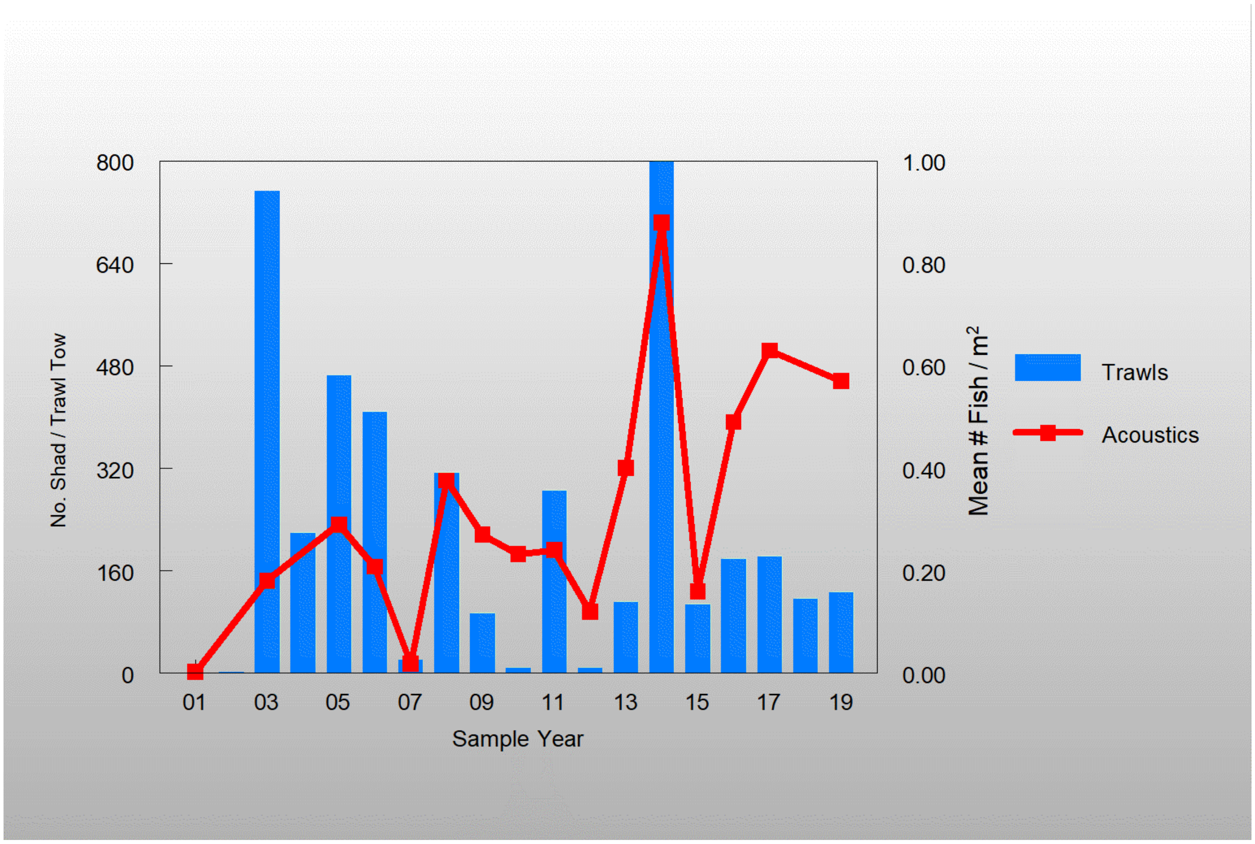


Figure 34. Comparison of mean number of shad/trawl tow (July/August) vs mean number of forage fish/m^2 (TL: 0.5" – 6.0") sampled during the hydroacoustical survey in September, Good Hope, 2001-2019, Lake Powell, UT/AZ.

Gizzard Shad were first discovered in the Lake in 2000, like Threadfin Shad, Striped Bass and Smallmouth Bass before them, and Quagga mussels that followed, their expansion was lake-wide after 3-years. Gizzard Shad YOY were first collected in the mid-water trawl survey at Good Hope in 2005 followed by Bullfrog in 2008 and Wahweap in 2009. Surprisingly, Gizzard Shad did not appear in the mid-water trawl at the San Juan station until 2012 although they had been collected in the gill-net survey as early as 2002 and in the electrofishing survey starting in 2003. All of the sites excluding the San Juan collected their first Gizzard Shad in the gill nets in 2003. Probably, some amount of time was required for a breeding population to develop in the near-shore areas before reproduction was sufficient to push large numbers of YOY into the pelagic zones.

Since first detection, Gizzard Shad have steadily increased their presence in the open-water at all sites. In the "boom" shad years of 2011 and 2014, Gizzard Shad dominated the trawl catches at both Good Hope and Bullfrog. While in 2016, Gizzard Shad comprised 83% of the trawl catch at Wahweap, 71% at Bullfrog, 94% at Good Hope, and 41% at the San Juan station (Figure 35). Since 2009 Gizzard Shad have not been absent in the mid-water trawls at Good Hope Bay and only once (2010) at Bullfrog. At the San Juan station only two years had an absence of Gizzard Shad in the mid-water trawls, and on one of those years (2018) only a July trawl was performed. Wahweap has had 3 years since 2009 where no Gizzard Shad were collected: 2012, 2013, and 2018, with 2012 and 2013 being "bust" shad years where only 6 and 4 unidentifiable shad were collected respectively. 2018 was another "bust" year where only a very limited number of shad were collected.

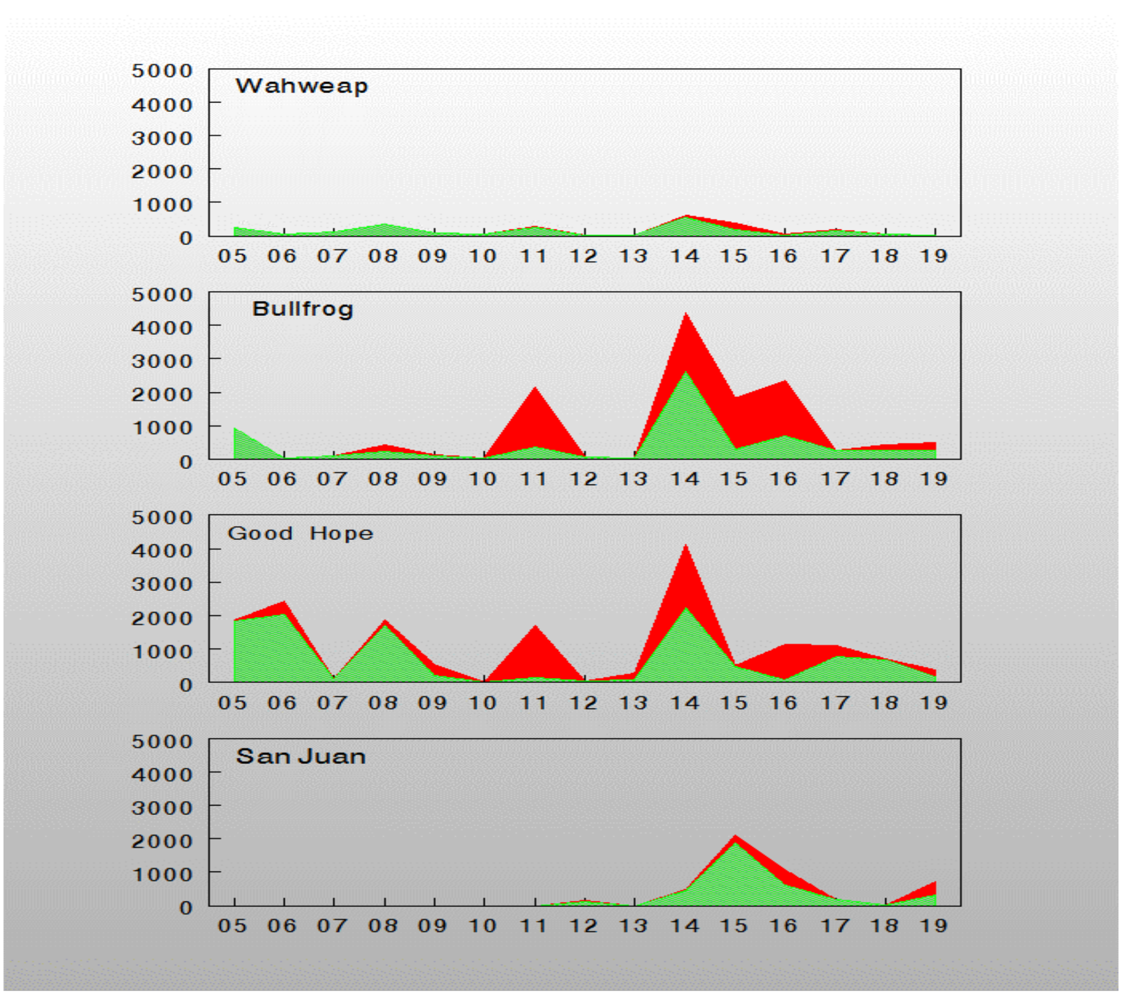


Figure 35. Measurable portion of Threadfin Shad (green) and Gizzard Shad (red) collected in the mid-water trawl survey at Lake Powell, UT/AZ 2005-2019.

Gizzard Shad are just recently appearing in the mid-water trawls on the San Juan in sizable numbers compared to Threadfin Shad. In 2016, 41% of the catch from the August mid-water trawl was comprised of Gizzard Shad and again in 2019, 55% of the July trawl was Gizzard Shad. But in 2017 the July trawl collected only Threadfin Shad, suggesting that Gizzard Shad and Threadfin may have their own separate cycles that only occasionally synchronize.

Pelagic shad sizes tend to follow the productivity gradient with down-lake mean TL at Wahweap averaging 26.2mm in July and 38.0mm in August for the years 2005-2019. These sizes increase at Bullfrog to 35.6mm and 47.8mm. At Good Hope Bay mean shad size was 35.3mm in July and 50.4mm in August. Meanwhile, the mean TL in July in the San Juan was a 41.9mm and 50.7mm in August for the years 2012-2019.

Threadfin Shad were smaller in July with a mean TL of 37.8mm (SD = 5.6) than Gizzard Shad at 42.2mm TL (SD = 3.8). However, Threadfin Shad sizes increased an average of 11.1mm (SD = 4.4) by the August Trawl, whereas, Gizzard Shad TL actually decreased at Wahweap and the San Juan stations while showing only slight increases at Bullfrog and Good Hope stations when averaged out over the last 15-years. This may reflect larger Gizzard Shad moving out of the pelagic zone and into the near-shore areas. There may also be an influx of late spawned Gizzard Shad moving into the open water zones or perhaps differential mortality as Striped bass selectively feed on the larger Gizzard Shad.

We examined the relationship between the mean TL of shad collected in the July and August mid-water trawls and the number collected for each station. No significant relationship existed at any of the sampling stations between shad density and growth, which may suggest that zooplankton resources are not a limiting factor in pelagic shad growth. However, the possibility of selective foraging by yearling Striped Bass on larger pelagic shad and other such factors could complicate our understanding of the relationship.

We also looked for possible effects of the Quagga Mussel invasion on pelagic shad sizes. We surmised that adult mussels, by filtering vast quantities of water, would reduce the availability of planktonic forage available for pelagic shad growth. Overall, this may not be the case, with post-invasion shad sizes larger than pre-invasion sizes for the July trawl at all but the down-lake station at Wahweap. However the reverse was true for the later trawl where all but the Good Hope station shad sizes were smaller following the Quagga invasion. It may be that there is plenty of planktonic forage in July but by August that resource is now becoming depleted in a post Quagga era. More data are needed before drawing any definitive conclusions.

The utilization of Threadfin Shad by all of the major sport fishes is well documented in Lake Powell. Striped Bass, once past the yearling stage are dependent upon shad to fuel their metabolic needs. The prolonged absence of pelagic shad has quickly led to the loss of condition and starvation periodically throughout the history of Striped Bass in Lake Powell (Gustaveson 1999). Since 1986 shad have consistently been present in the stomachs of Striped Bass captured in the fall gill net survey. The percent occurrence of shad in Striped Bass stomachs ranged from 11% to 94% with an average of 68% for those years. The high utilization of shad emphasizes the dependency of Striped Bass on shad species. As expected, the % of shad occurring in the stomachs of Striped Bass is positively correlated with the abundance of pelagic shad sampled in the mid-water trawl survey ($r = 0.51$, $p = 0.01$, Pearson Corr).

Smallmouth Bass, the second most popular sport fish in Lake Powell, were more opportunistic feeders on shad rather than dependent. Shortly following introduction, Smallmouth Bass began utilizing shad as forage and the % occurrence of shad in the stomachs of fall gill-net caught Smallmouth Bass ranged from 0 – 44% with a mean % occurrence of 13% for the years 1989-2019. Like Striped Bass the % occurrence of shad in the stomachs of Smallmouth Bass captured in the fall gill-net survey was positively correlated with the abundance of pelagic shad as measured in the mid-water trawl survey (r = 0.48, p = .005, Pearson Corr). Smallmouth Bass could occasionally be seen "boiling" on open water shad much like Striped Bass but most of their foraging was subsurface among the rocks where crayfish *Orconectes virilis* and centrarchids comprised the majority of their diet.

Surprisingly, the mean % occurrence of shad in Walleye stomachs (71%, SD = 17) eclipsed the occurrence of shad in Striped Bass stomachs and ranged from 25% - 94% for the years following Gizzard Shad introduction (2004-2019). The resurgence of the Walleye population in the upper reservoir has been largely attributed to the establishment of Gizzard Shad and the consequent increase in stability of the shad forage base. However, data spanning the previous 16 years fail to show a relationship between pelagic shad abundance and % occurrence in Walleye stomachs. Most years Walleye were equally successful in foraging for shad regardless of shad abundance as measured by the mid-water trawl survey.

Interestingly, correlation analysis showed that the mean catch of Walleye and Smallmouth Bass per station in the fall gill net survey was positively related to mean pelagic Shad abundance per station as measured in the mid-water trawl survey (Walleye: r = 0.75, p=.0001; Smallmouth Bass: r = 0.59, p = 0.0002). Perhaps as shad populations increased, the heightened feeding opportunities and the predator activity associated with it allowed for the increased capture of these species.

Largemouth Bass, similar to Smallmouth Bass, are opportunistic but not dependent feeders on shad. The mean % occurrence of shad in Largemouth Bass stomachs captured in the fall gill-net survey from 1990-2019 was 14.5% (SD = 17) and ranged from 0-75% (Figure 36). Correlation analysis shows a positive relationship between pelagic shad abundance and % occurrence of shad in gill net captured Largemouth Bass stomachs (r = 0.39, p = 0.04), similar to the other major predators. Where Largemouth Bass differed was in their ability to exploit the near-shore component of the shad population. Correlation analysis between the near-shore fall electrofishing catch of shad and the % occurrence of shad in the stomachs of selected predators collected from the fall gill net survey failed to show a significant relationship for all but Largemouth Bass (r = 0.65, p = .0003). These bushy littoral habitats are the preferred feeding areas of Largemouth Bass, where they could effectively feed on shad unavailable to many of the other major predators.

Because larval sampling could be oftentimes inconclusive in predicting pelagic shad abundance we also examined the abundance of pelagic shad, as measured in the mid-water trawl survey, and the same hydrological factors that were used in comparisons with larval shad sampling metrics. All water elevation, inflow and release data were obtained from the BOR website. First we compared mean pre-spawn (March/April) dam release data with lake-wide pelagic shad abundance as measured by the mid-water trawl survey (July/August), but found no significant relationship using regression analysis at the p = .05 level. The same held true for the May/June active spawning period where no relationship was detected between lake-wide pelagic shad abundance and dam water releases.

We also looked to see if water levels peaking earlier or later in the spawn were associated with larger or smaller pelagic shad abundance as measured by the July/August mid-water trawl survey, but failed to

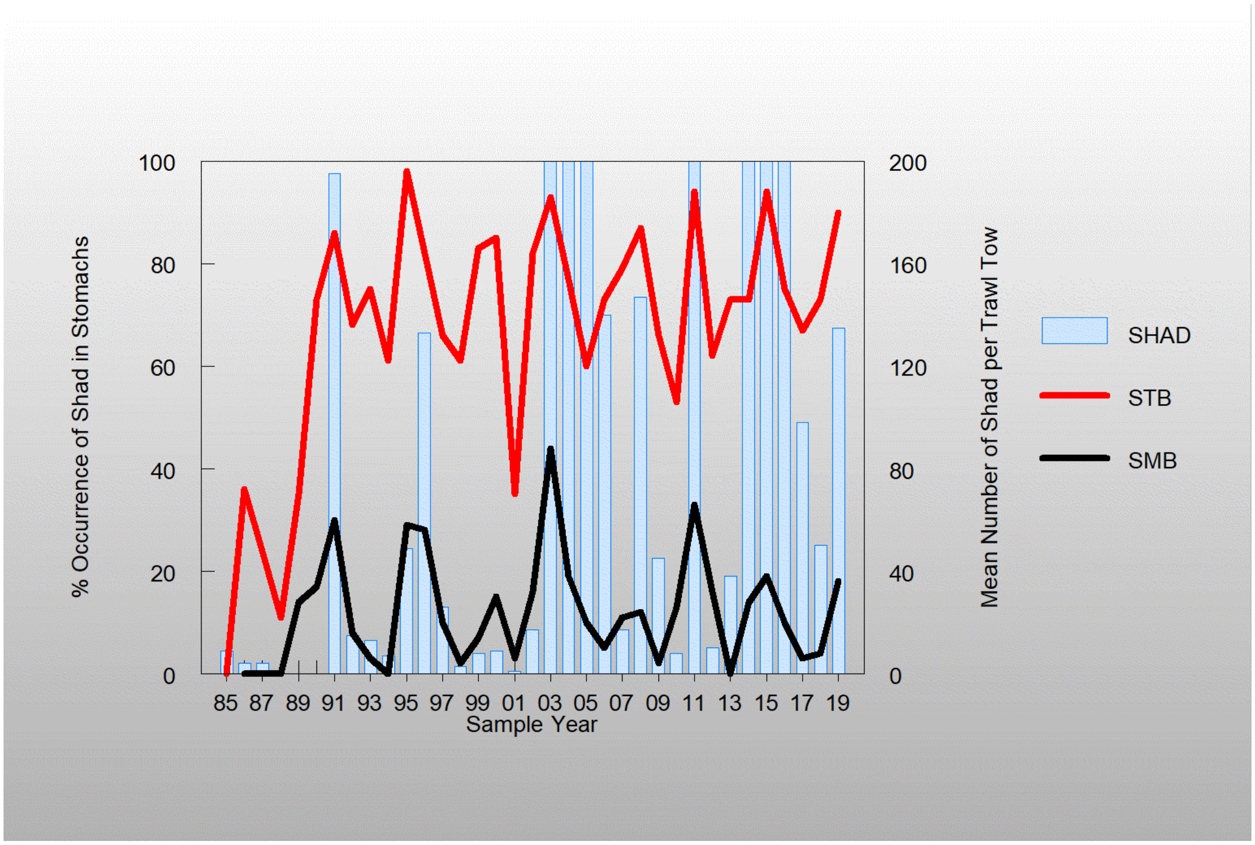


Figure 36. Percent occurrence of shad in the stomachs of Smallmouth Bass and Striped Bass compared with the mean number of shad/trawl tow, Lake Powell 1985-2019.

find a significant relationship on a lake-wide bases. Next we looked at how the duration of the spawn might be related to the abundance of pelagic shad. We compared the duration of the spawn from the Wahweap Creek larval net tows against the mid-water trawl pelagic shad abundance estimates at Wahweap Bay for the years 1982-2019. Correlation analysis showed a positive relationship (r = .39, p = .02, Pearson Corr) suggesting that longer spawns equated to larger pelagic shad abundances in July and August. The same was not true at mid and up-lake sites where the duration of the spawn was not correlated with pelagic shad abundance at either Bullfrog Bay or Good Hope Bay.

Finally we examined the abundance of open-water shad (lake-wide) and how that estimate related to water level elevation at the beginning of the spawn and the magnitude of change in elevation during the spawn for the years 1982-2019. A highly significant correlation (Pearson Corr, SAS) existed with lower elevations at the start of the spawn equating to higher pelagic shad abundance in July/August (r = -.60, p = .0001; Figure 37). This finding was in contrast to the comparison between lake water elevation and the larval PI, where no significant relationship was discovered at the 0.05 alpha level (Pearson Corr, SAS). We also discovered that greater elevation changes during the spawn was positively and significantly related with higher open-water shad abundance although it only accounted for 34% of the variation. This finding was also in contrast with the comparison between the change in water levels during the spawn and the larval shad PI where no significant correlation existed.

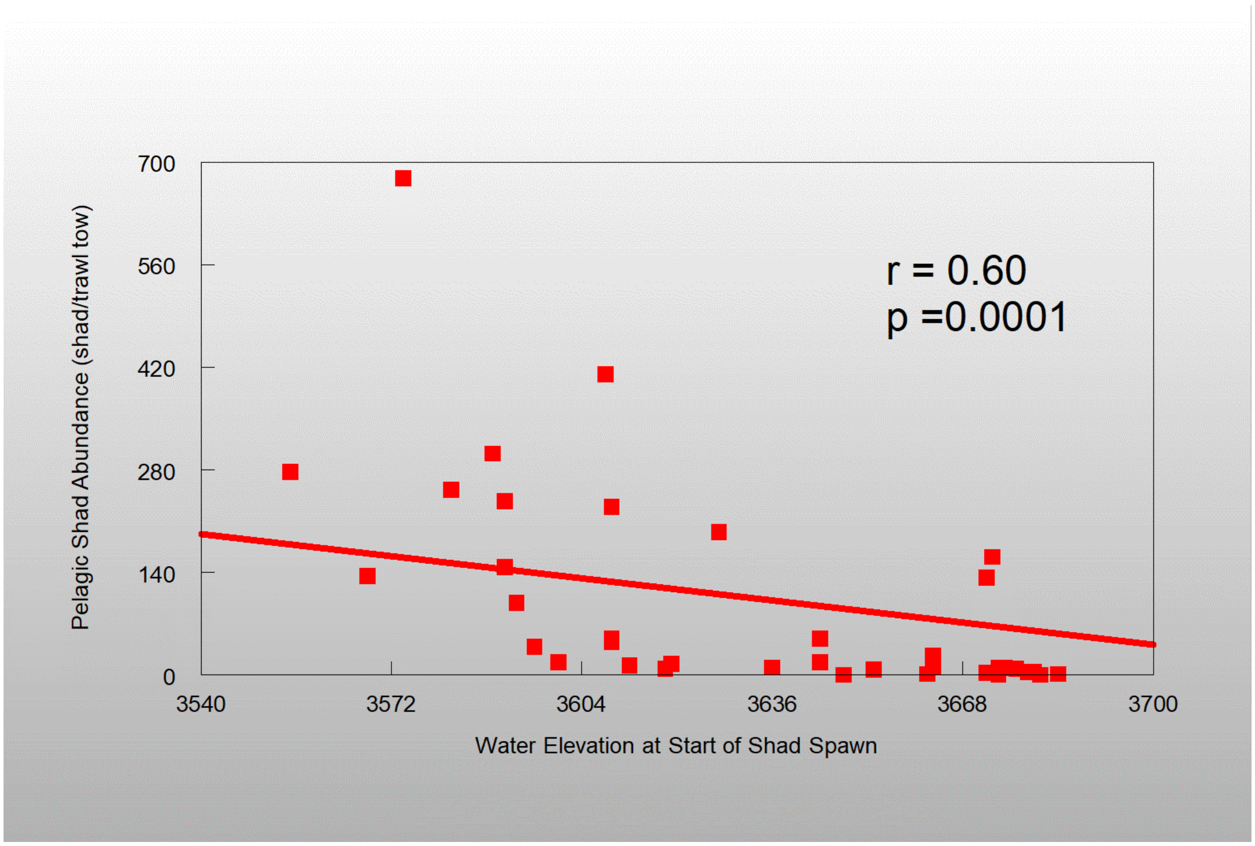


Figure 37. Relationship between water level elevations at the start of the shad spawn vs pelagic shad abundance (shad/trawl tow), lake-wide, Lake Powell, UT/AZ, 1982-2019.

Conclusion:

Shad are the lifeline for the Striped Bass population in Lake Powell and are an important component in the diet of numerous other sport fishes. Understanding the relationship between the shad species and Striped Bass remains one of the biggest challenges in managing the fisheries on Lake Powell. Certainly, the introduction of Gizzard Shad in 2000, while being a positive outcome for the fishery, complicated our understanding of the predator\prey dynamics. Nevertheless, since the lake-wide establishment of Gizzard Shad in 2003, 11 out of the last 17 years have been “boom” shad years as measured by the mid-water trawl survey and\or the acoustical survey. This easing of the drastic “boom\bust” cycle has been brought about largely by the ability of Gizzard Shad to successfully reproduce in the face of intense

Striped Bass predatory pressures. Vatland (2006) found that within 1.5-years Gizzard Shad in Lake Powell have outgrown the gape size of the average Striped Bass predator, which leaves a yearly abundance of brood size shad available for spawning. This further eases the predatory pressure on the Threadfin Shad population allowing for more survival and reproduction within that critical population.

The “bust” part of the predator/prey dynamics between shad and Striped Bass still appears to be strongly top-down driven, with intense predatory pressure periodically decimating the pelagic component of the shad population (Gustaveson 1999; Vatland 2006). However, the “boom” part of the cycle is still, for the most part, largely unknown. Various hydrological triggers have been examined but no definitive event or single condition appears to drive the successful reproduction and recruitment of shad into the pelagic zone during these “boom” years. However, this latest report suggests that lower water elevations at the start of the spawn coupled with larger increases during the spawn equate to larger open-water shad abundance in July and August. Furthermore, the ability of shad to sense when their population has reached a critical low level and respond with a big spawn event has been suggested by a least 1 researcher and should not be discounted.

The Quagga Mussel invasion has not had the feared effect on the shad species. Although more research is needed, it appears that the Threadfin Shad component are extremely flexible in their diet choices and can shift their diet to not only survive but reproduce and prosper. A USFWS research information bulletin noted that following a zooplankton crash, shad switched to a 92% - 100% phytoplankton diet and were able to maintain excellent condition and continue to reproduce (USFWS, 1986). Likewise, Ziebell (1983) showed experimentally that shad deprived of zooplankton can switch to benthos. This diverse and flexible feeding ability of Threadfin Shad, coupled with the resilience and bottom feeding behavior of adult Gizzard Shad, bodes well for the combined shad forage population well into the future.

Future researchers should examine multi-variable modeling techniques to more closely describe and predict the Lake Powell shad population dynamics. Since these dynamics have been altered greatly due to the establishment of Gizzard Shad, it behooves future researchers to consider separating pre and post Gizzard Shad data to add clarity to their individual contributions. Better integration of hydroacoustical data into pelagic shad abundance estimates would also be a worthy goal in better understanding true recruitment into this most important portion of the population. The utility of conducting larval net tows in the mid and up-lake regions is of questionable merit due to the difficulty of logistically accessing these regions on a weekly bases. Conducting these surveys should be limited to coincide with the angler survey, which is conducted every third year and when we have personnel and equipment stationed out of Bullfrog Marina.

STRIPED BASS

Introduction:

Plans to create a Striped Bass fishery at Lake Powell were underway well before the first stocking occurred in 1974. The popularity of Striped Bass as a sport fishery in lower reservoirs on the Colorado River and elsewhere in the continental US inspired managers to replicate their success in the newly impounded waters of Lake Powell. In 1968 Threadfin Shad were stocked in anticipation of this future Striped Bass introduction that by 1974 would be able to take advantage of the underutilized pelagic component of the Threadfin Shad population that by that time would have grown exponentially. In conjunction with this effort, UDWR developed a hatchery below Glen Canyon City (now Big Water, Utah) on Wahweap Creek for the purpose of producing Striped Bass fingerlings for annual stocking into Lake Powell. A total of 815,000 fingerlings were raised and stocked from this facility starting in 1974 through 1979 when stocking was curtailed due to the discovery of natural reproduction and recruitment in Lake Powell (Gustaveson 1999). The initial fry (2-5d) were brought into the hatchery from sources in California, North Carolina and Virginia, with the California fry being the most successful at producing fingerlings for stocking into the reservoir in the first two years (Hepworth et al 1976).

The unique hydrology of Lake Powell, and other lower Colorado River reservoirs, which allowed for eggs which settled on the bottom to hatch and survive, meant an almost unlimited cohort could be produced on any given year. Consequently, the first shad population crash occurred in 1980 as a burgeoning Striped Bass population exerted immense top-down pressure on the pelagic shad forage population. What followed was a boom and bust dynamic, the downside of which resulted in dire consequences for the health and survival for the adult Striped Bass population which depended on pelagic shad for survival. The “bust” part of the cycle could last for up to 6 years (1985-1990) although 3-4 years were more typical, with Threadfin Shad all but exterminated from the pelagic zones.

UDWR responded to the vicious “boom/bust” cycle by progressively implementing management actions that focused on reducing the overabundant Striped Bass population (Table 10). Most of these actions involved relaxing, and finally removing, creel limits. Multi-media and other promotional venues were also implemented to encourage and promote the harvest of Striped Bass.

In June of 2000, a survey team lead by Gordon Mueller of the United States Geological Survey (USGS) collected the first Gizzard Shad *Dorosoma cepedianum* in Lake Powell. This fish was collected in the inflow area of the San Juan arm of the lake at Piute Farms (RM-52) (Mueller et al. 2001). It is believed that the Gizzard Shad migrated out of Morgan Lake, an impoundment upstream on the San Juan River near Farmington, New Mexico. Apparently, these fish were inadvertently included along with several other non-target species in an earlier Fish and Wildlife Service (USFWS) stocking, and subsequently became firmly established in that reservoir (Mueller et al 2001). Expansion of the population was rapid and by 2002 they were the most collected species in the annual gill-net survey at the San Juan station and by 2003 they were being collected lake-wide at all of the annual fall gill-net survey stations (Blommer and Gustaveson 2017). This introduction was to have a profound effect on the status of the shad forage base and consequentially a drastic effect on the Striped Bass population.

Table 10. Management actions taken by UDWR to increase harvest of Striped Bass on Lake Powell, 1974-2019.

YEAR	Management Actions
1974	Fish Stocked, creel limit set at 2-fish
1983	Creel limit increased to 4-fish
1984	Creel limit increased to 10-fish
1990	Creel limit increased to 20-fish
1991	Telephone "Hotline" established
1993	Creel limits removed: unlimited harvest
1996	Chumming with anchovies allowed for Striped Bass
1997	Two pole stamp issued
2000	Wayneswords.com: private web site established to promote management objectives
2004	Bow and spear fishing allowed for Striped Bass
2019	Reciprocal stamp between UT/AZ removed

From strictly a forage enhancement point of view, the introduction and establishment of Gizzard Shad was fortuitous for many sport fish predators in Lake Powell, and Striped Bass in particular. The result was that the forage condition on the lake was greatly enhanced, and the classic "boom/bust" cycle, although not totally eliminated, was diminished and replaced by a more stable predator/prey balance.

Other challenges continue to effect the fishery. Mercury studies performed by DEQ and others resulted in a fish advisory being placed for portions of the reservoir in 2012. Striped Bass were one of the species that were included. Anecdotal evidence suggests that these advisories have had minimal effect on angling pressure.

Quagga Mussels veligers were discovered in 2012 with adults confirmed in 2013. This introduction has the potential to greatly change the forage dynamic on Lake Powell. Understanding the relationships between mussels, zooplankton, shad, and predators like Striped Bass is the next challenge for the effective management of the sport fishery at Lake Powell. To date, there appears to be no catastrophic consequences to the Striped Bass population at Lake Powell or at Lake Meade, where the mussel invasion is 5-years advanced. The primary productivity, zooplankton and general water quality monitoring program that is in place will take on greater importance in understanding these dynamics.

Trend Sampling:

The lake-wide mean catch of Striped Bass in the annual fall gill-net survey has statistically remained fairly consistent since the initial decline following introduction (Figure 38). The 2015 catch was the last time the catch of Striped Bass spiked: averaging 211 fishes/station (SD = 109) with most of the catch originating from the up-lake station at Good Hope Bay. By contrast, the last 4-years the gill-net catch of Striped Bass averaged 81 fishes / station (SD = 7.6). This compares with the historical mean catch of 99.7

fishes/station (SD = 48, n = 35). Over the life of the survey (1981-2019), yearlings returned strongest to the catch followed by age II and older with YOY being the least captured.

However, during those years when Striped Bass return strongly to the annual gill-net survey, The composition of the catch favored YOY and yearling fishes over age II and older. Although it might have been an anomaly, up until 1996 yearlings dominated during peak capture years with YOY tending to dominate from 1996 to present, with 1997 and 2006 being the exception.

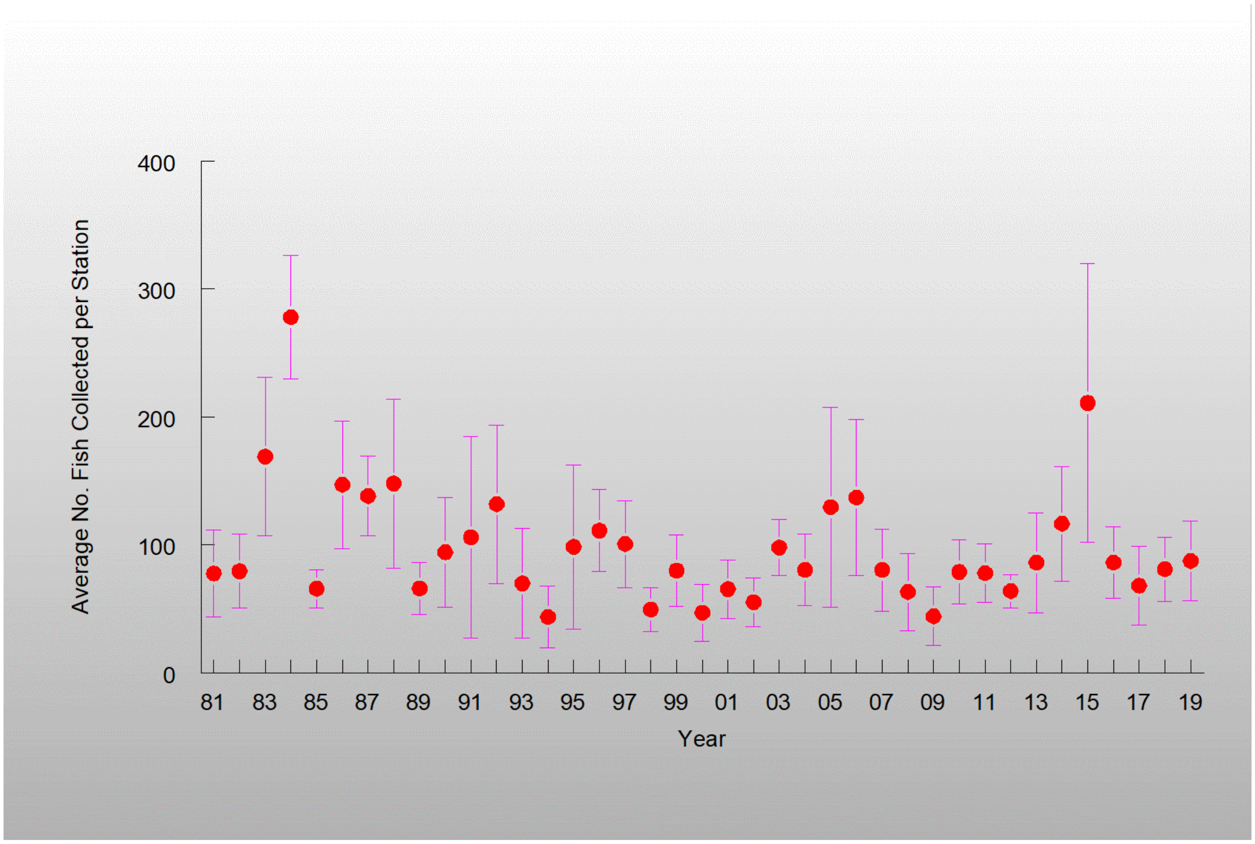


Figure 38. Average catch of Striped Bass per station from the annual gill-net survey with SE, Lake Powell, UT/AZ 1981-2019.

While Striped Bass are well distributed lake-wide, the annual fall gill-net survey has historically collected the most fishes from the up-lake sampling site at Good Hope Bay. The mean total catch over the last 39 years was 179 fishes (SD = 109) from Good Hope Bay compared with 114 (SD = 74) from Wahweap, followed by 60 (SD = 38) at the San Juan, and 43 (SD = 60) at the Rincon (Figure 39). The higher productivity and increased foraging opportunities characteristic of sites closer to the inflows would appear as logical choices to harbor greater portions of the Striped Bass population. The fact that the Wahweap station, which is the farthest from the inflows and the least productive in terms of pelagic shad abundance, accounts for the second highest mean catch of Striped Bass from the annual fall gill-net survey is harder to explain. Gustaveson (1999) stated that although Striped Bass can spawn throughout the lake they have a strong tendency to migrate towards the inflows and outflows to spawn, and the annual fall gill-net survey may be reflecting these concentrations at either end of the reservoir. It should be remembered that Striped Bass are a highly mobile species and can move great distances in search of food or seeking spawning opportunities. Striped Bass tagging studies performed on Lake Powell in the early 1980's showed that the average distance traveled between tagging and recapture was 29.4 miles with the average duration between tagging and recapture being 10.75 months. One tagged fish moved 90 miles in the space of 5 weeks (Gustaveson 1999).

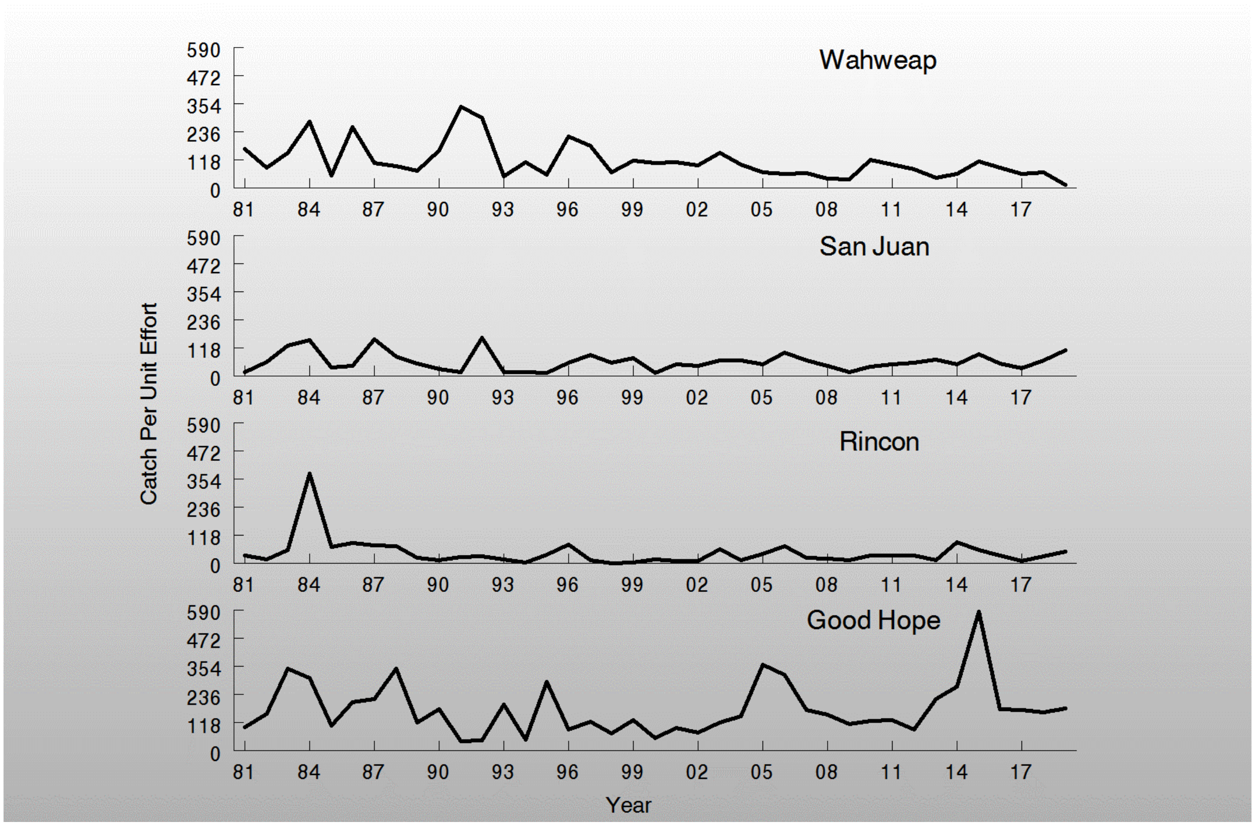


Figure 39. Total catch per standard sample of Striped Bass from the annual fall gill-net survey, Lake Powell, 1981-2019.

Recruitment:

Reproduction and recruitment of YOY Striped Bass into the population is best measured by the fall gill-net survey. Following the record catch of YOY in 2015 of 4.62 fishes (fishes/1000 ft^2 gill net/12 hr set) the previous 4 years mean catch was only 0.90 (SD = 0.29), which was below the historical average of 1.2 fishes (SD = 1.25; Figure 40). Interestingly, the catch of YOY Striped Bass from the annual fall gill-net survey is highly correlated (r = .64, p < .0001: Pearson Corr) with the catch of open water shad from the

July/August mid-water trawl survey (Figure 41). Possibly YOY Striped Bass survival and recruitment was enhanced by the abundant presence of readily available shad forage. However, it should be noted that Striped Bass is not the only sport fish on Lake Powell that exhibit high capture rates during peak pelagic shad years. It is speculated that increased fish activity due to the abundance of shad forage could also result in more gill net captures of actively foraging fishes.

The annual fall electrofishing survey also samples YOY fishes, but has shown a lack of precision when detecting YOY peaks, with peak YOY Striped Bass catches rarely occurring at more than a single station on any given year (Figure 42). Furthermore, regression analysis fail to show any relationship between this catch and that of YOY Striped Bass captured in the annual fall-gill net survey or with the abundance of pelagic shad sampled in the mid-water trawl survey. Electrofishing and gill netting were in agreement only in 1996 and 2005 in predicting peak YOY Striped Bass abundance. The littoral type of habitat sampled in the annual fall electrofishing survey does not appear conducive to the accurate detection and representation of the strength of a YOY Striped Bass year class.

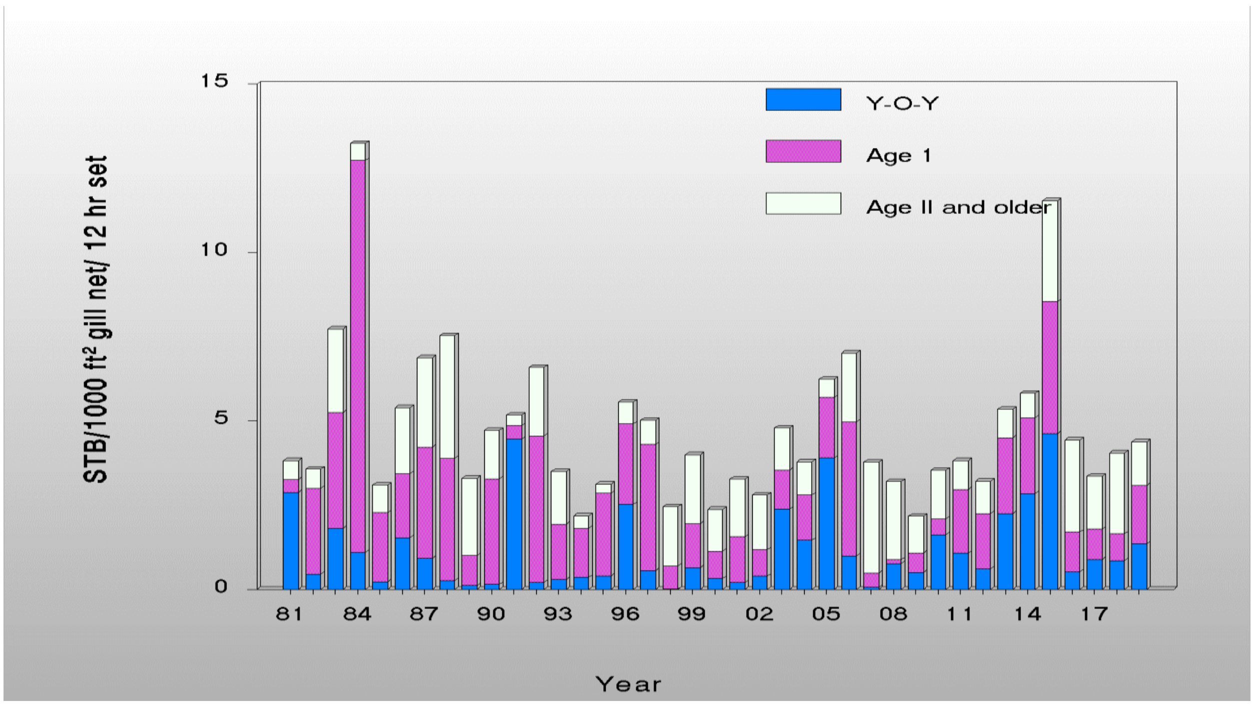


Figure 40. Abundance of various age classes of Striped Bass collected in the annual gill net survey, Lake Powell, 1981-2019.

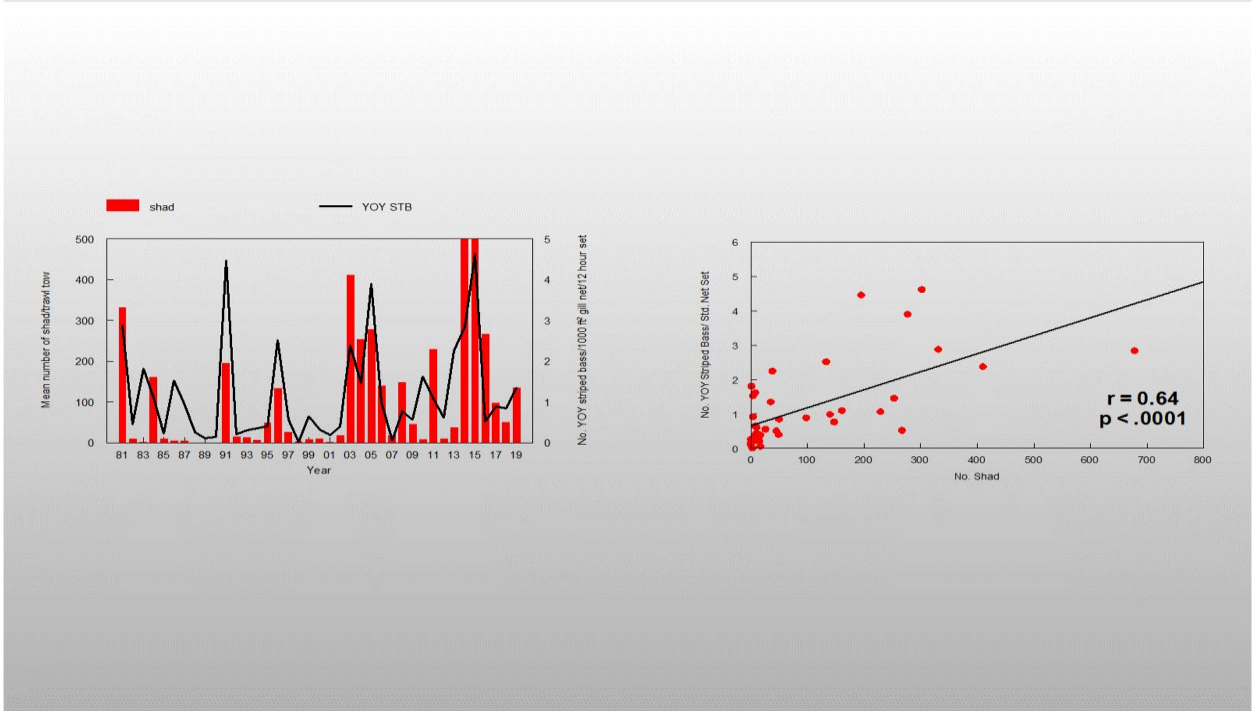


Figure 41. Relationship between the catch of YOY Striped Bass in the annual gill-net survey and the mean number of shad/trawl tow, Lake Powell, 1981-2019.

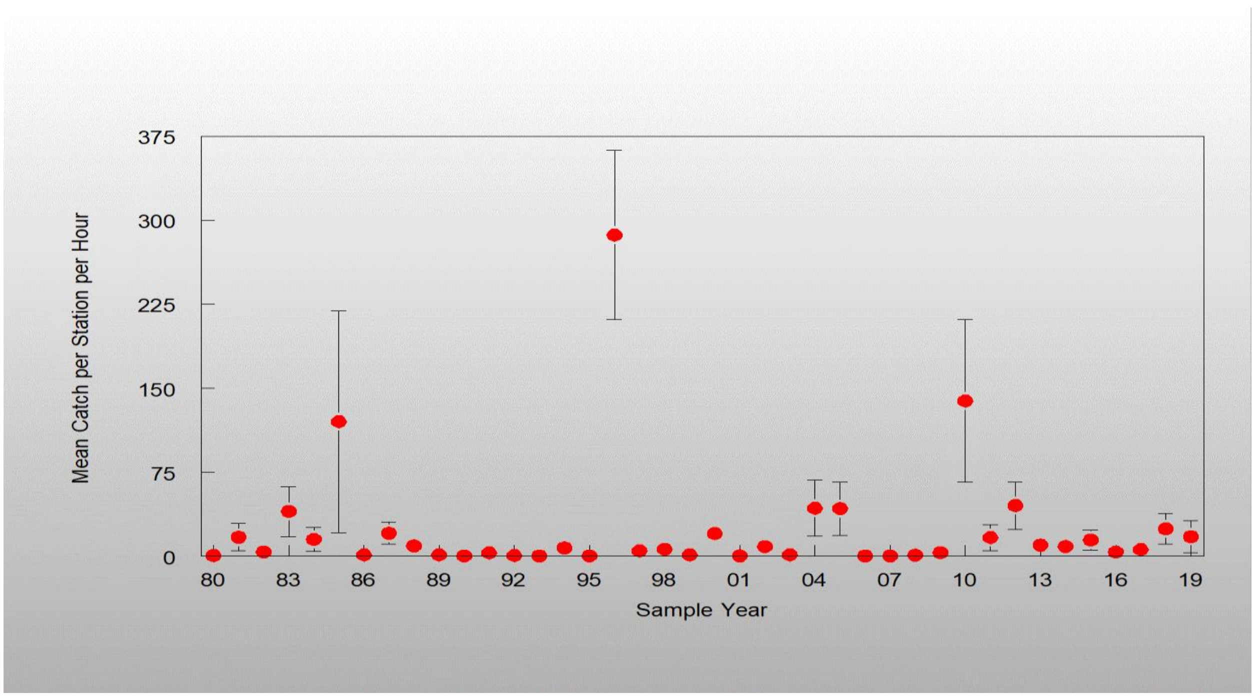


Figure 42. Mean catch\hour of YOY Striped Bass collected in the annual fall electrofishing survey with SE, Lake Powell, 1980-2019.

Diet:

Striped Bass are unique in that as adults they are dependent on Threadfin and Gizzard Shad to maintain growth and survive. Gustaveson (1999) stated that Striped Bass typically begin life feeding on zooplankton, but convert to larval shad upon reaching a total length of 95mm – 100mm: which occurs in their first summer of life. In the absence of shad forage, Striped Bass can remain on a zooplankton diet and thrive throughout their second year but after that growth stops.

Stomach analysis from Striped Bass collected in the fall gill nets reflected the dependence on shad to the diets of older fish. Throughout the history of the survey shad have averaged 66% occurrence in the stomachs of Striped Bass that contained food items while zooplankton represented 22% occurrence. The next most occurring food item was unidentified species which represented only 9% of the stomachs and was suspected in most cases to be unidentified shad species. Crayfish accounted for 4% occurrence historically and were found most often in adult Striped Bass in poor condition. Centrarchids accounted for only 2% occurrence (Table 11).

The importance of shad in the Striped Bass diet cannot be understated with shad occurring in stomachs at significant levels even during years when pelagic shad abundance is low. Even with limited pelagic shad abundance in 2010, 2012, 2013, and 2018 between 53% - 74% of the Striped Bass stomachs that contained food items had shad present. Additionally, adult Striped Bass stomachs collected in the annual fall gill-net survey are less likely to be empty when pelagic shad abundance is high ($r=.45$, $p=0.01$, Pearson Corr; Figure 43). Moreover, the percent occurrence of shad in the stomachs of Striped Bass captured in the annual gill-net survey is also positively correlated with pelagic shad abundance ($r=.51$, $p=0.01$, Pearson Corr; Figure 44).

Gizzard Shad, since their appearance in Lake Powell in 2002, have steadily increased their presence in the pelagic zone. However, their presence in the stomachs of Striped Bass collected in the annual fall gill-net survey have remained at low levels, typically ranging from 0% to 9% of identifiable shad species (Blommer and Gustaveson 2016). No Gizzard Shad were positively identifiable in Striped Bass stomachs collected in 2013-2015 but 1% of the Striped Bass stomachs that contained food items had identifiable Gizzard Shad in 3 of the previous 4-years. Blommer and Gustaveson (2016) stated that anecdotal evidence suggests that the contribution of Gizzard Shad to the diet of Striped Bass is far greater than empirical evidence suggests. Angler caught Striped Bass that were actively surface feeding on shad schools in July of 2016 were dissected and contained larval Gizzard Shad. We postulate that Striped Bass utilize Gizzard Shad throughout the summer months when the shad are available in the pelagic zone and before they migrate to near-shore habitats in the fall months. The increasing portion of Gizzard Shad in recent shad booms that correlate with strong Striped Bass condition also suggests that Gizzard Shad are an important component of Striped Bass diets. Comparing the % occurrence of shad in Striped Bass stomachs for pre vs post Gizzard Shad establishment show shad present in 75% of stomachs that contained food after Gizzard Shad establishment (2004) versus only 62% before. This may also suggest that some of the unidentifiable shad in Striped Bass stomachs were Gizzard Shad.

Table 11. Percent occurrence, and number (n) of major food items in the stomachs of Striped Bass collected in the annual gill-netting survey, Lake Powell, 1985-2019.

			% OCCURRENCE(N)				
YEAR	# Checked	# w/Food(%)	Crayfish	Shad	Zooplkt	Centrarchids	Other
1985	349	184 (53)	8 (14)	0	82 (150)	3 (6)	8(14)
1986	424	195 (46)	15 (29)	36 (71)	48 (93)	1 (2)	5 (9)
1987	359	179 (50)	21 (37)	24 (43)	51 (91)	2 (4)	2 (4)
1988	373	182 (49)	15 (27)	11 (20)	69 (125)	1 (2)	11 (20)
1989	246	140 (57)	11 (16)	35 (49)	52 (73)	1 (2)	5 (6)
1990	179	107 (60)	12 (13)	73 (78)	13 (14)	2 (2)	5 (5)
1991	140	73 (52)	4 (3)	86 (63)	4 (3)	1 (1)	3 (2)
1992	163	66 (40)	1 (1)	68 (45)	23 (15)	0	6 (4)
1993	212	117 (55)	6 (7)	75 (88)	14 (16)	4 (5)	4 (4)
1994	218	122 (56)	4 (5)	61 (75)	33 (40)	1 (1)	2 (2)
1995	262	165 (63)	1 (2)	96 (159)	1 (2)	0	2 (3)
1996	447	255 (57)	0	82 (208)	18 (46)	1 (3)	1 (1)
1997	387	192 (50)	1 (1)	66 (126)	32 (61)	1(1)	1 (1)
1998	192	69 (36)	4 (3)	61 (42)	25 (17)	5 (4)	4 (3)
1999	311	200 (64)	1 (1)	83 (166)	15 (30)	1 (2)	3 (5)
2000	181	90 (50)	1 (1)	88 (77)	17 (15)	0	0
2001	249	88 (35)	1 (1)	35 (31)	43 (38)	3 (3)	19 (17)
2002	216	100 (46)	1 (1)	82 (82)	6 (6)	1 (1)	10(10)
2003	NA	-	-	-	-	-	-
2004	205	127 (62)	0	77 (98)	5 (6)	0	21(27)
2005	326	224 (69)	1 (1)	83 (135)	43 (69)	0	12(19)
2006	315	162 (51)	4 (6)	73 (118)	16 (26)	0	7 (11)
2007	315	152 (48)	3(5)	61(92)	3(5)	1 (1)	32(49)
2008	177	110 (62)	1(1)	87(96)	7(8)	1(1)	7(8)
2009	119	57 (48)	0(0)	67(38)	19(11)	7(4)	9(5)
2010	308	134 (43)	1(2)	53(71)	23(31)	5(6)	19(26)
2011	205	146 (71)	1(1)	97(141)	3(4)	11(16)	9(13)
2012	231	95 (41)	3(3)	63(60)	8(8)	1(1)	25(24)
2013	342	199 (58)	0	74(147)	23(45)	0	7(14)
2014	457	257(56)	1(1)	74(191)	12(32)	1(1)	14(35)
2015	469	327(70)	1(2)	89(291)	9(29)	2(7)	7(23)
2016	324	191 (59)	2(3)	75(144)	15(28)	2(4)	9(17)
2017	183	105(57)	2(2)	67(70)	12(13)	8(8)	16(17)
2018	312	150(48)	7(11)	73(109)	9(13)	3(4)	16(24)
2019	257	195(76)	0	91(178)	0	3(5)	8(15)
Mean %			4%	66%	22%	2%	9%

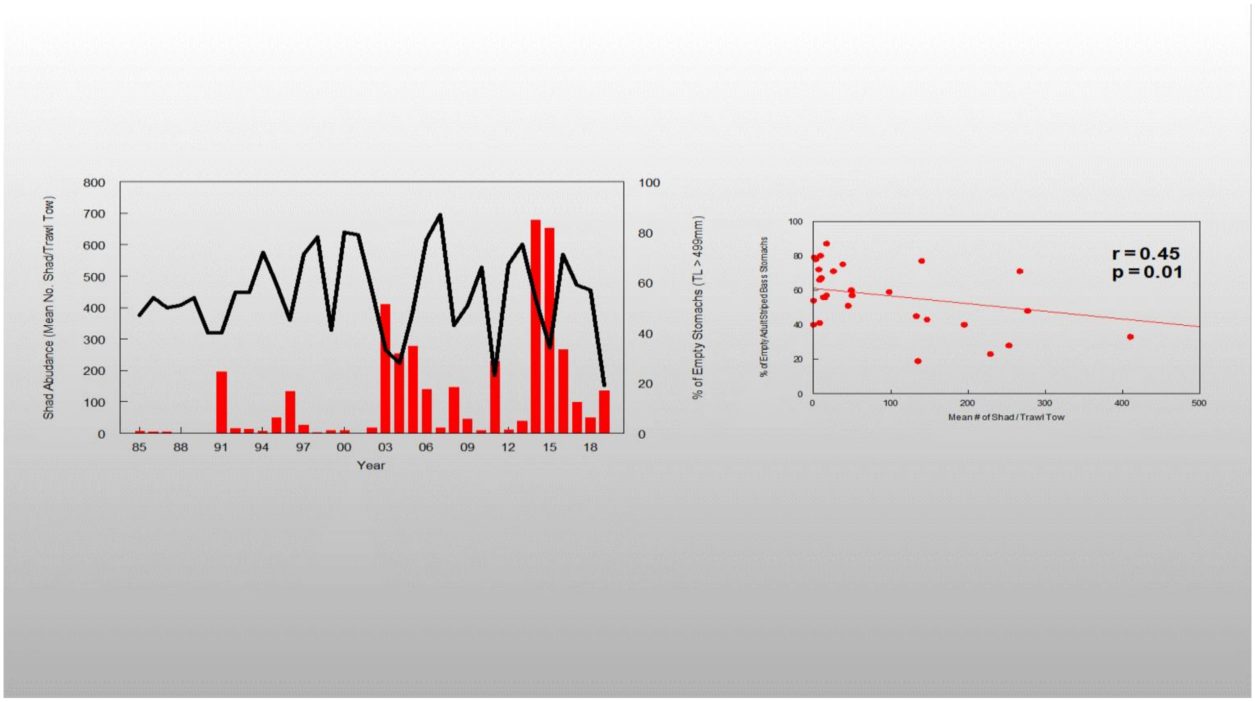


Figure 43. Relationship between the percent of empty adult Striped Bass stomachs (TL $\geq$ 500 mm) collected in the annual fall gill-net survey and the abundance of shad collected from the July/August mid-water trawl survey, 1985-2019.

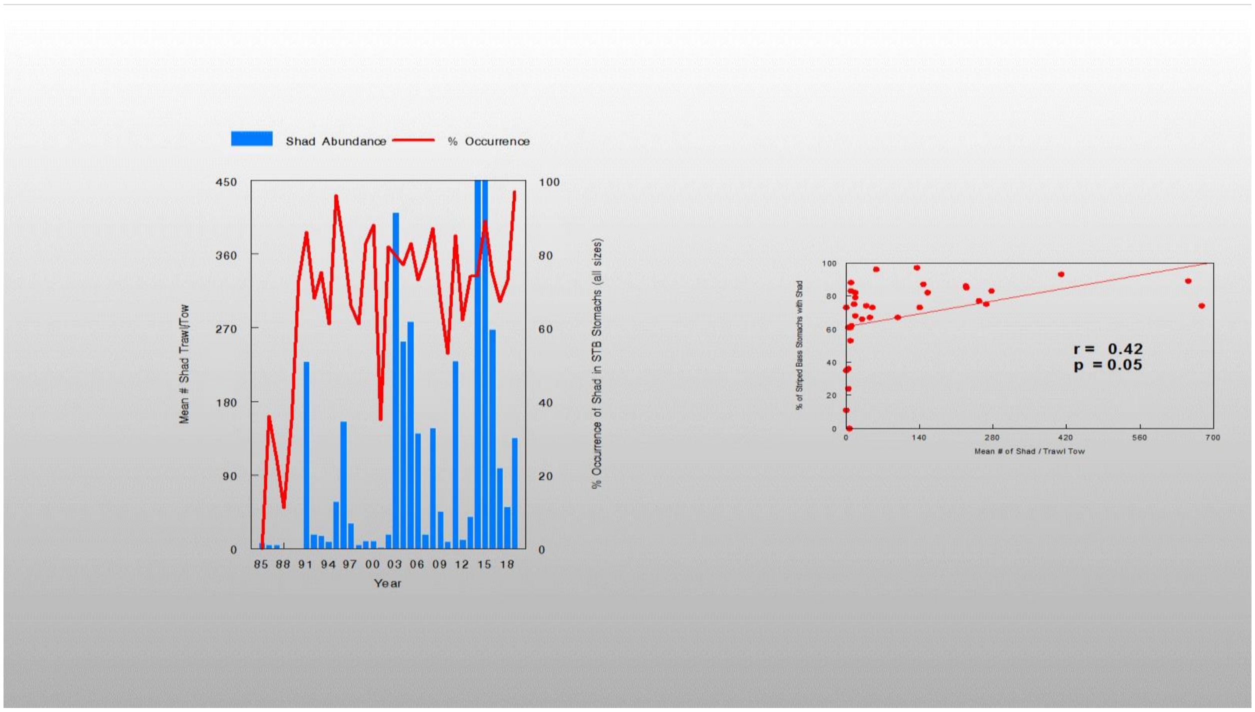


Figure 44. Relationship between the % occurrence of shad in the stomachs of Striped Bass captured in the annual fall gill-net survey and the abundance of shad collected in the July/August mid-water trawl survey, 1985-2019.

Condition:

Past the yearling stage, Striped Bass in Lake Powell are dependent upon shad forage for growth and reproductive success. Abundant plankton resources are more than sufficient to maintain and grow YOY and yearling Striped Bass but further growth and reproductive success relies on strong numbers of shad particularly in the pelagic zone. Consequentially, juvenile Striped Bass condition (Kfl) almost always is higher than that of adults, averaging 1.27 (SD = 0.12) historically, recording a peak of 1.55 in 1984 and a low of 1.1 in 2007. Meanwhile, adults (TL $\geq$ 500mm) had a mean historical condition of 1.05 (SD = 0.18), with a historic peak of 1.38 in 1991 and a low of 0.68 in 2007. Adult Striped Bass condition only exceeded the average in 2019 over the previous 4 years while juveniles exceeded the historical average 3 times during the same period (Figure 45).

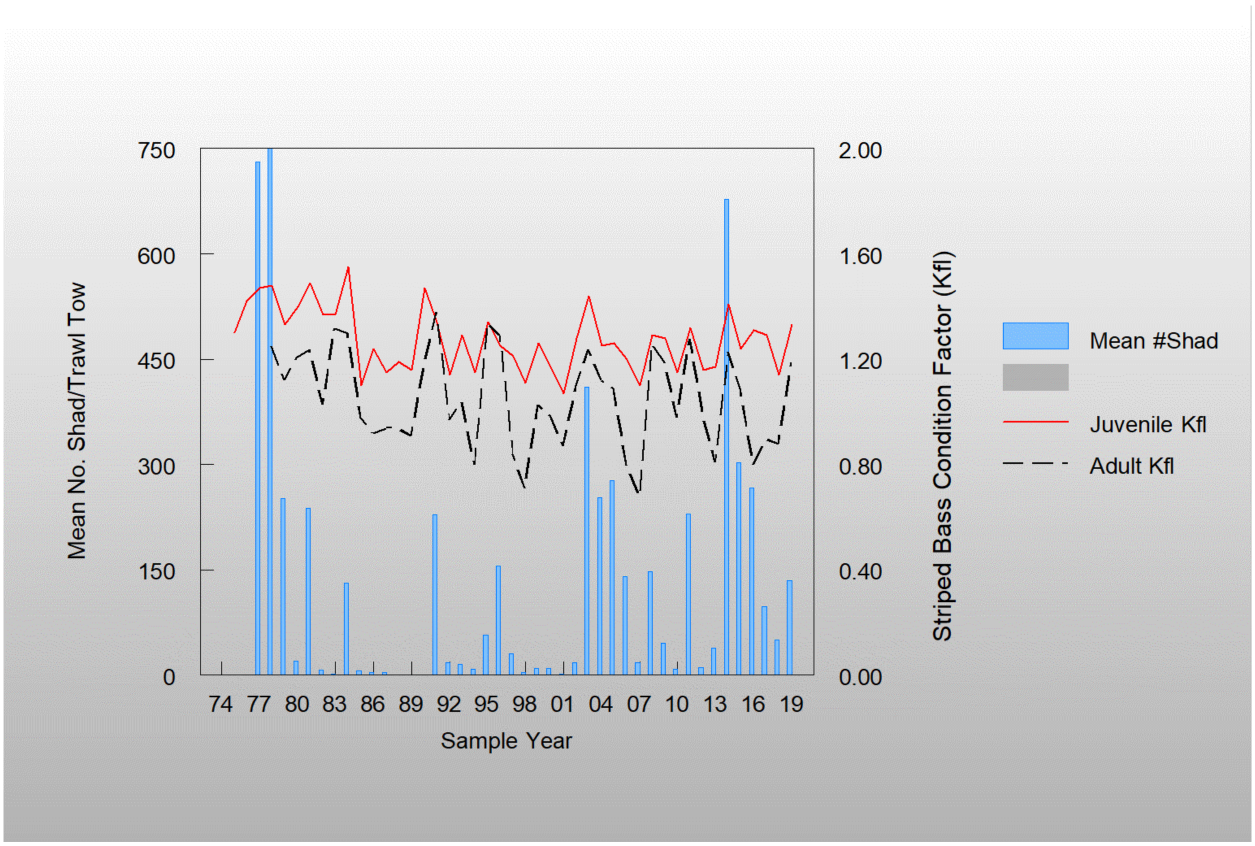


Figure 45. Relationship between pelagic shad abundance collected from the mid-water trawl survey (July/August) and the mean condition (Kfl) of Striped Bass collected in the annual fall gill-net survey, Lake Powell, 1976-2019.

Spikes in adult Striped Bass condition were always associated with higher levels of pelagic shad occurring mostly on the same year but occasionally on the year prior. Correlation analysis (Pearson, SAS) confirms this relationship ($r = .40$, $p = .01$; Figure 46). Likewise, juvenile Striped Bass condition is also closely tied in with the abundance of pelagic shad with open water shad peaks resulting in immediate and positive improvement in condition ($r = .49$, $p = .01$; Figure 47).

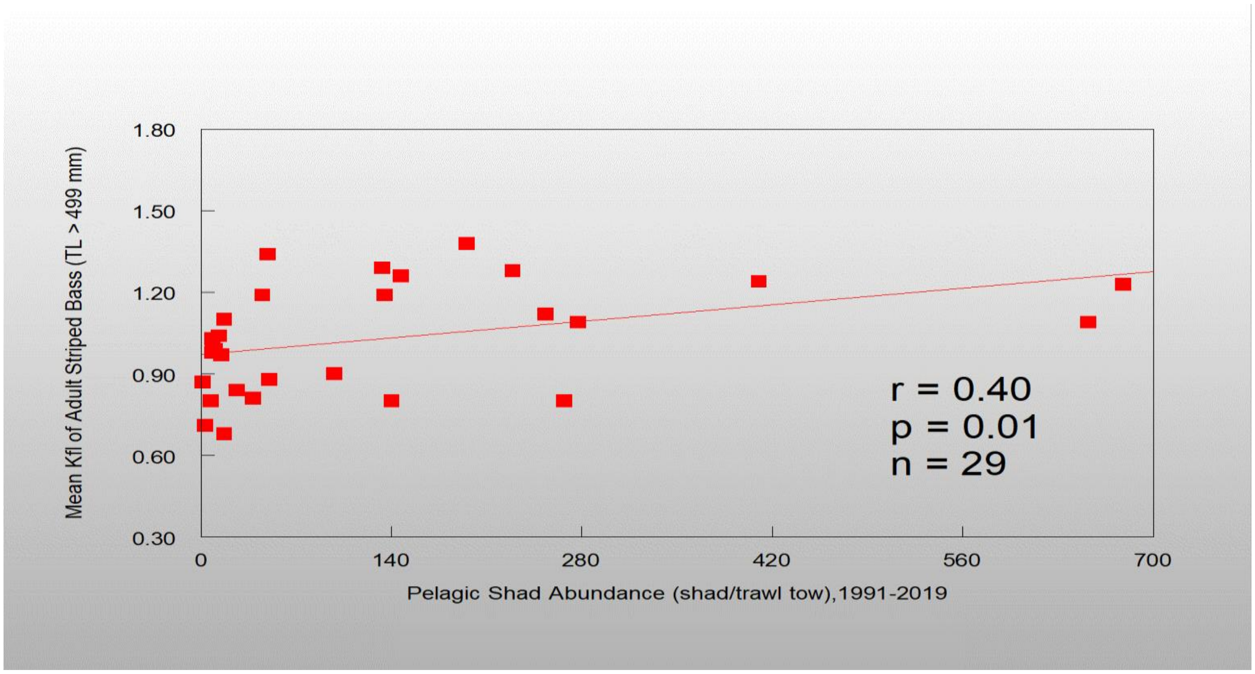


Figure 46. Relationship between pelagic shad abundance collected in the mid-water trawl survey (July/August) and the mean condition (Kfl) of adult Striped Bass (TL > 499mm) collected in the annual fall gill-net survey, Lake Powell, 1991-2015.

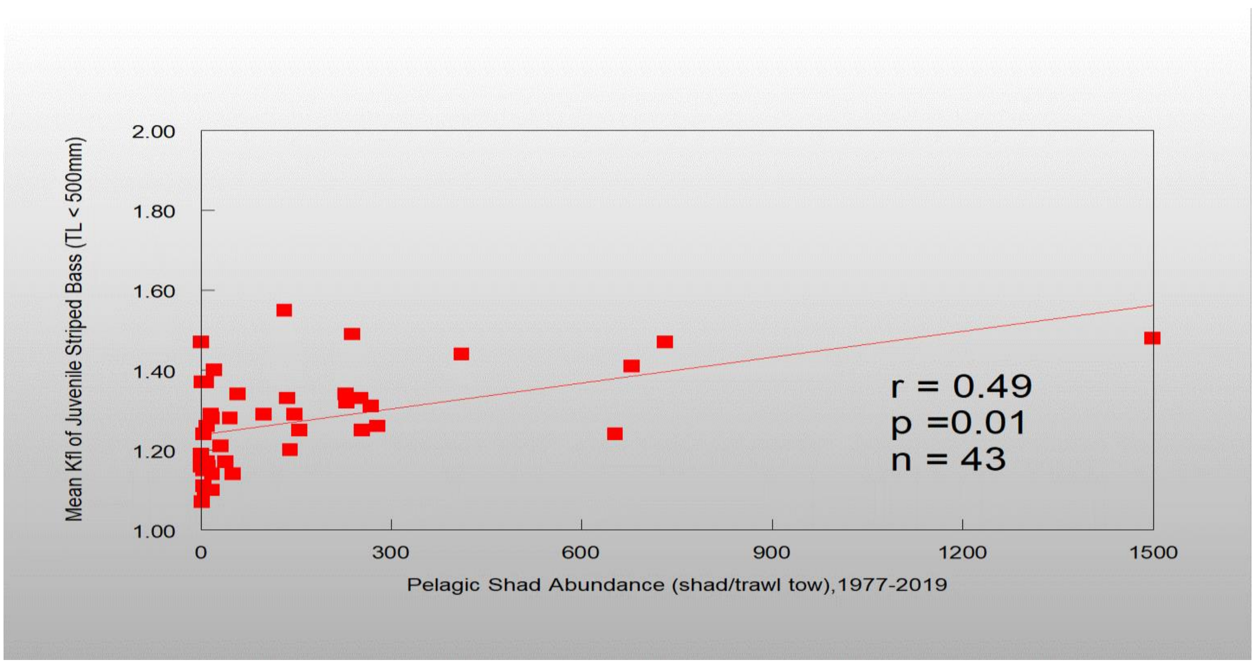


Figure 47. Relationship between pelagic shad abundance collected in the mid-water trawl survey (July/August) and the mean condition (Kfl) of juvenile Striped Bass (TL < 500mm) collected in the annual fall gill-net survey, Lake Powell, 1977-2019.

Condition (Kfl) of Striped Bass (all sizes) followed the same pattern found in the catch with the Good Hope station having the most Striped Bass and also having the best condition followed by Wahweap and the San Juan vying for second, followed by the Rincon. With Striped Bass being a highly mobile species, allowing them to move easily throughout the lake, it appeared that areas with the most Striped Bass were also areas that allowed for them to achieve the best condition. These conditions appeared to exist for all sizes of Striped Bass, adults as well as sub-adults (Table 12). Although analysis of variances failed to detect a statistically significant difference among sites at the 5% significance level. We also compared the mean condition of Striped Bass (all sizes) between pre and post Gizzard Shad periods to see if the introduction and establishment of Gizzard Shad had resulted in an increase in Striped Bass condition but analysis of variance testing failed to show a significant difference at the 0.01 level.

Table 12. Condition (Kfl) of Striped Bass collected in the annual fall gill-net survey, Lake Powell, 1991-2019.

Striped Bass TL(mm)	Wahweap (SD)	Rincon (SD)	San Juan (SD)	Good Hope (SD)
>499mm (adult)	1.04 (.25)	1.0 (.24)	1.01 (.20)	1.04 (.20)
< 500mm (sub-adult)	1.21 (.14)	1.19 (.16)	1.26 (.11)	1.26 (.09)
All sizes	1.12	1.10	1.13	1.15

Age & Growth:

Striped Bass scales were collected yearly from fishes collected in the annual fall gill-net survey. Scale data were analyzed using the Frasier-Lee method with Ball State FishBC software. A standard Y-intercept of 55mm was used in the calculations.

Striped Bass growth continues to be modest when estimated from scales collected from 2016-2019. Mean total lengths were back-calculated at 209mm, 369mm, 441mm, 493mm, 517mm, 536mm, and 959mm for scales collected in 2019 (Table 13). Striped Bass growth was significantly greater the first decade following introduction but declined and stabilized beginning in 1980. The main exception was the 1985-1989 period when Threadfin Shad forage reached a historical low level and Striped Bass growth declined sharply across the age classes (Table 14). The introduction of Gizzard Shad appears to have resulted in a modest increase in growth when comparing scales back-calculated from pre and post Gizzard Shad introduction. Furthermore, the establishment of Quagga Mussels have not shown to have effected either growth or cohort strength up to this point.

Table 13. Average back-calculated lengths for each age class of Striped Bass collected from the annual gill-netting survey, Lake Powell, UT. 2019. (Assumes margin is annulus and no additional growth for the year).

YEAR CLASS	AGE	N	ANNULUS 1	2	3	4	5	6	7
2019	0^+	51	233						
2018	1^+	74	192	382					
2017	2^+	20	202	337	428				
2016	3^+	15	232	387	455	502			
2015	4^+	16	200	365	455	493	521		
2014	5^+	6	209	306	413	466	505	532	
2003	6^+	1	127	189	404	503	527	558	595
AVERAGE			209	369	441	493	517	536	595
N ( )		(183)	(183)	(132)	(58)	(38)	(23)	(7)	(1)

Table 14. Back-calculated growth of Striped Bass in Lake Powell, UT. 1975-2019. Mean estimated total length (mm), with age classes not separated. YOY is considered age class 1.

Years	Age Class 1	2	3	4	5	6	7	8	9	10
1975-1979	253	440	564	663	690					
(n)	(939)	(324)	(111)	(41)	(1)					
1980-1984	227	429	555	634	673	702	735	815	967	946
(n)	(865)	(786)	(680)	(587)	(422)	(285)	(112)	(22)	(4)	(3)
1985-1989	148	269	386	438	551	604	707			
(n)	(597)	(473)	(345)	(179)	(50)	(11)	(1)			
1990-1997	202	356	434	478	511	542	558	603	635	650
(n)	(590)	(311)	(178)	(114)	(71)	(38)	(17)	(2)	(1)	(1)
2006	202	362	456	519	554	580	567			
(n)	(210)	(178)	(98)	(52)	(42)	(27)	(6)			
2009	214	372	438	492	518	584				
(n)	(119)	(88)	(55)	(50)	(23)	(2)				
2012	259	395	480	528	563	588				
(n)	(199)	(169)	(57)	(41)	(29)	(9)				
2015	212	370	459	514	544	563	566			
(n)	(72)	(99)	(37)	(21)	(12)	(10)	(2)			
2019	209	369	441	493	517	536	595			
(n)	(183)	(132)	(58)	(38)	(23)	(7)	(1)			

Angler Survey:

In 2018, 33% of the anglers targeted Striped Bass compared with 28% the previous survey (2015). This also compared favorably with the next most popular species (Smallmouth Bass) which accounted for 24%. Down-lake anglers targeted Striped Bass 39% of the time while up-lake anglers targeted Striped Bass 23%. Since 1985, Striped Bass have been the species most often targeted in all but 4 of the last 12 surveys when compared to black bass (Largemouth Bass and Smallmouth Bass combined). Historically, between 17% - 41% of Lake Powell anglers target Striped Bass.

In 2018 Striped Bass made up 37% of the catch, second to only Smallmouth Bass (43%). This compares with previous surveys where Striped Bass made up 63%, 41%, 42% and 33% of the total catch for 2006, 2009, 2012 and the 2015 survey respectively. The declining portion of Striped Bass in the catch shows the increasing importance of black bass, and Smallmouth Bass in particular, to the fishery. An estimated 609,272 Striped Bass were caught by anglers in 2018 compared with 909,989 caught in the previous survey (2015) and the record catch of 1.6 million caught in 2006. Slightly more (53%) Striped Bass were caught down-lake than were up-lake (47%). Similar to the previous survey, July and August had the strongest total catch at 111,774 and 239,451 fishes respectively (Table 15).

Table 15. Total catch of Striped Bass by area and month estimated from the 2018 angler survey at Lake Powell, UT.

Area	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
Down-lake	14,808	47,494	77,202	24,421	97,519	37,192	25,937	324,573
Up-lake	3,198	1,782	19,692	87,353	141,932	24,857	5,885	284,699
Total	18,006	49,276	96,894	111,774	239,451	62,049	31,822	609,272

Because pressure was lacking in 2018, the overall catch of Striped Bass was also suppressed: but that was not to say that the fishing was bad. In fact, angler success in 2018 for Striped Bass was excellent with a lake-wide catch rate of 0.84 fishes/hr. This rate surpassed the 0.56 fishes/hr from the 2015 survey and was exceeded only by the 0.90 fishes/hr and 1.09 fishes/hr recorded in 2012 and 2006 respectively (Table 16). Similar to the 2015 survey, July and August afforded the best fishing with up-lake anglers edging out down-lake ones 0.88 fishes/hr to 0.79 fishes/hr (Table 17). There has been a marked improvement in fishing success that was first noticed during the 2006 angler survey that has continued through the latest survey. This may be due to the establishment of Gizzard Shad in the fishery.

Table 16. Catch rates (fish/hr) for Striped Bass by month and year, Lake Powell, UT. 1988-2018.

Year	Apr	May	Jun	Jul	Aug	Sep	Oct	Wt/Avg.
1988	0.23	0.42	0.40	0.33	0.52	0.41	0.37	0.40
1991	0.01	0.04	0.10	0.04	0.16	0.03	0.20	0.07
1996	t	0.10	0.05	0.08	0.12	0.10	0.04	0.06
1997	0.01	0.05	0.15	0.19	0.34	0.57	0.96	0.31
2000	0.12	0.20	0.30	0.18	0.48	0.23	0.30	0.24
2003	0.09	0.04	0.07	0.22	0.40	0.23	0.16	0.16
2006	2.86	0.78	1.25	1.07	1.70	1.19	1.22	1.09
2009	0.06	0.11	0.30	0.53	0.77	0.43	0.21	0.40
2012	0.16	0.46	0.53	1.16	1.34	0.95	1.24	0.90
2015	0.17	0.15	0.46	0.74	0.70	0.61	0.79	0.56
2018	0.29	0.49	0.62	1.17	1.70	0.56	0.48	0.83
Avg.	0.40	0.26	0.38	0.52	0.75	0.48	0.54	0.46

Table 17. Catch rates (fish/hr) of Striped Bass by month and area, estimated from the 2018 angler survey at Lake Powell, UT.

Area	Apr	May	Jun	Jul	Aug	Sep	Oct	Wt/Avg.
Down-lake	0.57	0.63	0.77	0.55	1.80	0.62	0.52	0.79
Up-lake	0.09	0.07	0.35	1.70	1.64	0.49	0.34	0.88
Wt/Avg.	0.29	0.49	0.62	1.17	1.70	0.56	0.48	0.83

The long term strategy for managing Striped Bass in Lake Powell continues to be maximizing the harvest. To this end 470,427 stripers were harvested in 2018: representing 77% of the catch (Table 18). The percent harvested was similar to the 78% of the Striped Bass catch that was harvested in 2015 but below the 94% and 86% that was harvested in 2012 and 2009 respectively. The % of the catch that was harvested was similar between down-lake (79%) and up-lake (75%) anglers.

Table 18. Percent of Striped Bass catch that was harvested, by area and month, estimated from the 2018 angler survey at Lake Powell, UT.

Area	Apr	May	Jun	Jul	Aug	Sep	Oct	Wt/Avg.
Down-lake	77	79	90	98	65	94	64	79
Up-lake	93	71	49	57	86	88	85	75
Wt/Avg.	80	82	82	66	77	92	68	77

Conclusion:

Striped Bass continue to be the main draw in terms of bringing anglers to Lake Powell. As a world class fishery they do not disappoint. The complete removal of catch and bag limits, and unique desert grandeur combine to make Lake Powell unsurpassed as an angling destination. Over 600,000 Striped Bass were caught by anglers in 2018 for an excellent catch rate of 0.83 fish/hr. This was historically the third highest catch rate achieved at Lake Powell for the Striped Bass fishery. UDWR management strategy continues to focus on maximizing the harvest of Striped Bass. Anglers harvested 77% of the catch in 2018 which, although good, pales in comparison to the 94% harvested in 2012. Additional work could be done to refocus on increasing harvest.

The well documented and understood predator-prey cycle that existed between Striped Bass and Threadfin Shad was expanded in 2000 to include Gizzard Shad. This new forage mix, over time, has much reduced the cyclic forage swings and brought more consistency to the Striped Bass fishery. Population numbers have remained constant as measured by the annual gill-net survey with condition varying by the availability of pelagic shad numbers. Growth as measured from scale analysis has shown modest improvements following Gizzard Shad establishment. Angling success, as measured by catch rates also improved following Gizzard Shad establishment.

The discovery of Quagga Mussels in 2012 and their subsequent rapid expansion have been an ongoing concern for Lake Powell fisheries. However, to date, in terms of population numbers (all age classes), growth and condition, the Striped Bass population has not shown any declines that would suggest that Quagga Mussels are having an impact. Lake Meade, whose Quagga Mussel infestation is 5-years advanced over Lake Powell, also has not reported a decline in their Striped Bass fishery. Forage species appear to be holding their own and still providing the resources necessary to sustain and allow Striped Bass to flourish.

Striped Bass continue to excite anglers at Lake Powell and timely management is imperative to continue to provide the first class fishery that the angling public has grown to expect.

SMALLMOUTH BASS

Introduction:

The decision to stock Lake Powell with Smallmouth Bass came after it was evident that the popular Largemouth Bass and Black Crappie fisheries were declining on a lake-wide bases. The flooded terrestrial vegetation that, up until the 1980's, had supported these species was much diminished as the reservoir aged. The affinity of Smallmouth Bass to rocky substrate was a perfect match for Lake Powell where this ubiquitous habitat dominates. UDWR began stocking Smallmouth Bass fingerlings in 1982. Fingerling stocking was terminated in 1989, with Smallmouth Bass established lake-wide.

Smallmouth Bass brood fish were collected from Flaming Gorge Reservoir in northeastern Utah and brought to UDWR's Wahweap Hatchery located on Wahweap Creek, a tributary of Lake Powell. These brood were believed to be the southern subspecies of Smallmouth Bass and of Tishomingo origin (Blommer and Gustaveson 1997). Most of the fingerlings stocked into the reservoir were of this origin, however in 1987 a limited number of fry were received from Arkansas Game and Fish Department and were brought into the hatchery. These fishes were of unknown origin and due to high mortality only limited numbers of fingerlings were stocked into the lake from this source (Gustaveson et al. 1988).

The initial stocking began in 1982 and was terminated in 1989. A single stocking followed in 1992. By this time Smallmouth had become established lake-wide. Due to the vast and remote nature of the reservoir, stocking was accomplished via aerial, truck and boat with over 297,000 fingerlings stocked in 21 different locations (Table 19).

Natural reproduction was documented in 1985 just 3-years following the initial stocking (Gustaveson et al. 1989) and by this time the population had expanded lake-wide. Growth in the early fishery was superb as a fast growing population capitalized on an unexploited niche. However, by 2000 the population was showing signs of stunting. In response UDWR increased the 6-fish creel limit to 20 fish/day in 2002 and educated the angler on the need to remove excess Smallmouth Bass. The anglers responded, and harvest was increased from 11% to 27% within a year. Size structure rapidly improved and the fishery was off and running once again.

Harvest rates peaked in 2012 at 33% but declined to 20% in 2015. Although growth has been moderate, the opportunity exists to increase harvest and possibly increase growth once again. The Smallmouth Bass fishery is very important and with timely and proper management will provide a consistently exciting fishing opportunity for years to come on Lake Powell.

Sampling for black bass consisted of an annual YOY electrofishing survey conducted each September, and an annual gill-netting survey conducted each November. Additional information was collected every three years during the angler survey. Relative abundance and growth information was collected from the electrofishing survey while a plethora of information was obtained from the annual gill-net survey including: relative abundance, age, growth, sex, condition, fat index, and stomach contents. The angler survey collected both catch and harvest statistics along with some demographic information.

Table 19. Smallmouth Bass stocking history Lake Powell, Utah/Arizona 1982-1992

Year	No. Stocked	Size (in)	Location	Method
1982	3,100	2-4”	Warm Creek	Truck
1982	59	10-15”	Warm Creek	Truck
1983		****************** No Stocking*********************		
1984	26,600	2-4”	Wahweap-Warm Creek	Truck
1984	4,000	2-4”	Stanton Creek	Aerial
1985	13,289	2-4”	Wahweap Creek	Truck
1985	12,389	2-4”	Antelope Canyon	Truck
1985	22	10-15”	Antelope Canyon	Truck
1985	31,995	2-4”	Rincon	Aerial
1985	19,390	2-4”	Good Hope Bay	Aerial
1985	26,328	2-4”	Neskahi Canyon	Aerial
1985	702	10-15”	Hite/ Dirty Devil	Truck
1986	12,785	2-4”	Escalante River	Aerial
1986	8,136	2-4”	Piute Farms Wash	Truck
1986	6,123	2-4”	Wahweap Creek	Truck
1987	220	3-6”	Wahweap Creek/ Warm Creek	Truck
1987	24,200	2-3”	West Canyon	Aerial
1987	7,200	2-3”	Nokai Canyon	Truck
1987	3,150	2-4”	Piute Farms	Truck
1988	20,536	2”	Knowles/ Cedar Canyon	Aerial
1988	24,643	2”	Llewellyn/ Cottonwood	Aerial
1988	4,307	2”	Middle Rock Creek	Aerial
1988	10,745	2”	San Juan (mouth)	Aerial
1988	10,800	2”	Navajo Canyon	Aerial
1989	21,002	2”	Trachyte Canyon	Aerial
1989	2,394	2”	Warm Creek (mouth)	Boat
1992	3,437	1-1.5”	Crosby Canyon	Truck

Trend Sampling:

Project wide trend sampling has been successful in tracking the establishment and rise of the Smallmouth Bass population since its introduction in 1982. By 1991, nine years following introduction, the catch of Smallmouth Bass in the annual fall gill-net survey had established a baseline mean survey-wide catch of 31 fishes (SD = 16) that would define the Smallmouth Bass population strength for the next 13 years. In 2003 a new mean catch of 51 fishes/survey (SD = 20) was ushered in that has persisted through the latest survey in 2019 (Figure 48). This uptick in catch corresponded with the lake-wide establishment of Gizzard Shad into the fishery and was noticeable in the strength of the catch in other sport fishes as well. It has been well established in Lake Powell that increased levels of pelagic shad resulted in an increased catch of various sport fishes, including Smallmouth Bass, in the annual fall gill-net survey (Blommer and Gustaveson 2017). Correlation analyses confirm this significant and positive relationship between the catch of Smallmouth Bass in the annual fall gill net survey and the catch of pelagic shad in the mid-water trawl survey (Pearson Corr, $r = 0.59$, $p = .0002$; Figure 49). Along with enhancing the forage base we speculate that increased shad abundance leads to increased Smallmouth Bass feeding activity which then leads to increased captures in the annual gill net survey.

In 2016-2018 the catch of Smallmouth averaged 45.75 fishes (SD = 1.5), slightly below the latest 16-year average, but in 2019 the catch rose to 59.5 fishes/survey well above the long term average. All sampling stations with the exception of Good Hope recorded a stronger catch in 2019 (Figure 50). At Wahweap, the 2019 Smallmouth Bass catch was the second highest recorded at that location for the entire history of the survey. The 66 fishes/survey exceeded all but the 2008 catch of 72 fishes and was well above the mean catch of 30 fishes (SD = 16) since 2003. The Good Hope Bay catch was only 43 fishes/survey in 2019, well below the mean survey catch of 61 fishes since 2003. However, the gill-net catch in 2018 at Good Hope was 90 fishes/standard sample, the third highest Smallmouth Bass catch ever recorded at that station.

Smallmouth Bass behaved like most of the other species in that gill-net catches were strongest at upper-lake stations and those nearest to inflows. As stated in previous sections, caution should be exercised in interpreting gill-net data as many factors that can vary greatly between years and even daily can affect the efficiency of gill netting irrespective of population abundance. Statistically, the Smallmouth Bass population has remained largely stable since becoming established in Lake Powell, rising only slightly after 2002 when Gizzard Shad had become established lake-wide.

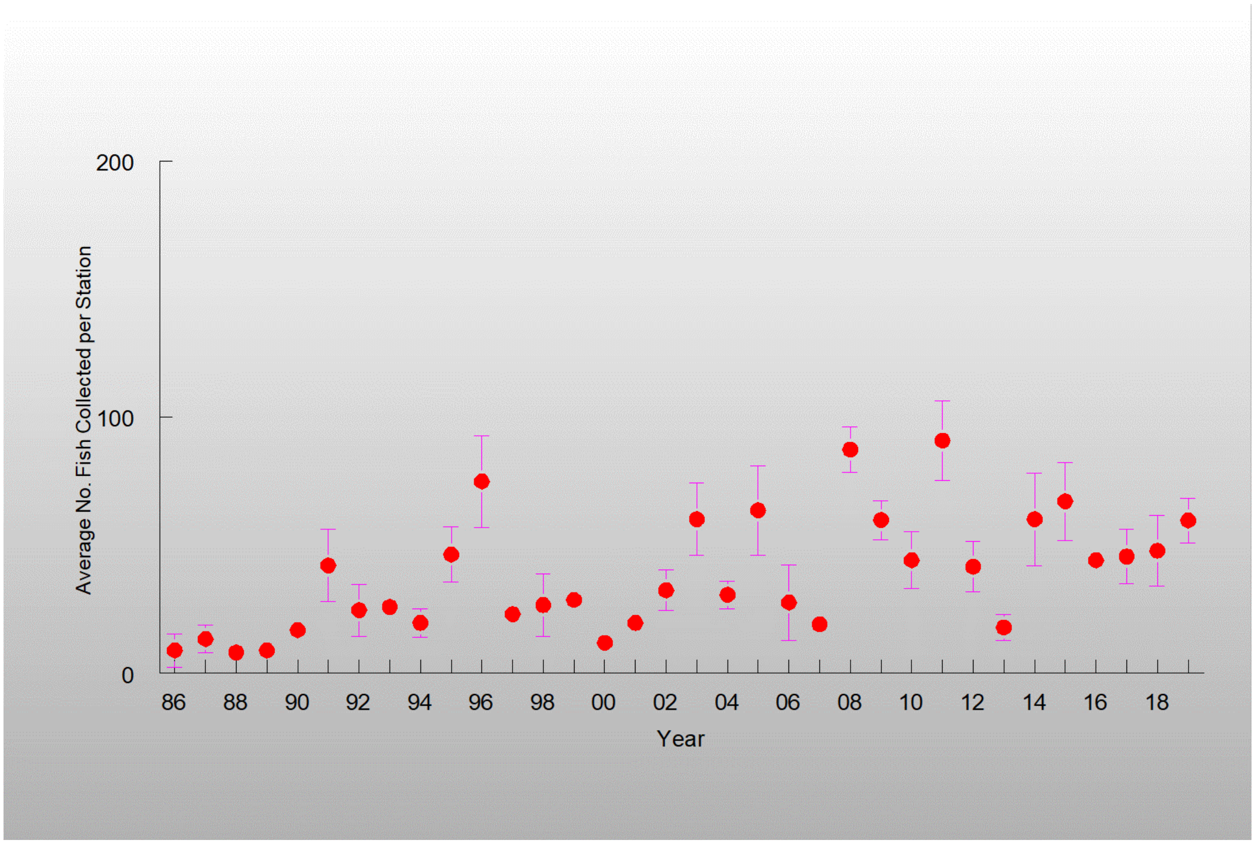


Figure 48. Mean catch of Smallmouth Bass per station from the annual fall gill-net survey with SE, Lake Powell, 1986-2019.

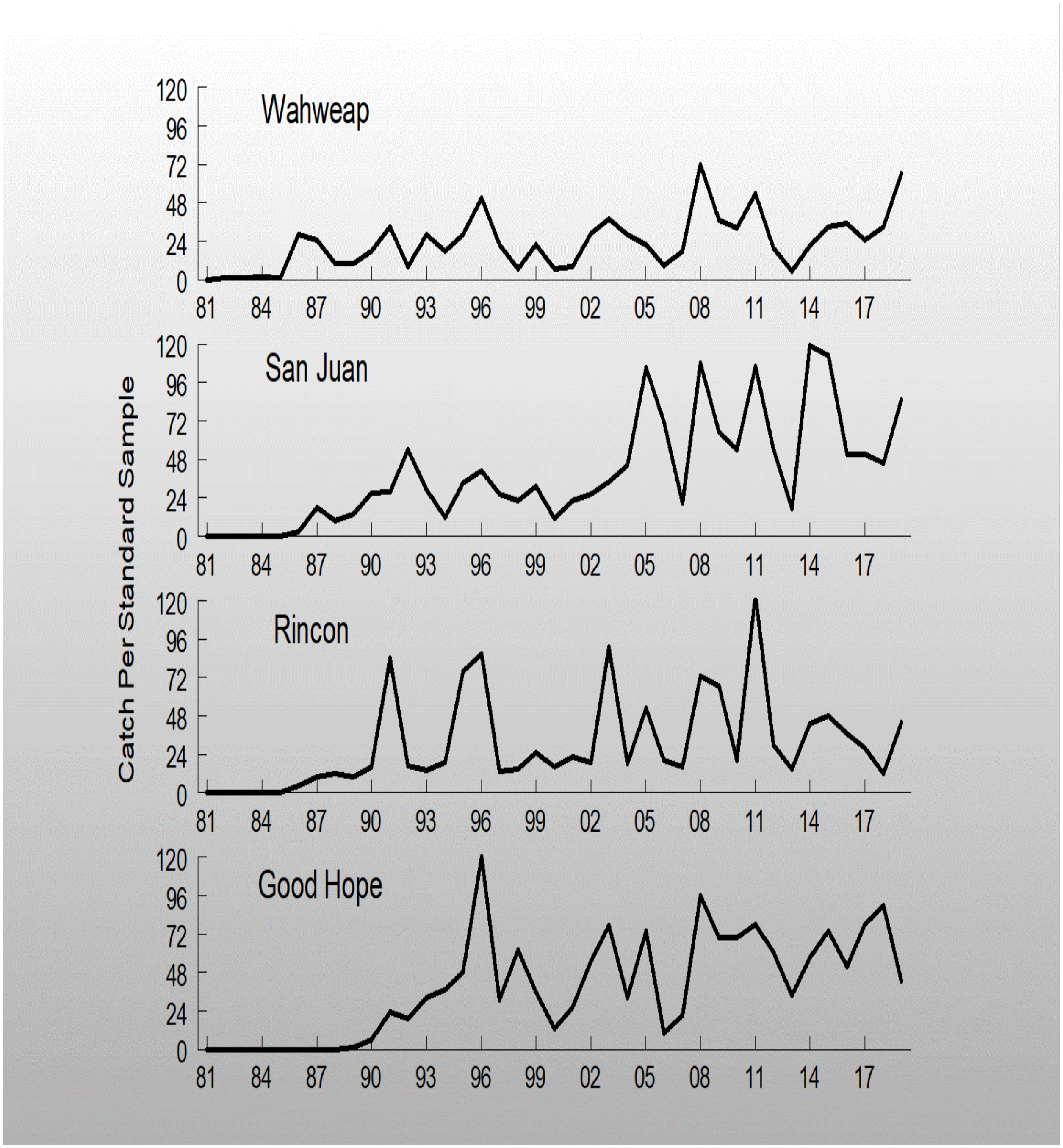


Figure 49. Total catch (standard sample) of Smallmouth Bass from the annual fall gill-net survey, Lake Powell, 1981-2019.

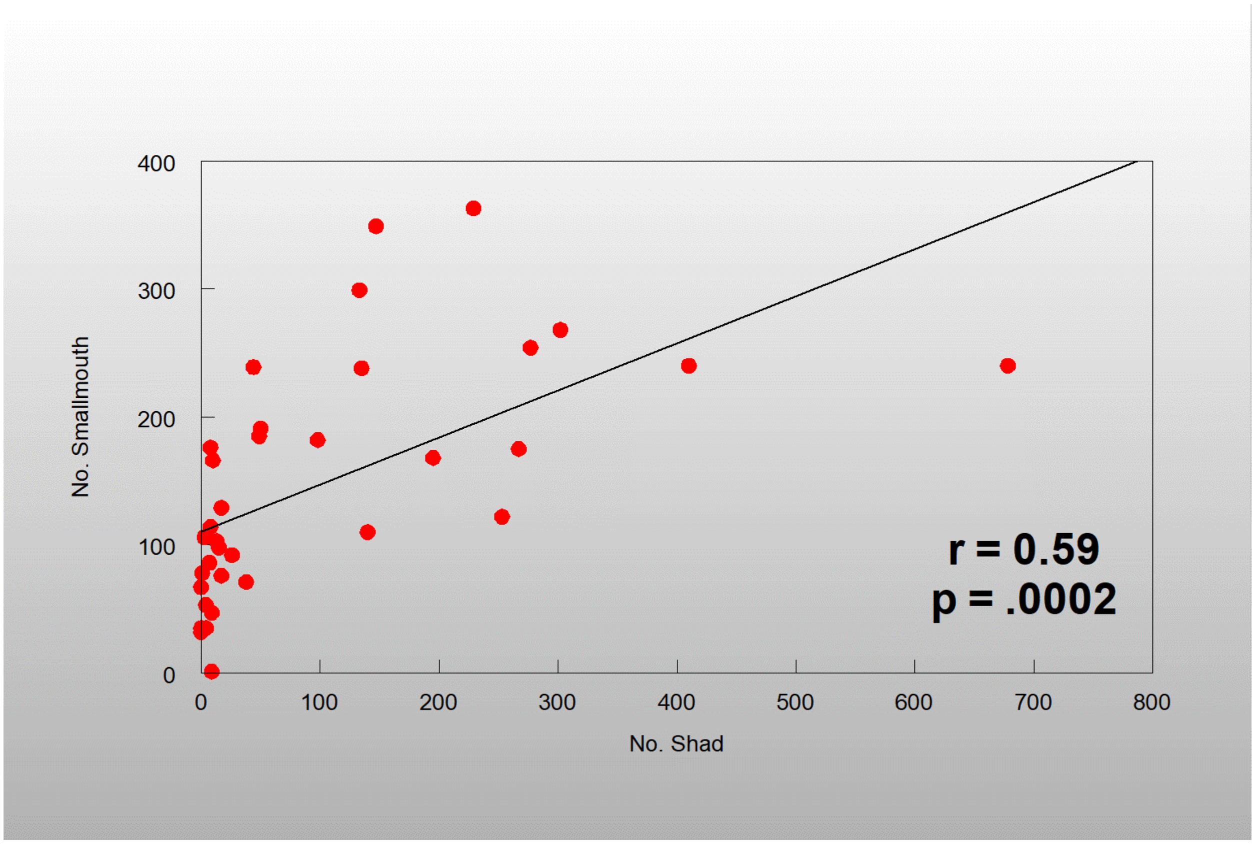


Figure 50. Relationship between the catch of Smallmouth Bass from the annual fall gill-net survey and the catch of shad from the mid-water trawl survey, Lake Powell, 1985-2019.

PSD/RSD:

By 1991 the catch of Smallmouth Bass in the annual gill-net survey had become large enough to analyze using stock density methods. Proportional stock density (PSD) (Anderson and Gutreuter 1983) and relative stock density (RSD) (Gabelhouse 1984) indices were used to analyze length frequency data collected from Smallmouth Bass obtained in the annual fall gill-netting survey. Minimum categories for stock, quality, preferred, memorable and trophy lengths were taken from Gabelhouse (1984) and were: 180, 280, 350, 430 and 510mm respectively. RSD, the proportion of fish of any designated size group in a stock, was calculated as a cumulative percentage. Most years sample size was sufficient for estimating PSD with a 5% probability that the predicted confidence interval (CI) exceeded 0.1 on each side of the PSD, however for many of the earlier years the sample size was insufficient for detecting a minimum change of at least 10% between years (Miranda 1993). Analysis was confined to the fall gill-net survey as sample size was generally sufficient whereas the spring gill-net survey returned low sample sizes due to larger mesh sizes and limited fish movement that occurred in the spring. Differential movement of black bass that is well document was also a factor that biased the spring survey with larger bass becoming active earlier in the spring than smaller fishes (Houser and Rainwater 1975; Carline et al. 1984; Miranda and Muncy 1987).

PSD values, which represented the proportion of Smallmouth Bass in the stock greater than 279mm averaged 71% (SD = 11) and ranged from 47% to 87% over the last 29 year period (Figure 51). Weithman et al. (1979) stated that as a general rule, a range of PSD for a predator of 30% to 70% is desirable. Although these values suggest an excellent quality size fishery they may also suggest a lack of smaller (< 280mm) fish in the stock as was suggested by Weiss-Glanz and Stanley (1984) who felt that PSD values above 60% indicated too few small fish in the population. However Carline et al. (1984) concluded that PSD was likely to be most influenced by recruitment rather than growth or survival of Largemouth Bass in medium to large impoundments. This may well be the case in Lake Powell Smallmouth Bass where YOY captures in the annual fall electrofishing survey can be highly variable. We also suspect that some sampling bias exists with the gill nets selecting for quality size fishes over stock size. Gear selectivity on a "clear" lake such as Lake Powell is always an issue and particularly in smaller mesh sizes (Willis et al. 1985). Other factors that could have contributed to increasing PSD values in Lake Powell include the stockpiling of quality sized fishes due to reduced mortality from the "catch & release" philosophy prevalent in black bass anglers. Coble (1975) cited studies done on Smallmouth Bass populations where slightly over half of the annual mortality was due to fishing. With the limited harvest rates at the time, mortality on Lake Powell Smallmouth Bass may have been greatly reduced. Furthermore, the rapid growth of smaller sized smallmouth may have allowed the fish to quickly move into the quality size class which occurred during their third year on Lake Powell (Blommer and Gustaveson 1997). However, the stability of the Smallmouth Bass population as measured by the creel and annual fall gill-net surveys over the last 30+ years strongly suggest that reproduction, recruitment and survival have been sufficient to support and maintain a quality fishery.

Relative stock density – preferred values (RSD-P), which measure the proportion of preferred (> 349mm TL) fish in the stock, averaged 16% and ranged from 0% to 32% over the previous 29 years (Figure 51). Although the earlier fishery recorded high RSD-P levels by 1998 they were in decline and by 2000 no preferred size Smallmouth Bass were collected in the annual fall electrofishing survey. When it became apparent that these levels were unacceptable to Lake Powell anglers a management solution was implemented with the objective of raising RSD-P to its former levels. The decision was made to increase the harvest of smaller (stock) sized Smallmouth Bass through media outreach efforts coupled with regulatory adjustments.

To this effect television, radio and internet resources were enlisted to encourage the harvest of smaller fish. Additionally, in 2000 the creel limit was increased on Smallmouth Bass in Lake Powell from 6 to 20 fishes/day. This had the desired effect and by 2003 the RSD-P had risen to 15% and then to 23% the following year. At the same time, the percentage of the catch that was harvested increased from a pre-2002 level of 11% to 27% in 2003. Since then the mean harvest rate has been 18%, ranging between 11% and 24%. For the previous four years RSD-P has averaged 15%, ranging between 13% and 17% (Figure 51). Efforts need to be on-going in encouraging anglers in harvesting additional younger Smallmouth Bass.

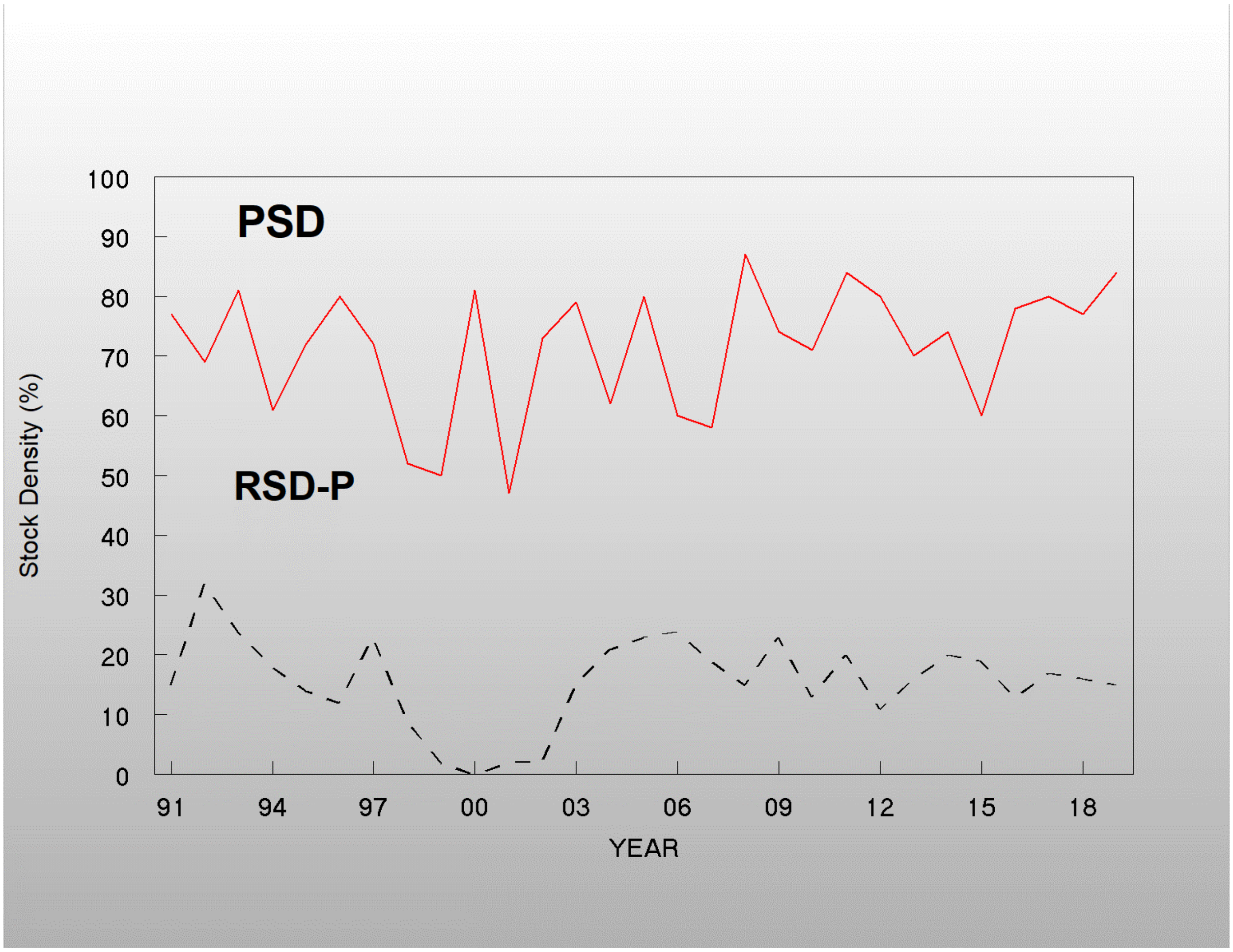


Figure 51. Stock density (PSD and RSD_P) of Smallmouth Bass collected in the annual fall gill-net survey, Lake Powell, 1991-2019.

Condition:

Relative weight (Wr) (Wege and Anderson 1978; Kolander et al. 1993) has historically been used to evaluate the condition of Lake Powell Smallmouth Bass. Early Wr values were high, as would be expected, as the newly establishing population was filling the unexploited niche. By 1992 a steady state was achieved that has remained largely static to the present (Figure 52). Mean Wr was 82 (SD = 2.9) for the years 1992-2019 and overall represented a healthy Smallmouth Bass population.

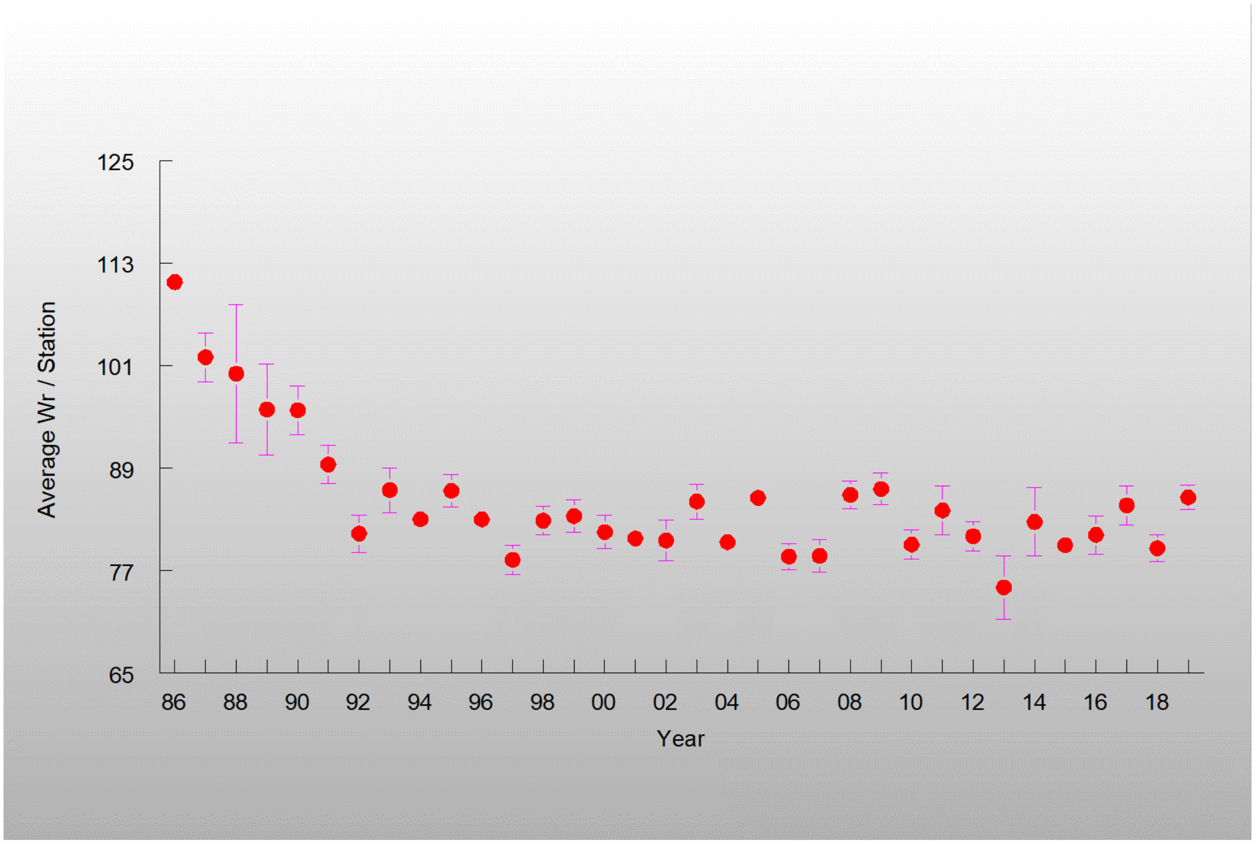


Figure 52. Mean Wr of Smallmouth Bass (TL > 149mm) per station from the annual fall gill-net survey with SE, Lake Powell, UT, 1986-2019.

The condition of Smallmouth Bass was similar to Striped Bass in that the two ends of the lake at Wahweap and Good Hope have historically held the healthiest fishes. Wahweap led the way, averaging a Wr of 85.5, followed by Good Hope at 82.8 (Table 20). Forage conditions are undoubtedly strongest at Good Hope for open water fishes as well as fishes occupying the littoral zone based on our sampling. Good Hope is also a highly productive area of the lake in terms of zooplankton abundance and chlorophyll *a* values. Wahweap, on the other hand, is much less productive and rarely returns strong numbers of forage fishes in our various sampling surveys. It could be that the reduced Smallmouth Bass catch from this location allows for less foraging competition hence better condition. Additionally, the relative status of crayfish throughout the lake is unknown and they constitute a sizable percentage of the Smallmouth Bass diet.

Table 20. Mean Wr of Smallmouth Bass Collected in the annual fall gill net survey, Lake Powell, 1992-2019.

	Wahweap	San Juan	Rincon	Good Hope
Mean	85.5	79.2	81.8	82.8
Standard Dev.	4.0	4.9	3.8	3.1
Sample Size	28	28	28	28

Bass tapeworm has been present in the Smallmouth Bass population probably since introduction, but was first noticed in 1987 at the Rincon 2-years after collecting the first smallmouth from the annual fall gill-net survey (Blommer and Gustaveson 1997). The adult Bass Tapeworm is known to cause loss of organ function particularly in the gonads resulting in sexual sterility (Mitchell and Hoffman 1980; Sullivan 1975). Additionally, the pleurocercoid stage can also cause fibrosis of the gonads reducing egg production (R.A. Heckman, Brigham Young University, personal communication). Furthermore, Smallmouth Bass of Lake Powell origin, when used as brood fish at Wahweap Hatchery, produced only half as many fry as similar sized brood from other sources (Blommer and Gustaveson 1997).

In 1991 UDWR developed a ranking system to quantify the severity of Bass Tapeworm in Lake Powell Smallmouth Bass. This ranking system assigned a number 0-3 based upon the severity of the parasite infestation. Upon inspection of the internal organs if no parasites were found, a ranking of 0 was assigned. If at first glance the organs appeared to be free of the parasite but upon closer examination evidence of a few tapeworms were discovered a ranking of 1 was assigned. If Bass Tapeworm was readily apparent upon examination of the internal organs a level 2 ranking was assigned. A ranking of 3 was assigned if the parasite infestation was so heavy that the internal organs were obscured by a layer of scar tissue. At the 3 level constrictions were evident in the male gonads and females often exhibited fibrous tissue along with adult tapeworms in their ovaries. A reduction in reproductive capabilities was assumed at level 3 (Blommer and Gustaveson 1997).

The severity of Bass Tapeworm is different throughout the lake with infestations consistently more noticeable in some areas than others. Interestingly, the severity of Bass Tapeworm is more pronounced in areas where the condition is the lowest. The mean percentage of Smallmouth Bass collected in the annual fall gill-net survey (2006-2019) with a severe (3 ranking) was highest at the Rincon (25%) followed by the San Juan (19%), Wahweap (13%) and Good Hope (12%) (Table 21). This closely mirrors the mean Wr values from the same survey (1992-2009) with the two lowest values at the Rincon and the San Juan reversed. Whether the intensity of the Bass Tapeworm infestation is driving the Wr values down or the condition dictates the susceptibility to the parasite is unknown but the first scenario is most likely. Also noteworthy, was that in 2013, when the water levels reached the lowest level since 2004 and 2005, Bass Tapeworm levels were elevated at all sites. Bass Tapeworm when correlated against shad abundance, as measured from the trawl survey, were significantly correlated at both Good Hope (r=.60, p=.02) and at Wahweap (r=.57, p=.03), the 2 locations where both gill netting and midwater trawl sampling are performed.

Another metric measured from Smallmouth Bass collected in the annual fall gill-net survey was a fat index. Developed at the UDWR Fisheries Experimental Station, this index measures the % of fat coverage on the mesenteries. A ranking of 0-4 is assigned representing 0, 25, 50, 75 and 100% coverage.

Unsurprisingly, fat index values followed the same overall pattern as condition and parasite loading values. When averaging the percentage of fishes with the highest fat level (level 4), over the years 2006-2019, Wahweap was highest at 15% followed closely by Good Hope at 11%. The Rincon and San Juan Smallmouth Bass trailed at 7% and 6% respectively (Table 22). Overall, fishes with no fat on their mesenteries was rare averaging only 3-4% over the last 14-years. Level 2 and 3 (50% and 75% coverage) were the most common. Fat index values when regressed at the highest level (4) against shad abundance, as measured from the trawl tows, show no relationship at the .05 alpha level.

Table 21. Percentage of Smallmouth Bass with various levels of Bass Tapeworm collected at standard locations from the annual fall gill net survey, Lake Powell, 2006-2019.

Site		**Parasite Levels**			
		0	**1**	**2**	**3**
Wahweap		21%	33%	33%	13%
Rincon		19%	24%	32%	25%
San Juan		12%	28%	41%	19%
Good Hope		22%	36%	30%	12%

Table 22. Percentage of Smallmouth with various fat-index levels from fishes collected at standard locations from the annual fall gill net survey, Lake Powell, 2006-2019.

Site		**Fat Index**			
	0	**1**	**2**	**3**	**4**
Wahweap	3%	17%	30%	35%	15%
Rincon	3%	14%	40%	36%	7%
San Juan	3%	25%	43%	23%	6%
Good Hope	4%	18%	35%	32%	11%

Diet:

The varied diet of Smallmouth Bass and their opportunistic feeding behavior has allowed them to maintain condition in the face of oftentimes fluctuating forage conditions. Crayfish *Orconectes virilis* occur most often in the stomachs of Smallmouth Bass collected in the annual fall gill-net survey, occurring on average in 54% (range = 29-92%) of the stomachs that contain food items (Table 23). The % occurrence of Crayfish in the diet usually declines when the % occurrence of Shad peaks (Figure 53). Correlation analysis further points out this relationship (r = .62, p= .0003). This may signal a preference for shad when their available or perhaps that shad are more easily obtained compared to foraging for Crayfish. UDWR does not have a sampling survey that allows us to evaluate the population status of Crayfish, but based on their occurrence in various sport fishes stomachs, they appear to be a consistent and reliable source of food.

Centrarchids are the second most prevalent food item with a mean occurrence of 18%, ranging from 6 - 47% (Figure 53). Interestingly, the % occurrence of centrarchids in the stomachs of Smallmouth Bass captured in the annual fall gill net survey increases during years when water levels increased over the previous year (r = .69, p = .0001). The importance of periodic rising water levels in providing enhanced productivity as well as adult and nursery habitat is paramount in providing additional sport and forage fishes in Lake Powell.

Shad, both Threadfin and Gizzard, are the third most occurring dietary item sampled in Smallmouth Bass stomachs. Shad have historically averaged 12% occurrence, ranging from 0% to 33% depending upon their availability. During years when open water shad population densities are high, the % occurrence of shad sampled from Smallmouth Bass stomachs showed a significant increase (r=.48, p=.005; Pearson Corr; Figure 54). High shad levels in 2016 and again in 2019 resulted in % occurrence values of 10% and 19% respectively. Meanwhile, lower levels of open water shad in 2017 and 2018 resulted in % occurrence levels of only 3% and 4% respectively.

The vast majority of shad found in Smallmouth Bass stomachs are Threadfin Shad with Gizzard Shad occurring only occasionally. Because Smallmouth Bass are only sampled for stomach contents in the fall, it is possible that Gizzard Shad may be more available and more heavily utilized at other times of the year. There was no statistical difference in the % occurrence of shad in Smallmouth Bass stomachs between pre and post Gizzard Shad introduction at alpha = .05 (ANOVA; SAS Institute 1987). Additionally, Condition (Wr) of Smallmouth Bass was not correlated with the % occurrence of any of the most prevalent food items.

Table 23. % Occurrence, and number ( ) of major food items in the stomachs of Smallmouth Bass collected in the annual gill-net survey. Lake Powell 1988-2019.

			% OCCURRENCE					
YEAR	# Checked	# w/Food	Crayfish	Shad	Unk Fish	Centrarchids	Zoop	Other
1988	19	12	19(11)	0	17(2)	0	8(1)	0
1989	24	14	36(5)	14(2)	7(1)	21(3)	21(3)	0
1990	73	44	64(28)	16(7)	9(4)	4(2)	9(4)	10(4)
1991	134	70	37(26)	30(21)	20(14)	11(8)	1(1)	6(4)
1992	72	31	65(20)	6(2)	6(2)	13(4)	10(3)	0
1993	88	40	65(26)	3(1)	3(1)	33(13)	3(1)	5(2)
1994	91	54	59(32)	0	9(5)	34(18)	6(3)	0
1995	166	76	40(34)	26(22)	12(10)	28(24)	0	3(3)
1996	345	178	48(85)	28(49)	12(22)	13(22)	3(6)	1(1)
1997	90	42	48(20)	10(4)	12(5)	33(14)	2(1)	0
1998	110	53	64(34)	2(1)	2(1)	25(13)	6(3)	0
1999	113	72	43(31)	7(5)	13(9)	12(9)	22(16)	5(4)
2000	47	33	70(23)	15(5)	6(2)	0	12(4)	6(2)
2001	76	55	64(21)	3(1)	3(1)	6(2)	15(5)	15(5)
2002	128	67	70(47)	16(11)	9(6)	2(2)	3(2)	6(4)
2003	NA	-	-	-	-	-	-	-
2004	96	42	67(28)	19(8)	7(3)	2(1)	2(1)	2(1)
2005	211	110	60(66)	9(10)	17(19)	10(11)	3(3)	4(4)
2006	94	41	76(31)	5(2)	12(5)	5(2)	5(2)	0
2007	75	47	55(26)	11(5)	13(6)	15(7)	8(4)	4(2)
2008	296	153	53(81)	12(18)	22(33)	22(33)	0	3(5)
2009	98	97	55(56)	2(2)	4(4)	35(34)	1(1)	6(6)
2010	171	82	44(36)	13(11)	11(9)	21(17)	12(10)	2(2)
2011	291	143	29(41)	33(47)	17(24)	29(41)	1(1)	1(2)
2012	147	68	60(41)	16(11)	9(6)	20(14)	6(4)	3(2)
2013	67	34	65(22)	0	6(2)	15(5)	21(7)	0
2014	239	100	54(54)	14(14)	13(13)	21(21)	1(1)	0
2015	228	102	39(40)	19(19)	20(20)	22(22)	7(7)	2(2)
2016	170	89	54(48)	10(9)	17(15)	23(21)	1(1)	1(1)
2017	139	72	61(44)	3(2)	11(8)	32(23)	1(1)	6(4)
2018	185	109	77(85)	4(4)	12(13)	13(14)	1(1)	1(1)
2019	232	126	34(43)	19(24)	23(29)	26(33)	1(1)	7(9)

Table 23 cont'd

MEANS	54	12	11	18	6	3

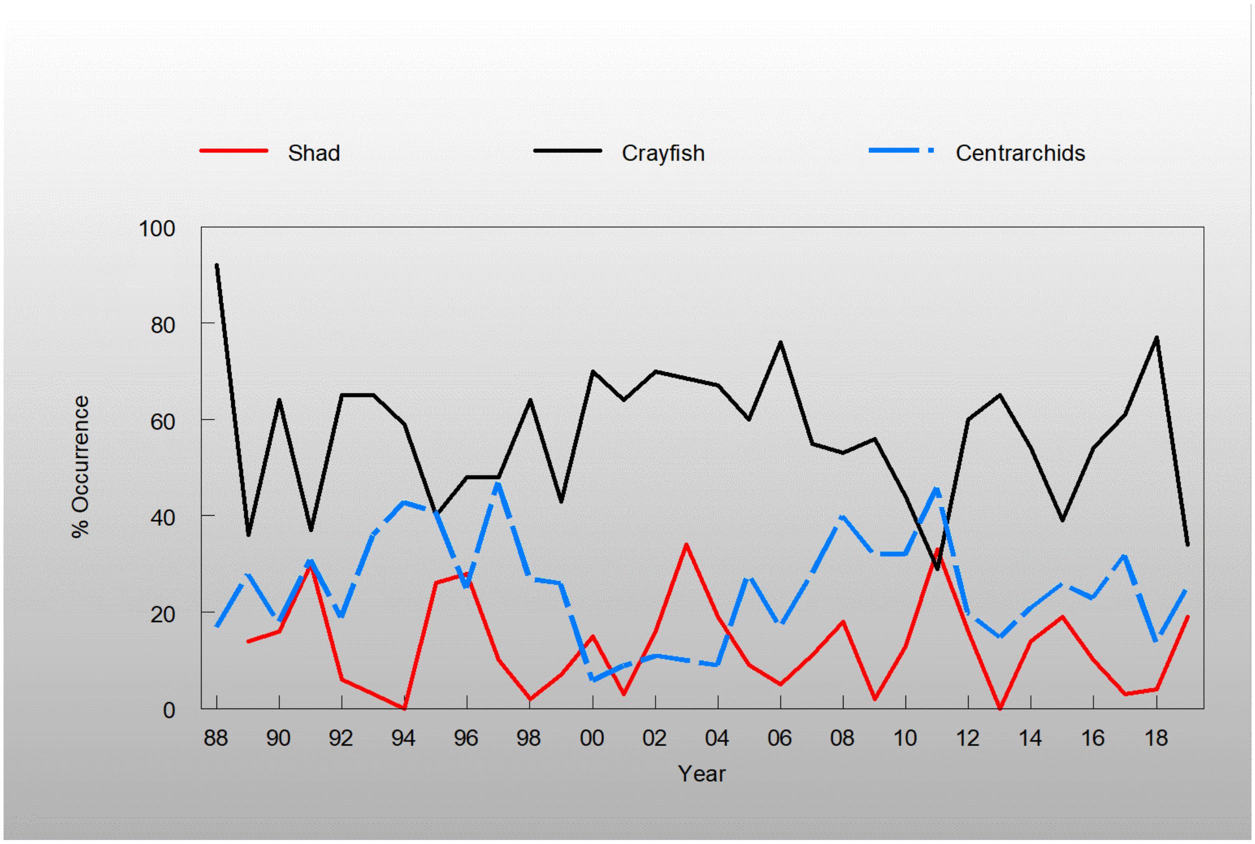


Figure 53. Percent occurrence of food items in the stomachs of Smallmouth Bass collected in the annual fall gill-net survey, Lake Powell, 1988-2019.

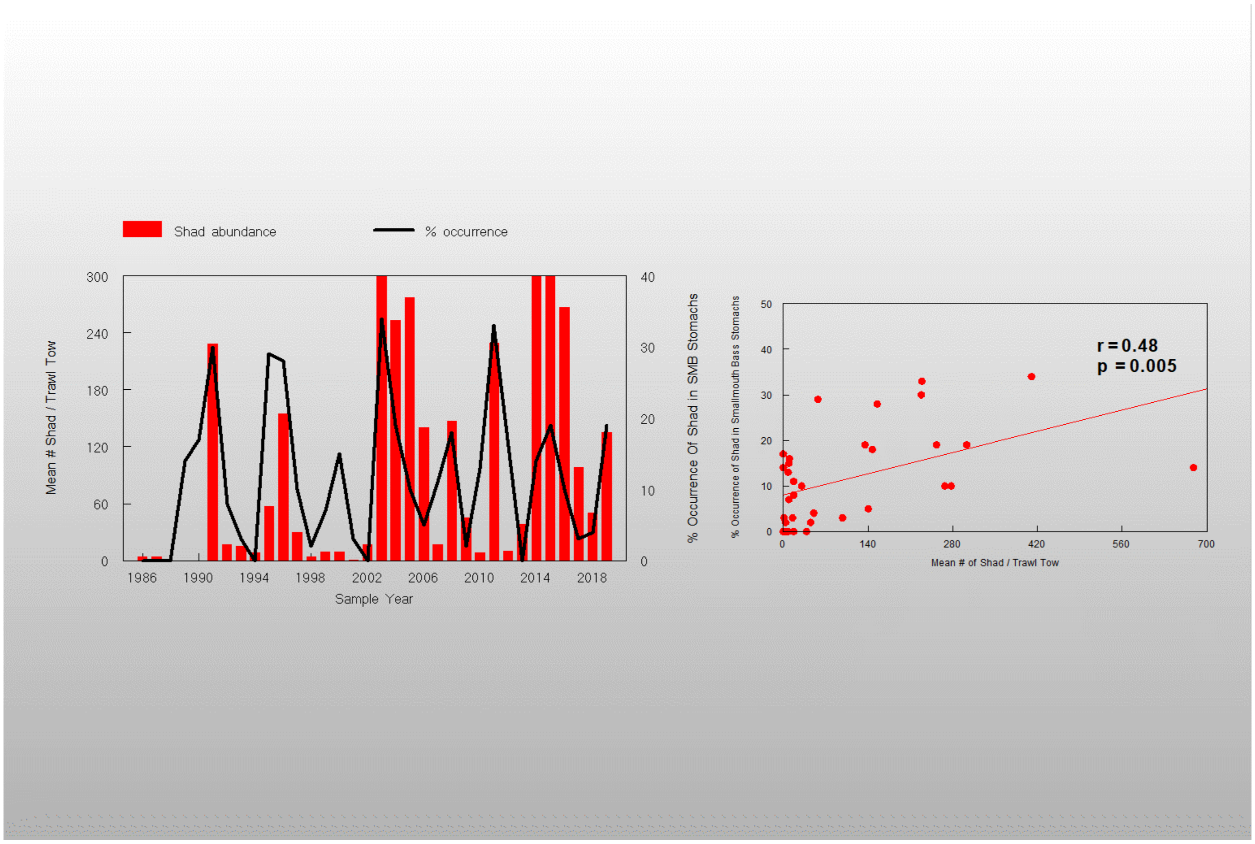


Figure 54. Relationship between the %occurrence of shad in the stomachs of Smallmouth Bass collected in the annual fall gill-net survey and the abundance of pelagic shad collected in the July/August mid-water trawl survey, Lake Powell 1986-2019.

Reproduction and Recruitment:

Smallmouth Bass spawning begins on Lake Powell in late April and early May and can continue through June. Water temperatures at the start of the Smallmouth Bass spawn range from 16-18^{0}C (Gustaveson et al 1986. Hepworth and Pettengill (1980) reported 50% of age 2 and virtually all age 3 and older Largemouth Bass are sexually mature with Smallmouth Bass appearing to follow a similar pattern (Blommer and Gustaveson 1997). The electrofishing survey began detecting natural reproduction of Smallmouth Bass the second year after fingerlings were stocked at every site (Gustaveson et al 1990). This further suggested that Smallmouth Bass take 2-years to reach spawning maturity in Lake Powell. This compares favorably with other populations where 3-4 years have been cited (Carlander 1977). By the annual electrofishing survey in September YOY Smallmouth Bass average a maximum of 150mm TL.

The electrofishing survey has been successfully used to monitor YOY reproduction and first season recruitment. The Smallmouth Bass YOY catch was highly variable following introduction as the population was establishing and expanding but by 1998 had reached a steady state with very limited statistical differences in yearly lake-wide mean catch estimates (Figure 55). This report differs from previous ones in that they compared current data with data from the earliest years of the fishery as it was expanding and was highly variable, that plus limited logistics allowing for only 5 stations to be sampled per survey making rigorous lake-wide statistical analysis problematic. However, gross population changes and trends could be detected and correlated with other data which could then be used to assist in the yearly black bass population assessment.

Reproduction is variable between years which is characteristic of black bass populations (Coble 1975). The mean catch/station from 2016 thru 2019 was 19, 35, 40, and 19 YOY Smallmouth Bass / station respectively. These results, when compared to the mean catch estimate for sampling years 1998-2015 of 40.58 fishes/station (SD = 12.79) were at or below average.

Catch appears to be mainly a function of available habitat, which changes with water levels, but factors such as turbidity and temperature are also important. Historically (1998-2019) the San Juan station has recorded the highest mean catch/hr of YOY Smallmouth Bass at 57 fishes/hr (SD = 26) followed by the station at Bullfrog (discontinued in 2013) at 45 fishes/hr (SD = 27). Wahweap, Rincon and Good Hope followed with mean catches of 33, 32 and 31 fishes/hr (SD = 22-26) respectively (Figure 56). Performing a one-way ANOVA suggests a significant difference in catch among sampling sites (p = .009).

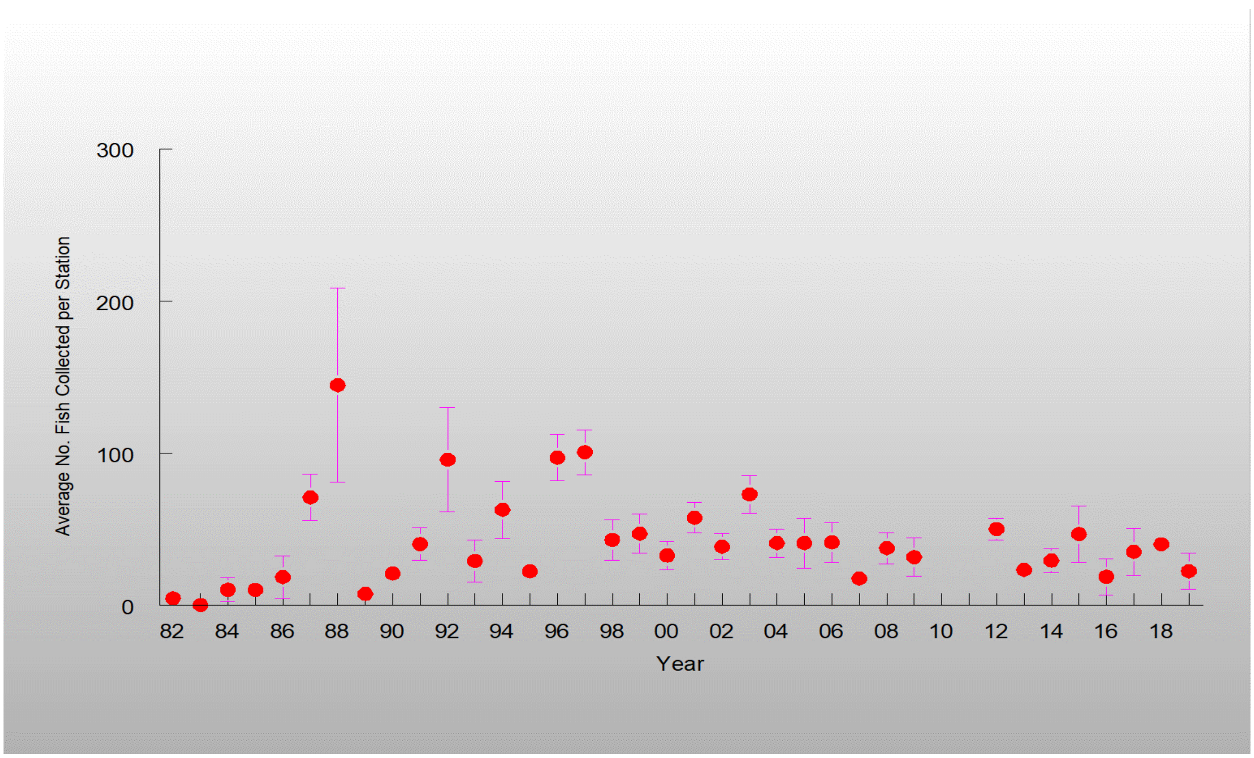


Figure 55. Mean catch of YOY Smallmouth Bass collected per station from the annual fall electrofishing survey with SE, Lake Powell, 1982-2019.

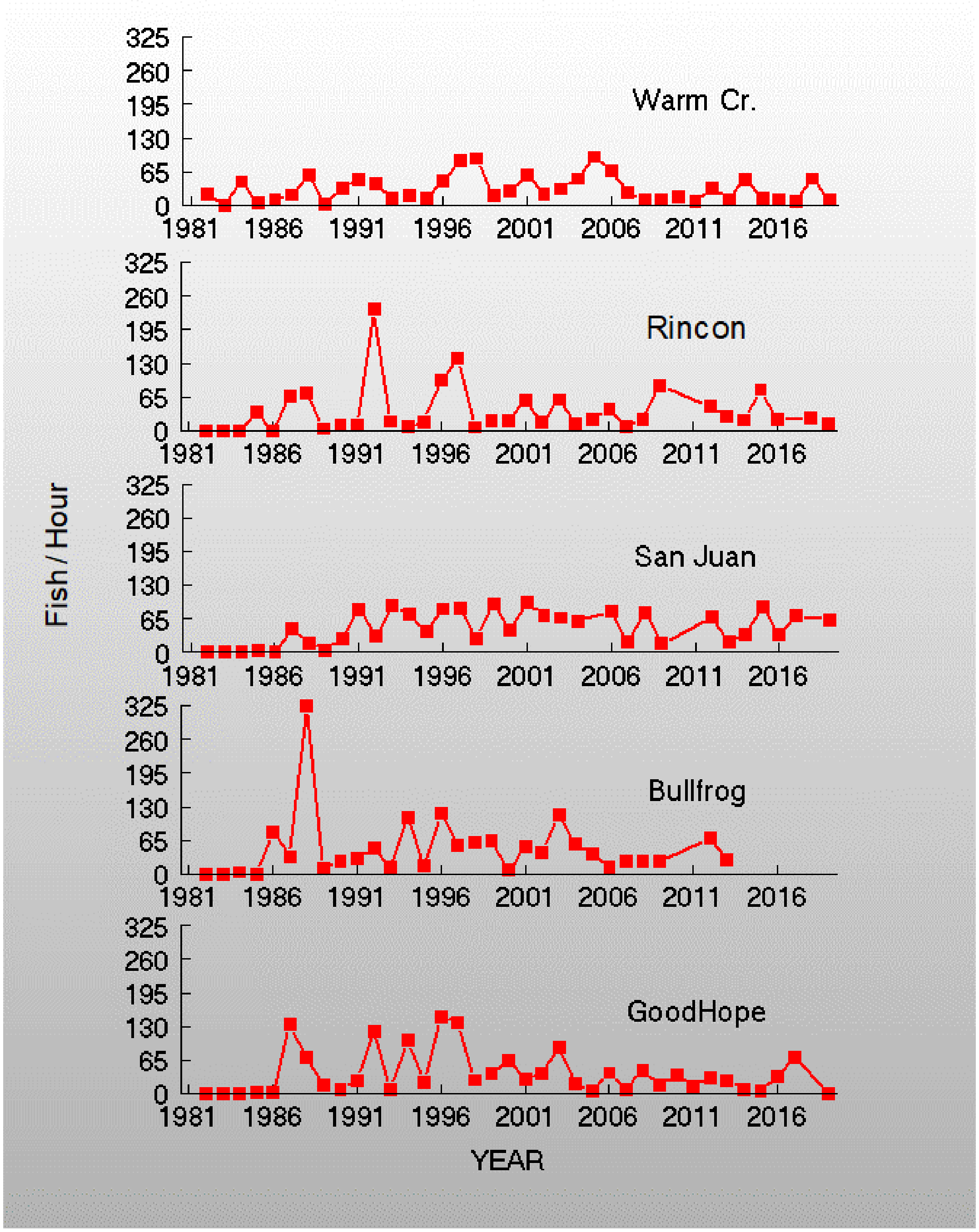


Figure 56. Catch by site of YOY Smallmouth Bass from the annual fall electrofishing survey, Lake Powell, 1982-2019.

From our experience of raising Smallmouth Bass at the UDWR Wahweap Hatchery we suspect that successful reproduction of black bass is initially dependent on water temperatures, with any drastic drop in temperature after egg deposition being detrimental. Further recruitment through the first winter is strongly dependent on available cover. Literature also suggests that TL of YOY black bass going into their first winter can also effect over-winter survival.

Historical (1989-2019) lake-wide mean TL of YOY Smallmouth Bass was 90mm (SD = 2.4), ranging from 87mm to 94mm. Lake-wide mean TL was 94.8, 92.1, 88.5 and 105.9mm for the last 4-years respectively (Table 24). Interestingly, 2018 had the smallest YOY TL and was also the only year that water levels were lower than the previous year. Young-of-year Smallmouth Bass sampled in the annual electrofishing survey tend to be larger at Good Hope compared with Wahweap (Table 24). However, comparison of means (ANOVA, alpha = .05) show no statistical differences in YOY total length between sites when averaging data from 1987-2019. Correlation analysis (Pearson Corr) suggests the mean TL of YOY Smallmouth Bass decreases when open-water shad populations are increasing ($r = -.42$, $p = .005$; Figure 57).

Table 24. Mean TL of YOY Smallmouth Bass (<150 mm) collected from the electrofishing survey, Lake Powell, 1987-2019.

YEAR	LOCATION										Mean	SE	WT. Mean
	Wahweap	n	Rincon	n	San Juan	n	BullFrog	n	Good Hope	n			
1987	84.4	21	96.5	67	110.3	52	102.5	34	107.2	74	100.2	4.2	102.4
1988	76.5	58	91.1	74	96.5	21	107.5	93	111.1	65	96.5	5.6	97.8
1989	89.0	3	123.6	5	99.0	5	118.3	22	100.2	16	106.0	5.9	109.5
1990	112.8	23	96.0	13	88.6	26	92.8	26	114.3	17	100.9	4.8	100.0
1991	79.2	50	72.8	10	94.5	83	84.7	19	85.6	32	83.4	3.3	87.0
1992	98.2	44	96.2	237	97.0	32	104.0	52	117.0	125	102.5	3.5	102.6
1993	91.2	13	96.5	18	103.1	64	101.9	13	93.2	11	97.2	2.1	99.7
1994	92.9	32	106.9	9	97.8	74	93.4	110	110.5	103	100.3	3.2	100.1
1995	90.3	14	92.8	18	83.3	41	92.0	17	91.4	25	90.0	1.5	88.7
1996	90.9	36	69.8	99	68.8	84	70.9	118	69.2	69	73.9	3.9	71.7
1997	85.0	52	87.2	140	87.5	39	85.2	57	85.2	137	86.0	0.5	86.0
1998	81.9	91	97.7	10	83.9	25	87.6	58	117.9	26	93.8	6.0	88.9
1999	83.6	14	89.9	20	82.1	87	86.7	64	96.2	31	87.7	2.5	86.3
2000	82.1	20	96.9	26	91.6	43	78.6	7	92.8	47	88.4	3.5	91.0
2001	76.6	45	88.4	51	100.4	97	99.5	52	101.1	29	93.2	4.3	94.2
2002	132.0	18	90.0	18	98.2	38	79.1	43	90.2	23	97.9	8.2	94.3
2003	71.8	21	66.6	61	72.5	67	76.9	118	106.0	97	78.8	6.4	81.8
2004	88.0	55	93.9	15	77.4	63	75.3	54	71.3	18	81.2	3.8	80.4
2005	83.4	75	79.9	22	-	-	83.8	39	74.0	7	80.3	2.0	82.5
2006	91.1	52	80.1	43	87.5	82	94.5	11	103.0	5	91.2	3.4	87.6
2007	82.7	19	107.1	8	84.7	20	97.9	18	96.6	10	93.8	4.1	91.3
2008	81.8	12	86.4	22	92.3	77	83.5	26	71.5	45	83.1	3.4	84.5
2009	82.2	15	83.1	66	81.5	17	83.2	19	72.9	13	80.6	1.8	81.8
2010	75.9	17	-	-	-	-	-	-	82.3	40	79.1	2.3	80.4
2011	87.0	2	-	-	-	-	-	-	83.3	11	85.1	1.3	83.9
2012	84.5	26	73.7	49	88.3	59	82.9	64	102.3	33	86.3	4.2	85.3
2013	80.1	9	90.6	28	86.6	15	91.3	29	87.1	26	87.1	4.0	88.5
2014	86.6	48	118.1	21	86.9	35			61.0	10	88.1	20.2	90.2
2015	76.9	11	79.7	71	82.2	71			86.3	6	81.3	3.4	80.9
2016	77.2	9	103.0	22	83.3	29			115.8	5	94.8	7.7	91.6
2017	87.8	6			98.9	61			89.7	19	92.1	2.8	96.1
2018	85.1	25	89.9	20					90.4	46	88.5	1.4	88.8
2019	98.2	5	92.5	15	98.0	79			135.0	1	105.9	8.4	97.6
MEAN	86.9		90.1		89.9		90.1		94.3		90.3		

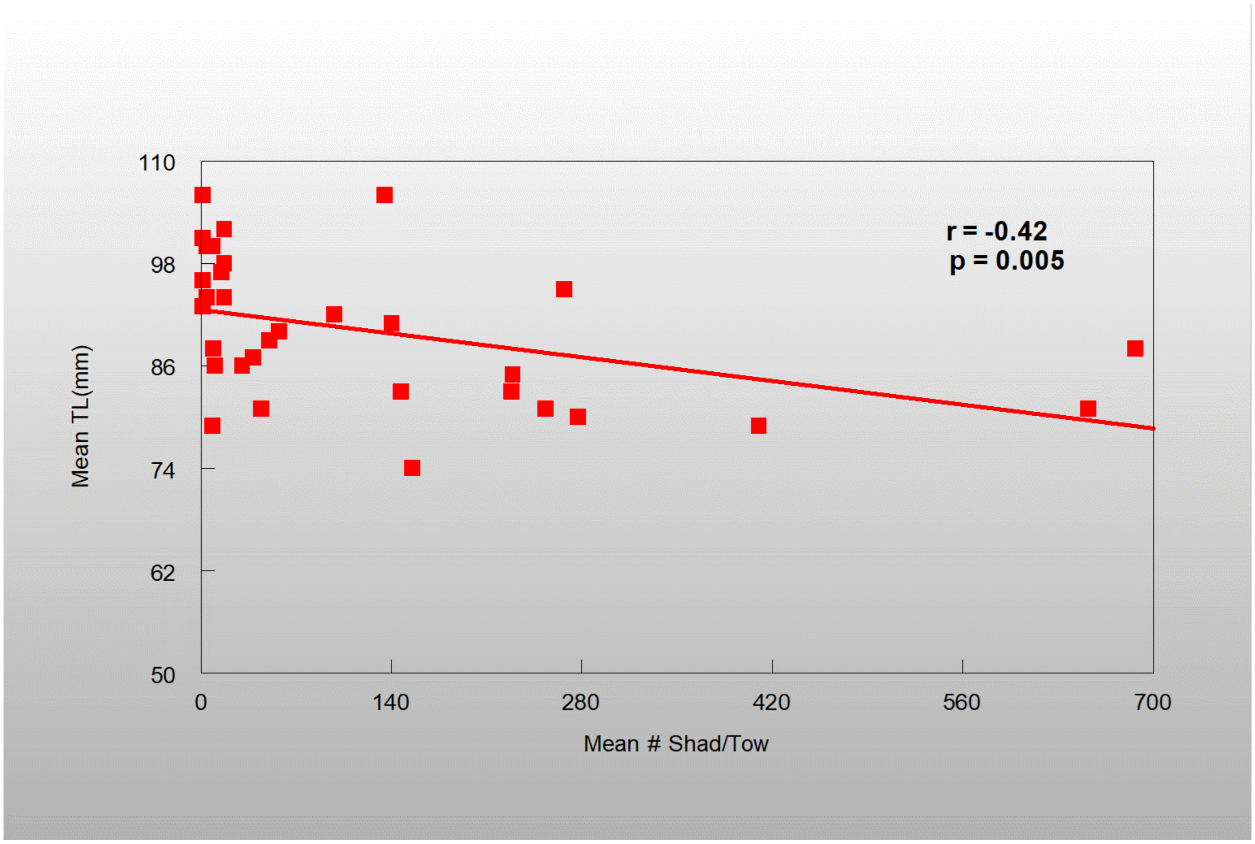


Figure 57. Relationship between the mean number of shad collected from the mid-water trawl survey (July/August) and the mean TL of YOY Smallmouth Bass collected from the annual fall electrofishing survey, Lake Powell, 1987-2019.

Bass Tapeworm infestations do not appear to have any effect on reproduction as measured by the number of YOY collected in the annual fall gill net survey or on the mean lake-wide TL of YOY fishes collected in the annual fall electrofishing survey. The same could be said of Smallmouth Bass response to the Quagga Mussel invasion. In fact mean YOY TL is actually greater (mean TL = 90.5mm, SD = 6.9) in the 8-years following the discovery of mussels than the 8-years prior to invasion (mean TL = 84.3, SD = 5.1). Temperatures, water level driven habitat changes, angling mortality, density of predators and forage appear to be the big drivers of the population status. Furthermore, any negative effects exerted on Smallmouth Bass reproduction may well be offset by the young age at which Lake Powell become sexually mature.

Age and Growth:

Scales have been used to age Smallmouth on Lake Powell since their introduction. In recent years scales collected from fishes captured in the annual fall-gill net survey were analyzed on an every 3-year bases. The Frasier-Lee method was used for back-calculations with the Ball State FishBC computer program. Scales from Lake Powell Smallmouth Bass are notoriously difficult to read. Growth checks and false annuli were common and compounded by the long growing season and short winter's uncertainty in aging was a common occurrence (Blommer and Gustaveson 1997).

Early studies of Y-intercept values of body-scale regressions and geometric mean functional regression statistics had values ranging from 47-80 (Blommer and Gustaveson 1997). Eventually it was determined to use a Y-intercept value of 35mm as suggested by Carlander (1982) as this allowed us to compare growth with other researchers.

Growth over the last 4 years was excellent especially for YOY fishes which was unsurpassed on Lake Powell (Table 25). Back-calculated lengths at age rivaled not only the earliest years of the Smallmouth Bass fishery but similar waters throughout their US range (Table 26). The largest contributing factors driving this growth appeared to be that 3 of the last 4-years were not only good open water shad years but also years when water levels were rising, which theoretically should have increased production of centrarchid forage.

Table 25. Average back-calculated lengths for each age class of Smallmouth Bass collected in the annual gill-net survey, Lake Powell, UT. 2019.

	Calculated Lengths at Annulus Formation						
Year Class	I	II	III	IV	V	VI	VII
2017 (1)	164						
2016 (33)	128	212					
2015 (59)	127	232	302				
2014 (25)	135	236	300	334			
2013 (3)	144	269	314	375	403		
2012 (0)	-	-	-	-	-	-	
2011 (1)	109	171	257	331	356	381	430
N	122	121	88	29	4	1	1
All Classes	129	228	301	338	391	381	430

Table 26. Mean estimated back calculated lengths for Smallmouth Bass from Lake Powell 1986-2019 and selected and other waters in North America.

LOCATION	AGE I	II	III	IV
Lake Powell: 1986-1989	92	201	278	301
Lake Powell: 1992-1995	143	212	263	303
Lake Powell: 2008-2011	103	151	201	244
Lake Powell: 2013-2015	118	174	216	256
Lake Powell: 2016-2019	129	228	301	338
Selected Waters[a] :	116	219	297	353
Other Waters[b]	94	170	234	279

[a] Calculated from selected southeastern waters in NC, TN, and KY, from Carlander 1977.
[b] Various North American waters from Coble 1975.

Angler Survey:

Smallmouth Bass along with Striped Bass continue to constitute the majority of the catch of sport fishes on Lake Powell. In 2018 Smallmouth Bass accounted for 43% of the catch, surpassing Striped Bass for the 4th consecutive survey when combined with Largemouth Bass. Historically between 14% and 44% of anglers list black bass as their target species. In 2018, 24% of the anglers were targeting black bass compared with 33% who were pursuing Striped Bass. By far the largest group of anglers on Lake Powell are non-specific accounting for 36% of the anglers in 2018.

The Smallmouth Bass total catch was 708,233 fishes in 2018. Although this paled in comparison to the record 1,143,187 fishes caught during the previous survey in 2015 it was still the second highest ever recorded. The spring and fall months were the best producing, as usual, with May and June recording 121,407 and 129,723 fishes respectively. The fall months of September and October recorded Smallmouth Bass catches of 121,329 and 115,354 respectively. Anglers fishing the down-lake areas of the lake accounted for 418,374 fishes compared with 289,859 for those fishing the up-lake regions. This is surprising as historically anglers fishing out of the up-lake marinas account for the majority of the Smallmouth Bass catch (Table 27).

Table 27. Total catch of Smallmouth Bass by area and month estimated from the 2018 angler survey at Lake Powell.

Area	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
Down-lake	25,383	83,488	65,183	40,893	38,610	73,530	91,287	418,374
Up-lake	18,782	37,919	64,540	41,925	54,827	47,799	24,067	289,859
Total	44,165	121,407	129,723	82,818	93,437	121,329	115,354	708,233

Fishing for Smallmouth Bass on Lake Powell was unsurpassed in 2018 with a record catch rate of .96 fish/hr. October was the best month to be fishing for Smallmouth Bass with a catch rate of 1.73 fish/hr. This was the second highest monthly catch rate ever recorded, surpassed only by the previous survey (2015) catch rate of 1.81 fish/hr, also recorded in October. May accounted for the next best fishing at 1.20 fish/hr. Overall, every survey month in 2018 surpassed their historical average catch rate (Table 28). Angler's down-lake achieved greater success in every month except May and June, where up-lake anglers did better (Table 29).

Table 28. Catch rate (fish/hour) for Smallmouth Bass by month and year, Lake Powell, 1988-2018.

Year	Apr	May	Jun	Jul	Aug	Sep	Oct	Wt/Avg
1988	.02	.04	t	t	.03	.25	.06	.05
1991	.02	.10	.06	.04	.04	.21	.07	.09
1996	.33	.69	.41	.22	.37	.33	.38	.40
1997	.67	1.24	.37	.31	.32	.51	.53	.54
2000	.35	.38	.38	.43	.42	.53	.27	.39
2001	-	.46	-	-	-	-	-	-
2003	.22	.28	.16	.06	.09	.27	.66	.22
2006	.60	.48	.18	.14	.44	.16	.35	.33
2009	.83	.60	.22	.18	.23	.31	.56	.34
2012	1.20	.55	1.07	.66	.62	.82	.63	.79
2015	1.11	1.06	.61	.11	.20	.60	1.81	.70
2018	.72	1.20	.83	.87	.66	1.09	1.73	.96
Avg.	.55	.59	.39	.27	.31	.46	.64	.39

Table 29. Catch rates (fish/hr) of Smallmouth Bass by month and area, estimated from the 2018 angler survey at Lake Powell.

Area	Apr	May	Jun	Jul	Aug	Sep	Oct	Wt/Avg.
Down-lake	0.98	1.10	0.65	0.93	0.71	1.22	1.84	1.02
Up-lake	0.53	1.51	1.16	0.81	0.63	0.94	1.41	0.90
Wt/Avg.	0.72	1.20	0.83	0.87	0.66	1.09	1.73	0.96

The rapid decline of RSD-P values in 1998-2002 spurred UDWR to take management action. Increasing the harvest of Smallmouth Bass, and in particular smaller sized fishes, became a UDWR priority. The creel limit was increased from 6 Smallmouth Bass/day to 20 fishes/day and established media contacts were used to encourage anglers to harvest more of this species. Traditional black bass anglers have a "catch and release" mind-set and are reluctant to harvest black bass so it has been an uphill battle to keep harvest rates high.

A total of 109,873 Smallmouth Bass were harvested in 2018 with 76,929 from down-lake anglers and 32,944 from up-lake anglers (Table 30). Overall, 15% of the Smallmouth Bass catch was harvested throughout the creel season. Anglers fishing out of the down-lake marina's kept 18% of their Smallmouth Bass catch while those from the up-lake areas harvested only 11% (Table 31). The highest % harvested occurred in 2012 when 33% of the Smallmouth Bass catch was harvested. Ideally, a harvest of 30% plus would to work best on Lake Powell.

Table 30. Total harvest of Smallmouth Bass by area and month, estimated from the 2018 angler survey at Lake Powell.

Area	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
Down-lake	4,696	16,578	14,411	2,134	5,719	11,765	21,626	76,929
Up-lake	313	3,554	3,324	3,055	15,899	2,672	4,127	32,944
Total	5,009	20,132	17,735	5,189	21,618	14,437	25,753	109,873

Table 31. Percent harvest of Smallmouth Bass by area and month, estimated from the 2018 angler survey at Lake Powell.

Area	Apr	May	Jun	Jul	Aug	Sep	Oct	Wt/Avg.
Down-lake	18	20	22	5	15	16	24	18
Up-lake	2	9	5	7	29	6	17	11
Wt/Avg.	11	17	14	6	23	12	22	15

Conclusion:

The Smallmouth Bass fishery in Lake Powell has been an unequivocal success. Not only have they rivaled Striped Bass as the most caught species but they have supplemented the historically reduced Largemouth Bass population that is much sought after by tournament anglers. Smallmouth Bass fishing on Lake Powell has never been better with a record lake-wide mean catch rate of 0.96 fishes/hr as recorded from the 2018 angler survey. Fishing pressure was reduced in 2018 compared to the record 2015 survey or the catch would have been at a historical high. However, even with over 700,000 Smallmouth Bass caught by anglers in 2018, and over 109,000 harvested, the fishery still could sustain substantially more pressure. Twenty four percent of the anglers surveyed in 2018 stated that Smallmouth Bass was their target species, second only to Striped Bass (33%).

The population has remained in a stable state over the last 13-years with reproduction and recruitment in apparent balance with mortality. The establishment of Gizzard Shad in the reservoir in 2003 corresponded to a noticeably stronger catch of Smallmouth Bass (and other sport fishes) in the annual gill-net survey. The population appears strongest near the more productive inflow areas with the Good Hope and San Juan sampling stations averaging the highest catch in the annual fall gill-net survey.

Condition has been good with a mean Wr of 82 over the previous 28-years. Some concerns over Bass Tapeworm and the effects of the Quagga Mussel invasion, which was confirmed in 2012, still exist. Parasite loading from Bass Tapeworm appears to be negatively affecting the condition of a portion of the population, and is most prevalent at low water levels and is more pronounced at the San Juan and Rincon sites. So far the effects of the Quagga Mussel invasion have been negligible, and this after 7-years following their discovery in Lake Powell.

Improving the size structure of Lake Powell Smallmouth Bass remains a priority for UDWR. The RSD-P values that averaged 15 over the past 4-years need to be in the 20+ range. To this effect, efforts to increase harvest will have to be implemented with a goal of achieving a 30% harvest rate. The success of previous efforts in increasing harvest along with increasing the bag limit from 6 to 20 fishes corresponded to a marked increase in size structure of the population. Replicating this effort is needed once again to maintain the quality fishery that Lake Powell anglers have grown accustomed to.

WALLEYE

Introduction:

Walleye were present in the Colorado River before the impoundment of Lake Powell behind the Glen Canyon Dam. The early population was slow to develop but after the introduction of Threadfin Shad in 1968 the population began to flourish (Hepworth and Gloss 1976). The total catch of Walleye in the spring gill-net survey steadily increased from 4 fishes in 1966 to 209 fishes in 1970. By 1979 the Walleye population comprised 51% of the sport fish gill net catch (377 fishes), surpassing the historically dominate Largemouth Bass population (Gustaveson et al. 1980). In 1981, the spring gill-net catch of Walleye peaked with 594 total captures, for a catch rate of 4.99 fishes/net night (Figure 58). Although the Walleye population remained strong in the gill-net survey throughout the early 1980's they have never returned strongly to the creel (Gustaveson et al. 1980). Still, the creel survey documented the increasing Walleye population with catch rates peaking in 1985 at 0.042 fishes/hr (Scott and Gustaveson 1986).

However, by the mid 1980's the population was in decline due to reservoir stabilization and increased competition for shad forage (Blommer and Gustaveson 2011). The burgeoning Striped Bass population was able to successfully compete directly with the Walleye population for the Threadfin Shad forage base and caused the first shad population crash in 1979 down-lake followed by Bullfrog and up-lake locations in 1980. Then, with the unintentional introduction of Gizzard Shad into the reservoir in 2000, and their subsequent rapid colonization, Walleye resurgence got underway starting in 2003 with gill net catches rivaling the early fishery, and angler success rising rapidly. In response, UDWR was able to remove the creel limit on Walleye in 2012.

When UDWR began writing the latest fishery management plan for Lake Powell in 2014 a decision was made to focus on more intensive management and promotion of the Walleye fishery. The expanding Quagga mussel population and the unknown and possible negative effect that it could have on the dominate Striped Bass fishery has led UDWR to consider promoting additional fisheries. Additional concerns have been raised concerning predation by Walleye on native species in the Colorado River above Lake Powell as Walleye presumably migrate upstream following the Gizzard Shad movement into these areas. UDWR has increased its scientific inquires of the Lake Powell Walleye population and has actively promoted Walleye angling through various media resources. In 2016 UDWR promoted a fishing contest that awarded anglers prizes for catching tagged fishes that proved to be very popular.

Trend Sampling:

The annual spring gill netting tracked the rise of the Walleye fishery that peaked in 1981 before declining in the face of the burgeoning Striped Bass population. In 1997 the spring survey was discontinued and the annual fall gill-net survey, which was instigated in 1981, was used solely to assess the population. The fall survey tracked the resurgence of the Walleye population that got underway after the expansion of the Gizzard Shad population in 2003-2004 (Figure 58). Although the Walleye population expansion is reported lake-wide, the gill-net survey suggests that it is more of an up-lake phenomena with the Good Hope station accounting for 76%, 67% and 78% of the lake-wide Walleye catch over the last 3-years respectively. (Figure 59).

The lake-wide mean Walleye catch/station was 39.5 (SE = 25), 44.25 (SE = 21.9) and 40.25 (24.8) for the years 2016-2019 respectively (Figure 60). Although these catch rates were below the record 69 and 70 fish/station recorded in 2014 and 2015 they were within the range of the average of 43.8 fishes/station established since 2003 when Walleye began their resurgence. The high variability in the estimate reflects the discrepancy in the catch between Good Hope and the other stations.

The catch of Walleye from the Good Hope station has remained elevated when compared to stations further downstream in the system. Total catch at Good Hope over the previous three years was 114, 118 and 126 respectively. Since their resurgence up-lake in 2003, the Walleye catch at Good Hope has averaged 140 fishes/ standard sample (SD = 76) compared to a mean total catch of 21 fishes/ standard sample (SD = 16) for the years 1981 – 2002. Based on gill-net sampling alone, the up-lake station at Good Hope Bay has been the only station that experienced resurgence in the Walleye population. However, anecdotal evidence as well as creel survey data strongly suggests that populations in mid and down-lake areas have also increased.

The catch of Walleye in the annual fall gill-net survey was positively correlated with the mean catch of pelagic shad sampled in the mid-water trawl survey ($r = .56$, $p = .03$, Pearson Correlation; Figure 61). It is believed that the increased catch of Walleye is at least partially measuring increased activity levels brought on by increased forage abundance and reflects Walleye activity and not necessarily attributed to a population level increase. Other major sport fishes exhibit a similar response on Lake Powell.

Determining reproductive success and recruitment of Walleye cohorts is difficult as YOY fishes are rarely captured in the annual electrofishing survey. Scale aging and analyses has also been difficult and inconclusive. UDWR collected a subsample of otoliths in 2018 and work is underway to mount and perform age and growth analysis on this sample, with the goal of making this a routine part of our annual gill-net survey sampling protocol. However, length frequency data, incidental mid-water trawl data and stomach analysis of predators collected in the annual fall gill-net survey have been somewhat useful in identifying particularly strong cohorts.

Incidental mid-water trawl catches of YOY Walleye and predator diet studies suggested a strong 2014 cohort (Blommer and Gustaveson 2017). No YOY Walleye have been collected in the mid-water trawl or electrofishing sampling through 2018 and only a single YOY Walleye was found in the stomach of a Striped Bass in 2018. However, length frequency analysis of Walleye captured in the annual fall gill-net survey suggest a stronger cohort was produced in 2017 which showed up as yearlings in the 2018 sampling. Overall, the Walleye population has remained strong and appears to display consistent recruitment.

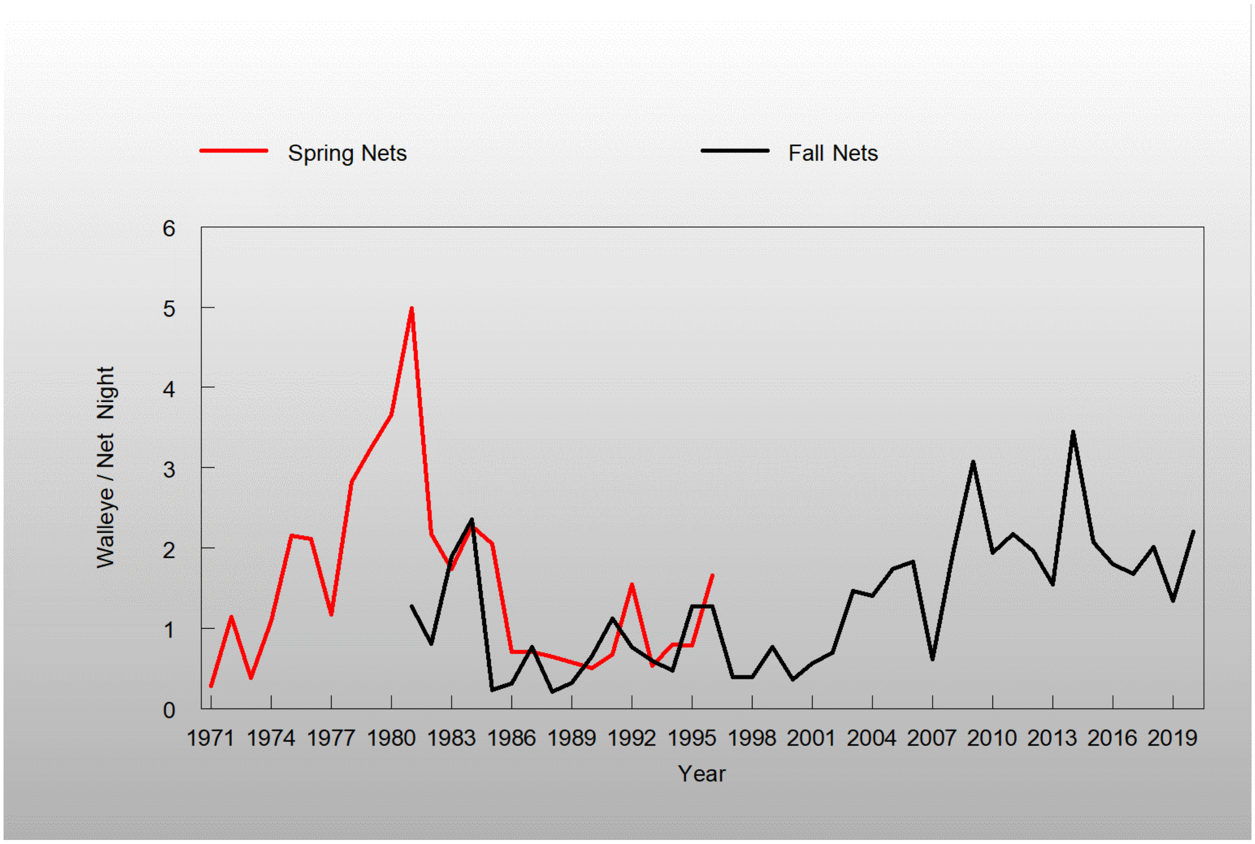


Figure 58. Catch of Walleye per net night in the annual spring gill net survey (red) and the annual fall gill-net survey (black), 1971-2020, Lake Powell, Utah/Arizona.

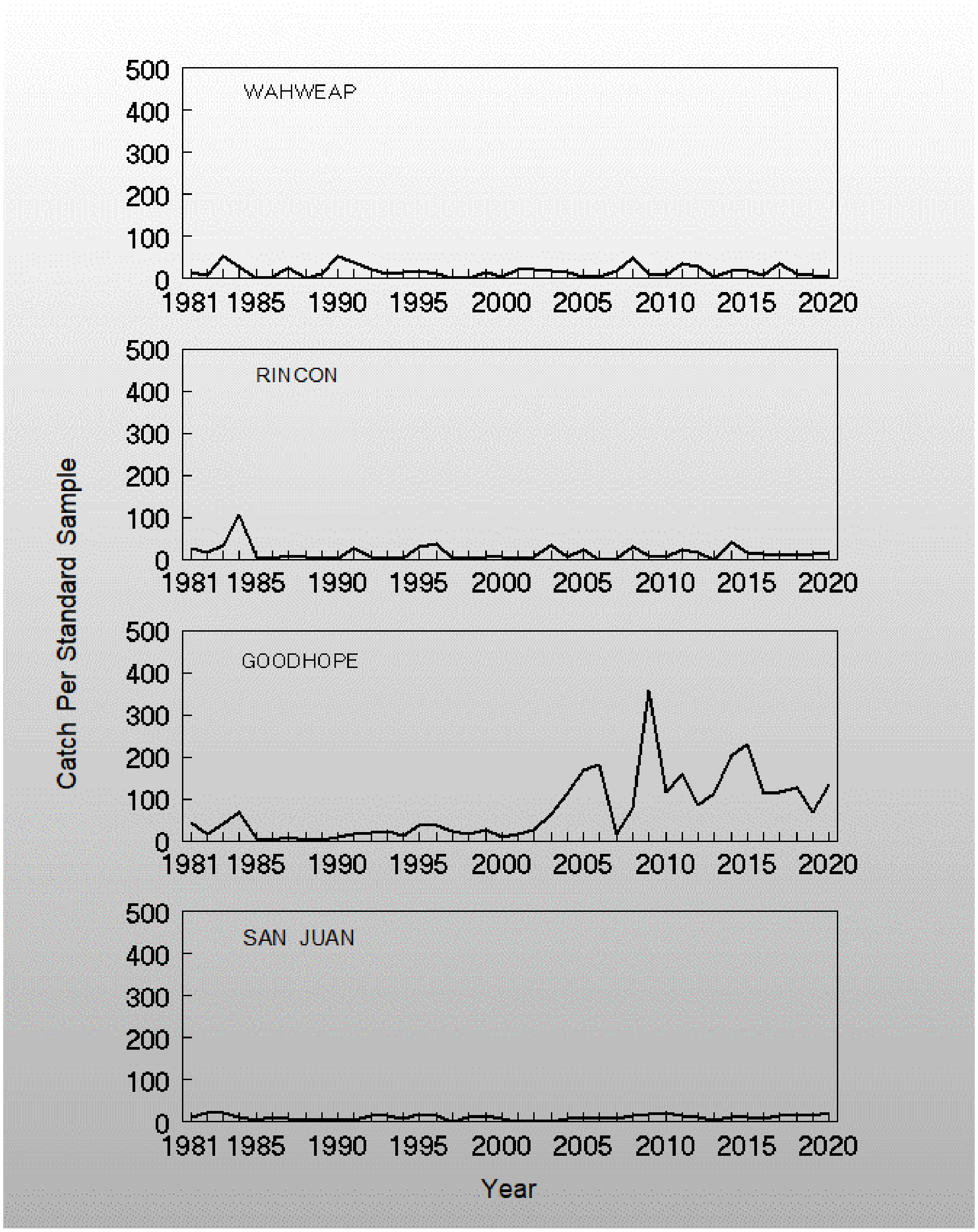


Figure 59. Standard fall gill-net catch of Walleye at various stations on Lake Powell, 1981-2020.

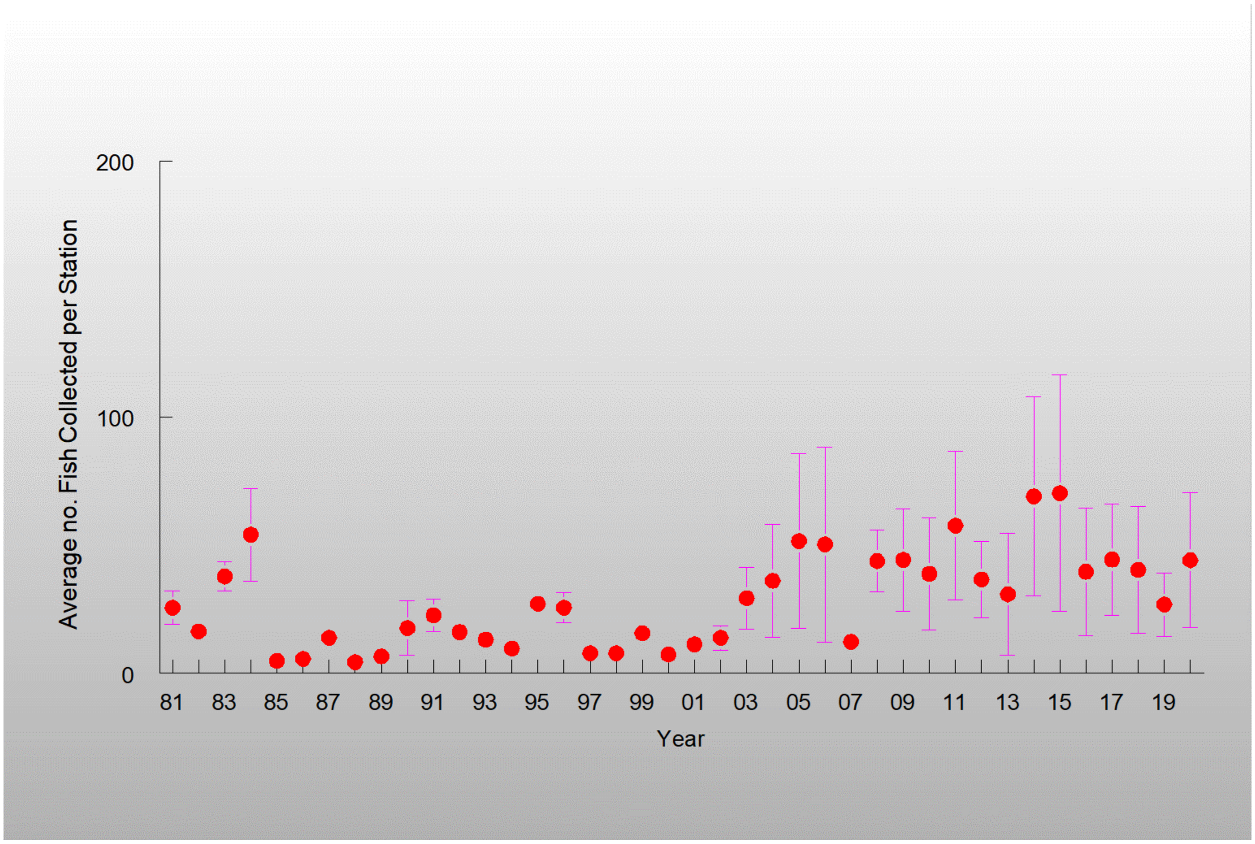


Figure 60. Average number of Walleye collected per station from the annual fall gill-net survey, 1981-2020, Lake Powell, Utah/Arizona

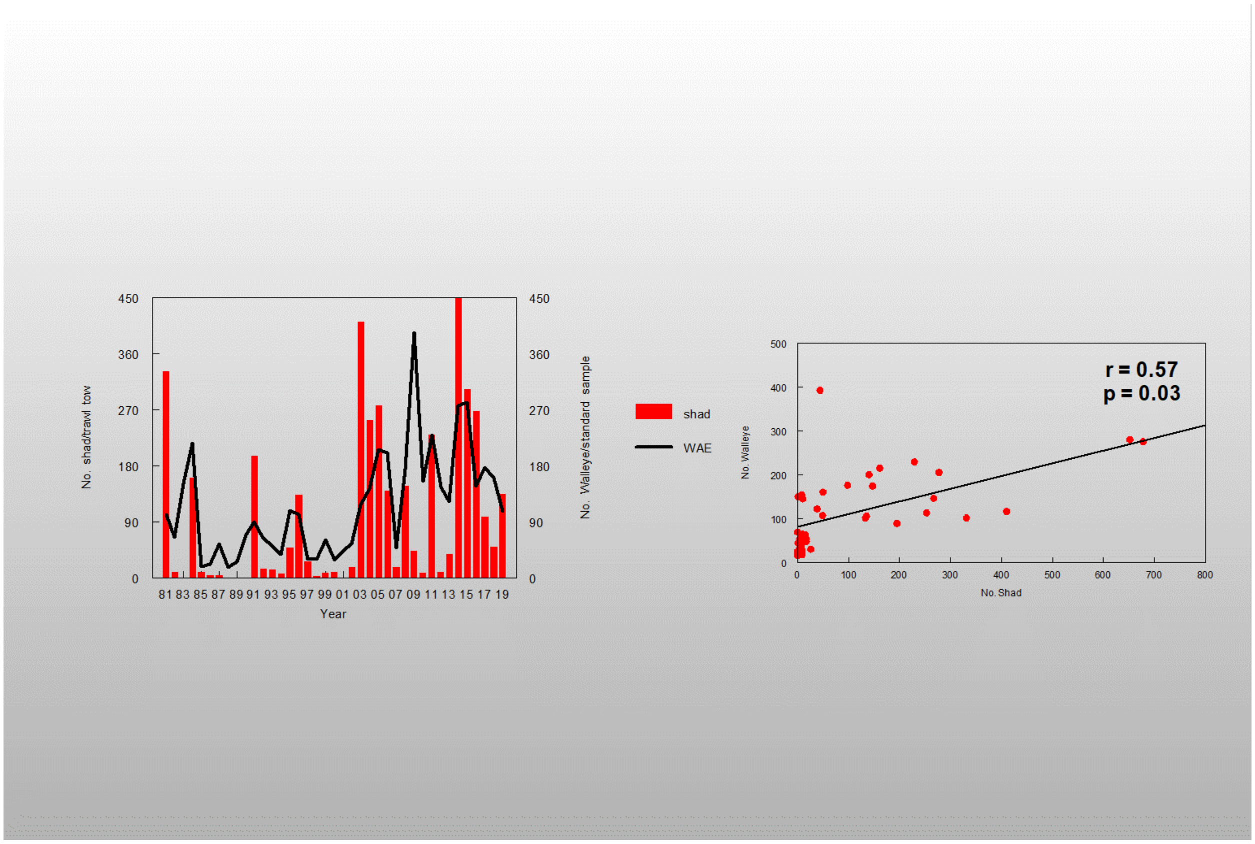


Figure 61. Relationship between the total number of Walleye collected in the annual fall gill-net survey and the mean number of shad collected per trawl tow, 1981-2019, Lake Powell, Utah/Arizona.

Angler Survey:

The percentage of anglers targeting Walleye has continued to increase with 6% of anglers targeting Walleye in 2018 compared with 5% from the 2015 survey and 2% in 2012. Up-lake anglers targeted Walleye 9% of the time while down-lake anglers targeted them 3% of the time. If anglers stating no species preference are factored out: 8% of anglers' lake-wide targeted Walleye in 2018.

The 2018 angler survey indicated a lake-wide Walleye catch rate of 0.06 fish/hr. This continues the up-tick in Walleye catch rates which was first recorded during the 2012 angler survey (Table 32). Up-lake catch rates were typically higher than those down-lake with 0.08 fish/hr caught in the upper lake compared to 0.04 fish/hr in the lower reaches (Table 33). The catch rate for anglers targeting Walleye was 0.49 fish/hr, which suggests that Walleye fishing can be somewhat of a specialized endeavor. This rate compares favorably to the 0.39 fish/hr recorded in the 2015 survey.

April, May and June were the best months to fish for Walleye up-lake with catch rates of 0.08, 0.10 and 0.08 fish/hour respectively while down-lake anglers had the most success in May (0.08 fish/hr) and August (0.13 fish/hr).

Table 32. Catch rate (fish/hr) for Walleye by month and year, Lake Powell, 2000-2018.

Year	Apr	May	Jun	Jul	Aug	Sep	Oct	Wt/Avg.
2000	0.01	0.02	0.02	*t*	*t*	0.01	*t*	0.01
2006	0.02	0.05	0.02	0.01	0.01	0.01	0.01	0.02
2009	*t*	0.04	0.02	*t*	0.02	0.01	*t*	0.01
2012	0.09	0.09	0.13	0.18	0.16	0.02	0.04	0.10
2015	0.15	0.08	0.07	0.01	0.01	0.01	0.01	0.04
2018	0.08	0.10	0.08	0.03	0.08	0.03	0.04	0.06
Avg.	0.06	0.06	0.06	0.04	0.05	0.01	0.01	0.04

Table 33. Catch rates (fish/hr) of Walleye by month and area, estimated from the 2018 angler survey at Lake Powell.

Area	Apr	May	Jun	Jul	Aug	Sep	Oct	Wt/Avg.
Down-lake	0.01	0.08	0.03	0.01	0.13	*t*	0.03	0.04
Up-lake	0.13	0.14	0.13	0.04	0.04	0.07	0.04	0.08
Wt/Avg.	0.08	0.10	0.08	0.03	0.08	0.03	0.04	0.06

A total of 46,634 Walleye were caught by anglers during the 2018 creel survey. This compares with 62,255 Walleye caught during the 2015 survey where fishing pressure was considerably higher (Figure 62). Down-lake fishers caught 21,617 Walleye while up-lake anglers caught 25,017 Walleye (Table 34). There were considerably more Walleye caught down-lake in 2018 than the 8,553 that were captured in 2015, but only about half of the 53,702 Walleye captured up-lake in 2015. Increased pressure down-lake relative to pressure up-lake and increased success compared to past years at down-lake areas allowed for the strong down-lake Walleye catch and suggests a stronger population in this area than might be deduced from gill-net sampling alone.

Walleye are considered excellent table-fare and Lake Powell anglers harvested 92% of the catch for a total of 43,017 (SE = 11,691) fishes. In comparison, the species with the next highest harvest rates were Striped Bass (77%) and Black Crappie (30%). Down-lake anglers harvested 18,950 Walleye while up-lake anglers harvested 24,067 Walleye for harvest rates of 88% and 96% respectively (Table 35). These harvest rates were considerably above the total lake-wide harvest rate of 64% recorded in the previous 2015 survey and the 85% reported from the 2012 survey.

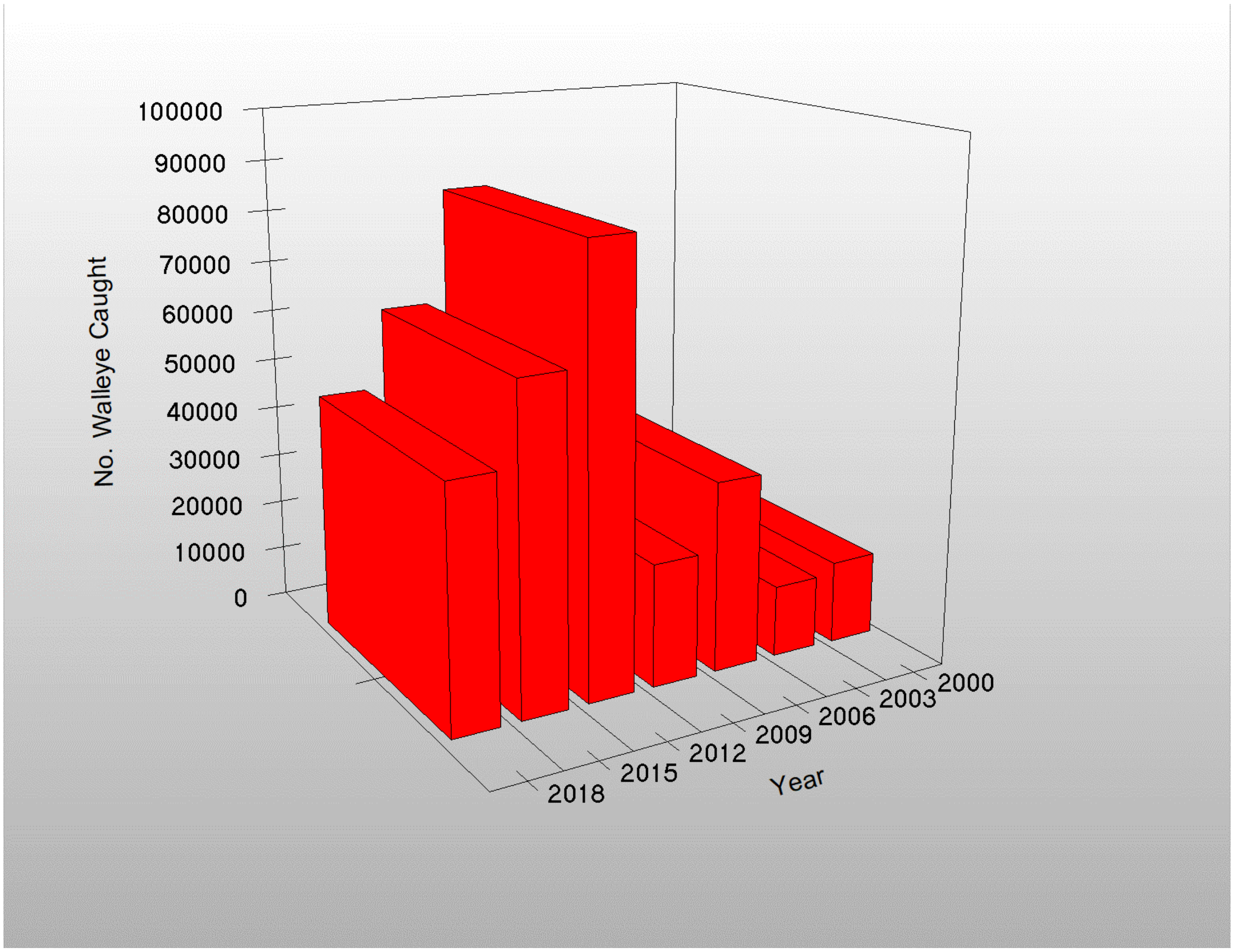


Figure 62. Total catch of Walleye by anglers, estimated from the April-Oct 2018 angler survey, Lake Powell, Ut.

Table 34. Total catch of Walleye by area and month estimated from the 2018 angler survey at Lake Powell.

Area	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
Down-lake	306	6,254	5,111	646	7,174	378	1,748	21,617
Up-lake	4,520	3,427	7,167	1,984	3,885	3,396	638	25,017
Total	4,826	9,681	12,278	2,630	3,375	3,774	2,386	46,634

Table 35. Total harvest of Walleye by area and month estimated from the 2018 angler survey at Lake Powell.

Area	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
Down-lake	306	5,248	5,111	647	7,174	213	251	18,950
Up-lake	4,207	3,182	4,930	1,147	8,667	1,296	638	24,067
Total	4,513	8,430	10,041	1,794	15,841	1,509	889	43,017

Diet and Condition:

Shad continue to be the food item most common in the stomachs of gill-net caught Walleye. Shad accounted for 73%, 78% and 72% occurrence of food items in the stomachs of Walleye collected in the annual fall gill-net survey for the years 2016-2018 respectively. This compares favorably with the 70% historical average (2004-2018) and points to the importance of shad forage in maintaining a successful Walleye population. While most shad were not identifiable to the species level, Gizzard shad were only identifiable in a single stomach in 2016 and no stomachs in 2017 and 2018. They were first identified in Walleye stomachs of gill-net collected fishes in 2007 where they represented 33% of identifiable shad. They were not identified in Walleye stomachs again until 2013 where they made up 50% of identifiable shad. They accounted for 23% and 37% of identifiable shad in 2014 and 2015 respectively. The vast majority of identifiable shad have continued to be Threadfin Shad. However, with the gill-net survey occurring in fall most of the faster growing Gizzard Shad are perhaps less available than earlier in the season. It is a real possibility that Gizzard Shad account for a sizable portion of the yearly Walleye diet.

Unidentifiable fish are the next most occurring food item and most of these are suspected of being shad. Centrarchids occurred in 8%, 9% and 5% of the Walleye stomachs that contained food for the years 2016-2018 respectively. This was fairly typical and compares with the 6% historical average for the years 2004-2015. Walleye are an opportunistic piscivorous species and other fish species identified in their stomachs during the last 15-years of the annual gill-net survey include Channel Catfish, Striped Bass and even other Walleye.

The condition factor (Ktl) of Walleye captured in the annual fall gill-net survey has historically remained largely stable: averaging 0.89 (SD = 0.05) over the length of the survey (1988-2019). The Ktl for the previous 4-years (2016-2019) was 0.83, 0.90, 0.82, and 0.93 respectively (Figure 63). Currently and historically, condition factors parallel the productivity gradient with the inflows and upper-lake areas at the San Juan and Good Hope net stations capturing Walleye that average higher Ktl values than the down-lake station at Wahweap and the mid-lake station at the Rincon (Table 36). Since the establishment of Gizzard Shad in 2004 Walleye Ktl has become closer tied to pelagic shad abundance. However, comparing the mean condition of pre and post Gizzard Shad Walleye captured in the annual fall gill-net survey show no statistical difference with pre years (1989-2003) having a mean condition factor of 0.9 (SD = 0.05) and post years of 0.87 (SD = 0.05).

Immediately following the establishment of Gizzard Shad the mean TL and weight of Walleye collected in the annual fall gill-net survey decreased due to a number of strong year classes being produced: presumably in response to increased forage opportunities (Blommer and Gustaveson 2017). The years 2016-2018 showed a more typical ratio of yearling (200mm – 300mm) to older (300mm + TL) fishes (Figure 64). Although, Mean TL for these years (2016-2018) were still below the historical pre-Gizzard Shad mean TL of 361mm (1997-2003). Larger Walleye would be more desirable from an angler stand point and hopefully the management goal of increasing harvest will allow for improved growth.

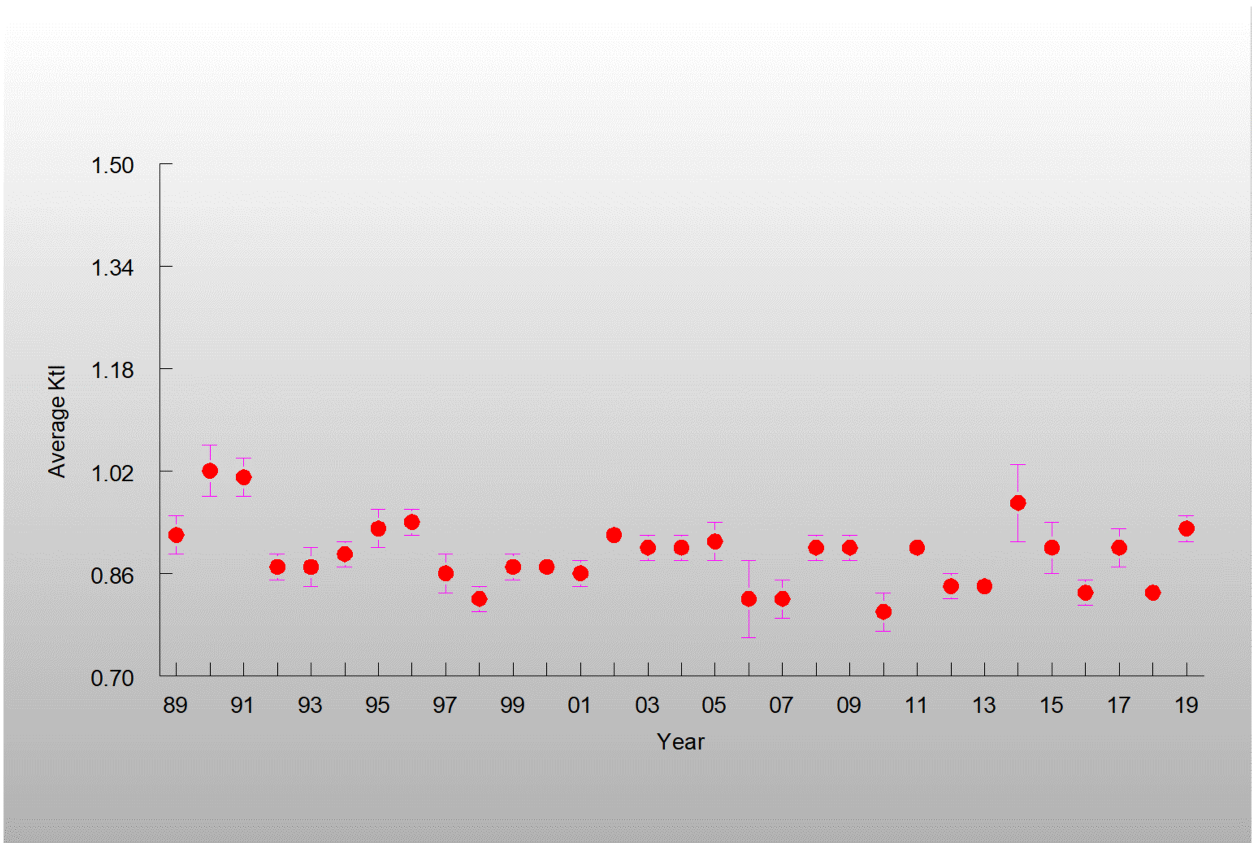


Figure 63. Mean condition (Ktl) of Walleye per station from the annual fall gill-net survey with SE, Lake Powell, UT/AZ, 1989-2019.

Table 36. Condition (Ktl) of Walleye collected in the fall gill-net survey, Lake Powell, UT, 2016-2018.

Location	**Year**			***Mean Ktl***
	2016	2017	2018	
Wahweap	0.78	0.86	0.81	*0.82*
Rincon	0.80	0.82	0.84	*0.82*
San Juan	0.91	0.97	0.81	*0.90*
Good Hope	0.84	0.94	0.83	*0.87*
Mean	*0.83*	*0.90*	*0.82*	0.85

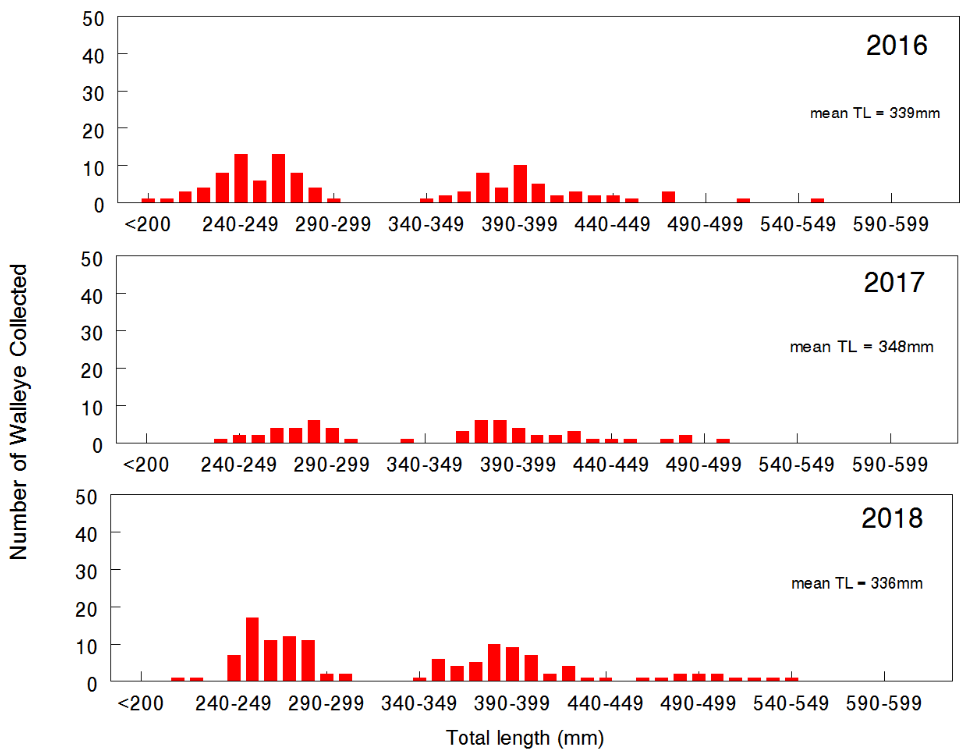


Figure 64. Length frequency of Walleye captured in the annual fall gill-net survey at Good Hope Bay, Lake Powell, Utah/Arizona 2016-2018.

Conclusion:

The continued strength of the Walleye population, particularly in the upper-lake regions, is encouraging. With the latest resurgence, anglers have responded by increasingly targeting them in the creel. Recent angler catch rates were at an historical high and UDWR attempts to highlight and promote the fishery have been largely successful to date. We credit the establishment of Gizzard Shad for the strong return of Walleye into the fishery. Not only did Gizzard Shad provide additional direct forage but probably removed some of the intense predatory pressure on the Threadfin Shad population. This mitigated the violent swings plaguing the historical Threadfin Shad population that existed following the lake-wide establishment of Striped Bass. Although annual gill-net sampling suggests that the population increase has been mainly up-lake the angler survey suggests that the down-lake population was also increasing.

Increased promotion of the fishery is paramount in the face of uncertainty over the effects that Quagga mussels may have on the Lake Powell fish assemblage as well as the effects of warming water temperatures. Removing the creel limits on Walleye was a positive first step. Promoting the Walleye fishery through media coverage and fishing contests is also vital in allowing UDWR to structure the fishery and keep it healthy and producing well into the future.

OTHER SPECIES OF INTEREST

Largemouth Bass:

Largemouth Bass continue to generate angler interest at Lake Powell although the population is much diminished from the early years of the impoundment. Historically, 924,000 Largemouth Bass fingerlings were stocked shortly following impoundment in 1963. A second stocking occurred the following year when 2 million fingerlings were stocked. From these original stockings an exciting fishery rapidly developed that lasted for approximately 20 years.

Largemouth Bass are dependent upon brush produced by extended lake level decline followed by rapid flooding of the brush zone. Newly inundated brush results in a recovery of the size and number of the Largemouth Bass population by providing nursery habitat thus increasing YOY survival and recruitment (Figure 65). The Largemouth Bass population will continue to fluctuate as water levels cycle through periods of drought but their popularity will remain high with interest maintained by the many tournament anglers using Lake Powell.

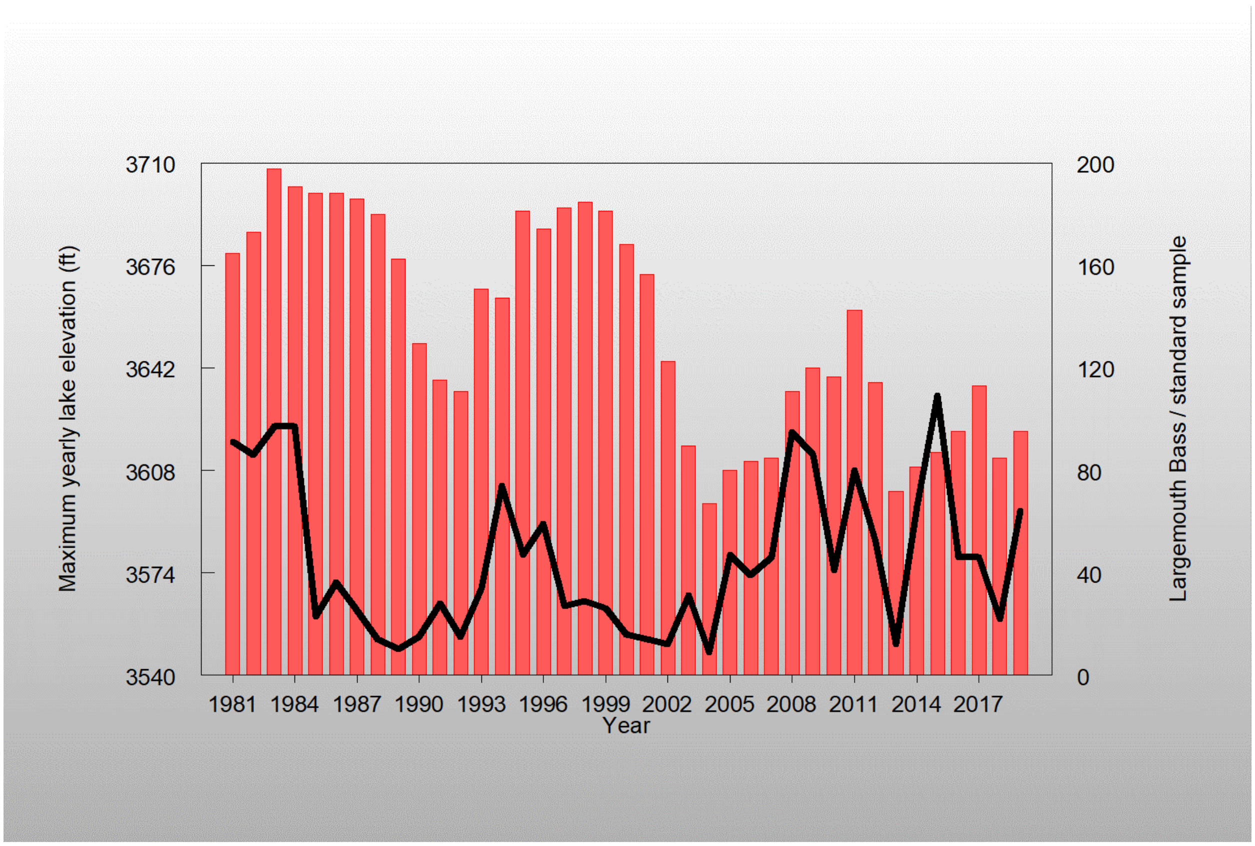


Figure 65. Relationship between maximum yearly lake elevation (Bar) and the total number of Largemouth Bass collected from the annual fall gill-net survey (line), Lake Powell, 1981-2019.

Like other species, Largemouth Bass began returning to the annual fall gill-net survey at a higher rate following the establishment of Gizzard Shad. Form 2005 to the present the mean catch has been 14 fishes/station (SD = 6.4) compared to 7 fishes/station (SD = 4.1) for the years 1985-2004 (Figure 66). Over the previous 4-years the survey catch of Largemouth Bass was strongly correlated with the change in lake elevation (Figure 67). The same is true for recruitment. Unlike Smallmouth Bass, successful recruitment of YOY Largemouth Bass is largely dependent upon rising water levels. The catch of YOY Largemouth Bass from the annual electrofishing survey is significantly correlated (r = .62, p = .005) with rising water levels over the previous year when the CPUE data were transformed [$\log_{10}(n+1)$] to better meet the assumptions of normality (Figure 68). However, this relationship holds true only up to a point. If the water level increase is too drastic the catch will stabilize or begin to decrease. We postulate that brushy habitat improves YOY survival by providing cover from predators and increased centrarchid foraging opportunities.

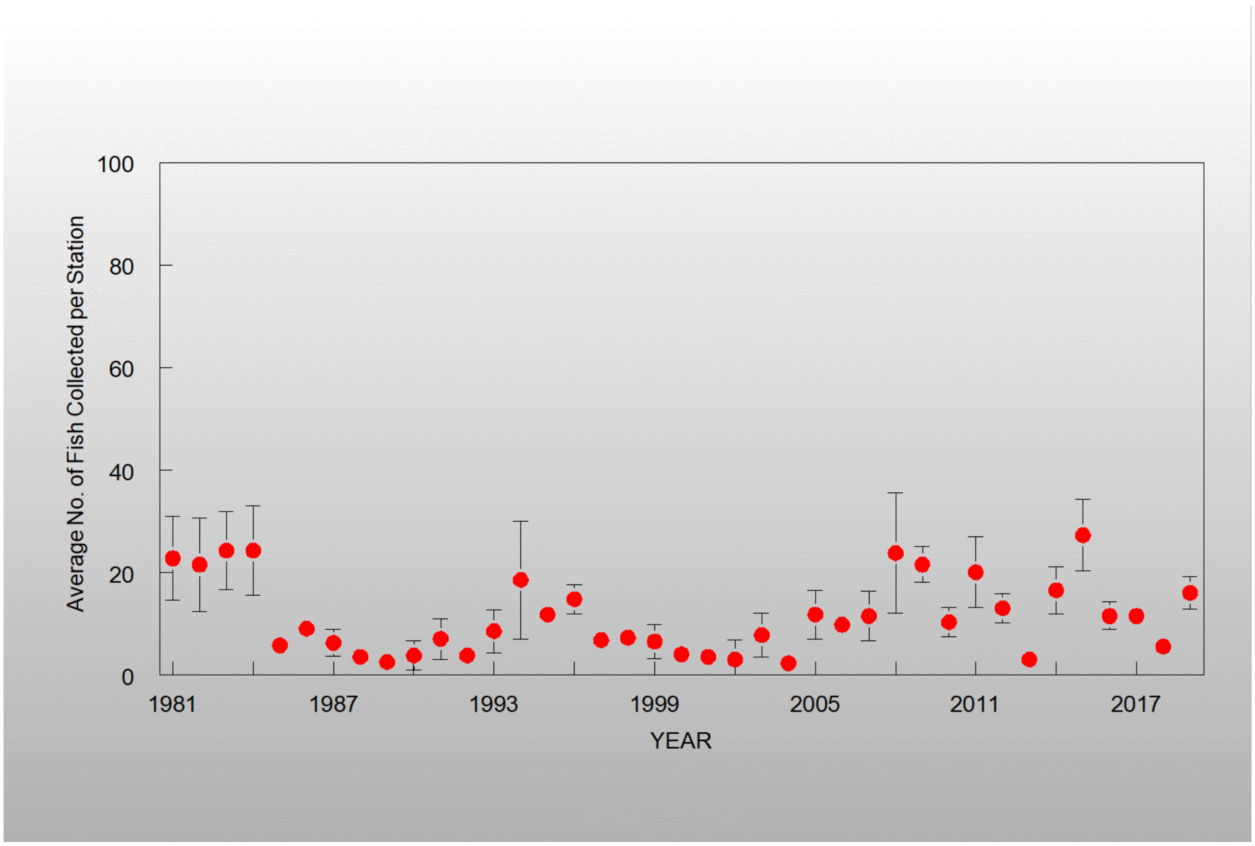


Figure 66. Mean catch of Largemouth Bass per station from the fall gill-net survey with SE, Lake Powell, 1981-2019.

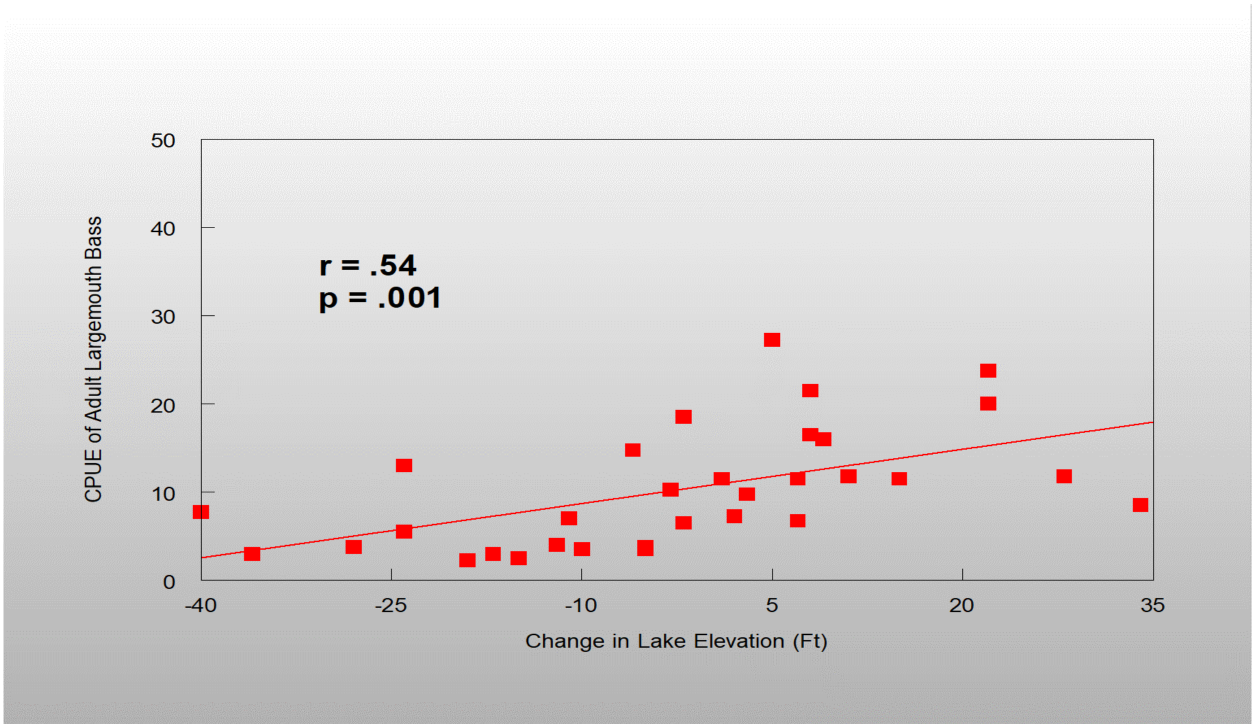


Figure 67. Correlation (Pearson) between the yearly change in maximum lake elevation and the mean catch/station of Largemouth Bass in the annual fall gill-net survey, Lake Powell, 1988-2019.

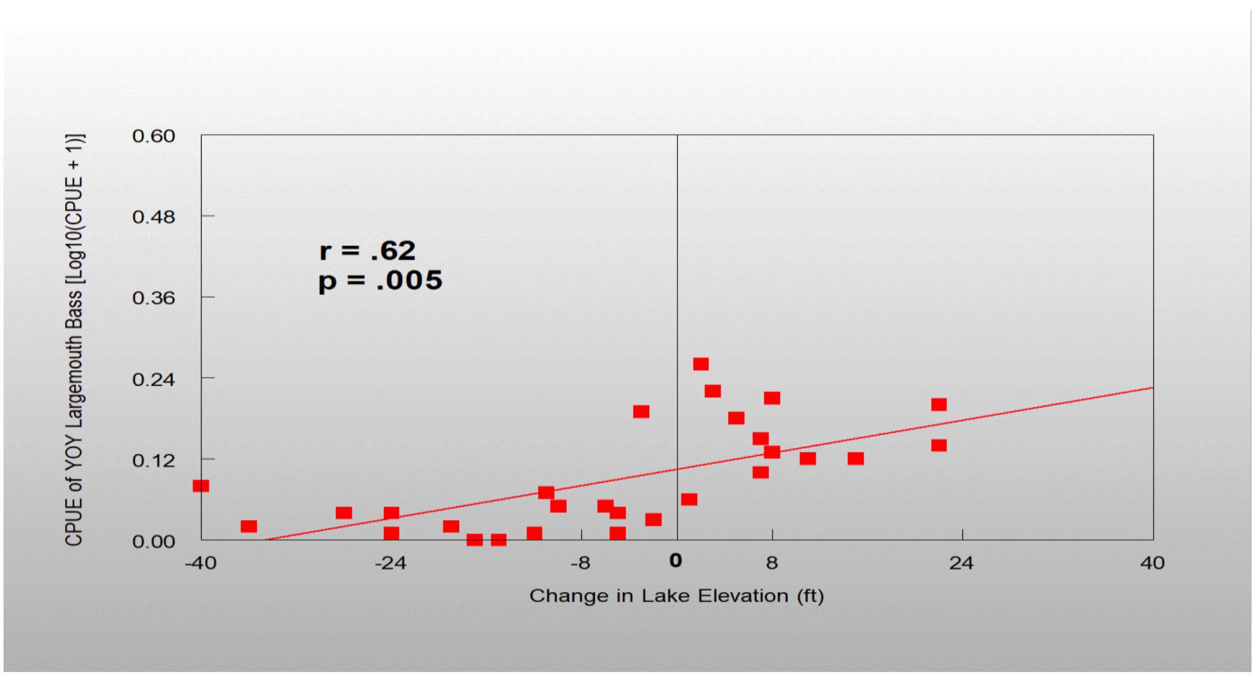


Figure 68. Correlation (Pearson) between the change in maximum lake elevation and the catch of YOY Largemouth Bass from the annual electrofishing survey, Lake Powell, 1988-2018.

Recruitment of YOY Largemouth Bass, as evidenced by the numbers captured in the annual fall electrofishing survey, declined drastically in 1986, shortly following the filling of the reservoir, which topped out in 1983 (Figure 69). Historically, Largemouth Bass recruitment was much stronger in 1978-1986, averaging 78 fishes/hr/station (SD = 40). The lake filling and the introduction of Smallmouth Bass in 1982 probably combined to suppress the Largemouth Bass population. Loss of productivity and habitat after initial reservoir filling and competition for forage from Smallmouth Bass were theorized as the main culprits (Blommer and Gustaveson 2017).

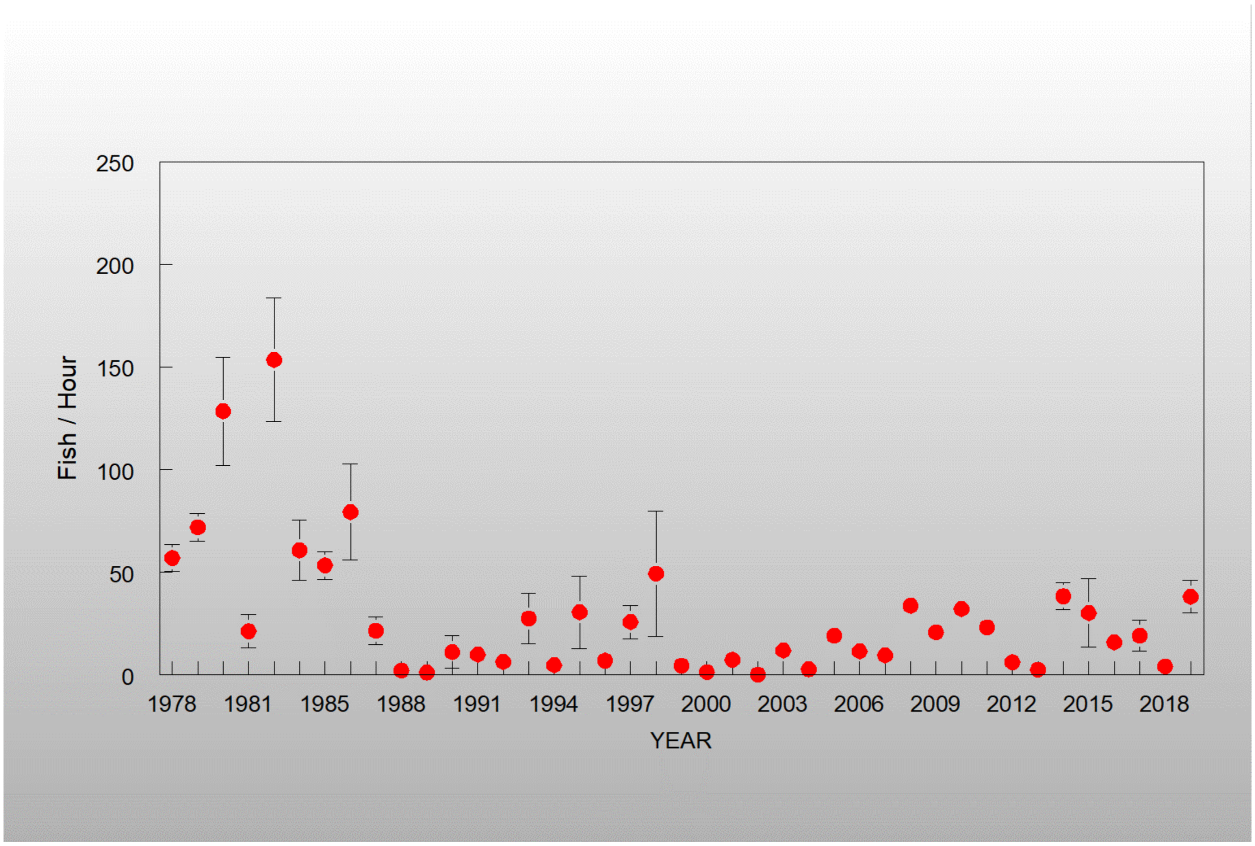


Figure 69. Mean catch per hour per station of YOY Largemouth Bass (TL < 200mm) from the annual fall electrofishing survey with SE, Lake Powell, 1978-2019.

The catch of Largemouth Bass from the annual fall gill-net survey can be variable between sites and between years. However the mean catch/station from 1981-2019 is fairly consistent ranging from 9.3 fishes/survey to 14.4. The Good Hope Bay station has the highest historical mean catch at 14.4 fishes/survey (SD = 14.1) followed by Wahweap at 11.4 fishes/survey (SD = 10.6), Rincon at 11.3 (SD = 10.6), and the San Juan at 9.3 (SD = 6.0); (Figure 70). However, no historical statistical difference exists between sites (ANOVA, alpha = .05).

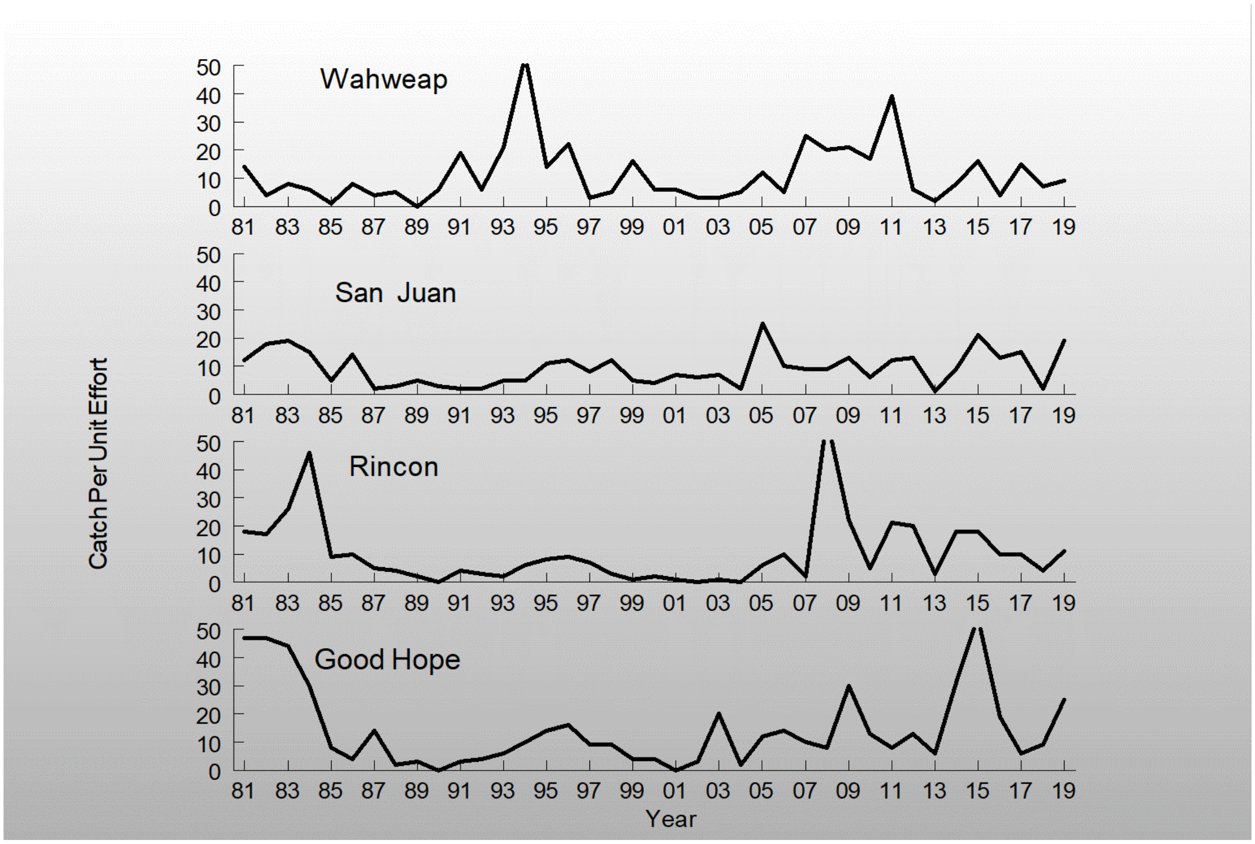


Figure 70. Catch per standard sample of Largemouth Bass from the annual fall gill-net survey, Lake Powell, 1981-2019.

The catch of Largemouth Bass estimated from the 2018 creel survey was 65,859 (± 12,484) fishes over the 7-month survey period. This compares with the 150,660 (± 23,342) estimate from the previous creel survey in 2015. The 40-year low in recorded fishing pressure was the major factor accounting for the limited catch in 2018. The estimated catch of Largemouth Bass represented 4% of the total survey catch. Up-lake anglers caught 38,597 Largemouth Bass compared with 27,262 fishes down-lake (Table 37).

Angling success was considerably better up-lake with a catch rate of 0.12 fishes/hr opposed to down-lake where the rate was only 0.07 fishes/hr (Table 38). The overall catch rate of 0.09 fishes/hr lagged behind that of Smallmouth Bass (0.96), Striped Bass (0.83), Bluegill and Channel Catfish (0.11).

Table 37. Total catch of Largemouth Bass by area and month estimated from the 2018 angler survey at Lake Powell.

Area	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
Down-lake	2,807	7,344	6,649	1,401	541	3,540	4,980	27,262
Up-lake	864	2,310	9,328	4,786	13,963	5,245	2,101	38,597
Total	3,671	9,654	15,977	6,187	14,504	8,785	7,081	65,859

Table 38. Catch rates (fish/hr) of Largemouth Bass by month and area, estimated from the 2018 angler survey at Lake Powell.

Area	Apr	May	Jun	Jul	Aug	Sep	Oct	Wt/Avg.
Down-lake	0.11	0.10	0.07	0.03	0.01	0.06	0.10	0.07
Up-lake	0.02	1.66	0.17	0.09	0.16	0.10	0.12	0.12
Wt/Avg.	0.06	0.09	0.10	0.06	0.10	0.08	0.11	0.09

A total of 3,695 Largemouth Bass were harvested in 2018 (Table 39). This represented only 6% of the total Largemouth Bass catch and was significantly below the 15% harvest rate reported during the previous survey in 2015. Up-lake anglers harvested only 4% of their catch opposed to down-lake anglers who harvested 9% (Table 40).

Table 39. Total harvest of Largemouth Bass by area and month, estimated from the 2018 angler survey at Lake Powell.

Area	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
Down-lake	966	1,053	175	0	0	0	150	2,344
Up-lake	0	183	770	99	299	0	0	1,351
Total	966	1,236	945	99	299	0	150	3,695

Table 40. Percent harvest of Largemouth Bass by area and month, estimated from the 2018 angler survey at Lake Powell.

Area	Apr	May	Jun	Jul	Aug	Sep	Oct	Wt/Avg.
Down-lake	34	14	3	0	0	0	3	9
Up-lake	0	8	8	2	2	0	0	4
Wt/Avg.	26	13	6	2	2	0	2	6

Although diet overlap exists between Largemouth Bass and Smallmouth Bass to a large extent, the mean historical (1994-2019) percent occurrence of centrarchids was greater in Largemouth Bass (31%) when compared with Smallmouth Bass (18%). Both species relied heavily on crayfish but more so Smallmouth Bass (54%) when compared with Largemouth Bass (38%). Both also utilized shad species when they were available with the mean % occurrence in Largemouth Bass stomachs at 14% compared with 12% for Smallmouth Bass. Correlation analyses showed a significant relationship between the % occurrence of shad in Largemouth as well as Smallmouth Bass stomachs and the abundance of pelagic shad as measured from the mid-water trawl survey at alpha = 0.05. Furthermore, a positive relationship (Pearson; r = 0.65, p = .0003) existed between the catch of shad in the annual fall electrofishing survey and the % occurrence of shad in Largemouth Bass stomachs collected from the annual fall gill-net survey. However, partial spatial segregation allows Largemouth Bass to forage more in the littoral zone where centrarchid species predominate (Table 41).

Table 41. % occurrence, and number ( ) of major food items in the stomachs of Largemouth Bass that contained food, collected in the annual gill-net survey. Lake Powell 2004-2019.

			% OCCURRENCE				
YEAR	# Checked	# w/Food	Crayfish	Shad	Unk Fish	Centrarchids	Other
2004	8	2	50(1)	0	50(1)	0	0
2005	41	13	15(2)	38(5)	23(3)	15(2)	8(1)
2006	27	15	93(14)	0	0	7(1)	0
2007	43	28	36(10)	75(21)	89(25)	39(11)	18(5)
2008	90	34	18(6)	6(2)	18(6)	38(13)	6(2)
2009	68	30	33(10)	0(0)	7(2)	76(23)	0(0)
2010	39	19	53(10)	5(1)	26(5)	26(5)	0(0)
2011	58	25	16(4)	24(6)	36(9)	32(8)	0(0)
2012	37	16	50(8)	0	6(1)	50(8)	6(1)
2013	12	3	100(3)	0	0	0	0
2014	65	26	0	35(9)	27(7)	31(8)	4(1)
2015	80	35	6(2)	29(10)	23(8)	37(13)	5(2)
2016	44	13	38(5)	15(2)	15(2)	30(4)	8(1)
2017	40	15	13(2)	0	13(2)	60(9)	0
2018	19	9	78(7)	0	11(1)	22(2)	0
2019	54	23	9(2)	4(1)	26(6)	39(9)	9(2)
MEANS			38	14	23	31	4

Condition (Ktl) of Largemouth Bass in Lake Powell has always been good even in the face of somewhat slower growth and the presence of Bass Tapeworm (Blommer and Gustaveson 2017). Researchers on the lake have long noted that the infestation of Bass Tapeworm is not as pronounced in Largemouth Bass compared with Smallmouth Bass, and fillets are thicker from the former compared with the latter. Condition has declined in later years (2000-2019) at 1.29 (SD = 0.08) compared with earlier (1983-1999) years at 1.47 (SE = 0.06). The 2 lowest lake-wide mean condition values have been recorded in the last 7-years (Figure 71). Historically, Wahweap and Good Hope stations have recorded the best mean condition factors followed by the Rincon and the San Juan (Table 42).

In 2019 the mean Condition (Ktl) was at a historical low (1.17, SE = 0.04) for Largemouth Bass collected in the annual fall gill-net survey. This was surprising given that the forage situation was favorable in terms of centrarchids and pelagic shad abundance. However, condition for the previous 3-years has been highly variable with condition also being low in 2016 but relatively high in both 2017 and 2018 (Figure 71). The sample size is often low when collecting Largemouth from the annual fall gill-net survey so caution is necessary when interpreting data.

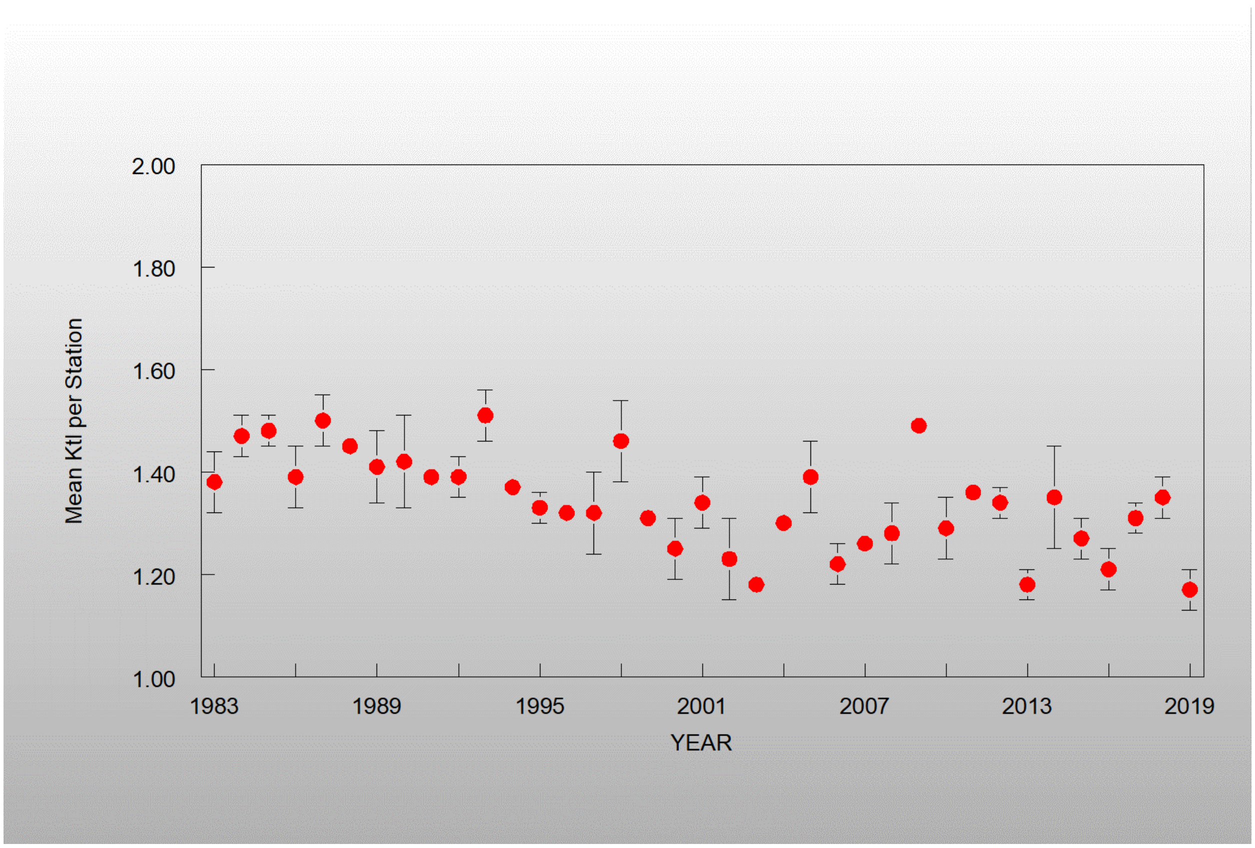


Figure 71. Mean condition (Ktl) of Largemouth Bass per station from the annual fall gill-net survey with SE, Lake Powell, 1983-2019.

Table 42. Mean Ktl of Largemouth Bass collected in the annual fall gill-net survey, Lake Powell, 2000-2019.

	Ktl (N)			
YEAR	Wahweap	San Juan	Rincon	Good Hope
2000	1.32 (5)	1.34 (4)	1.27 (2)	1.03 (4)
2001	1.29 (6)	1.21 (7)	1.41 (1)	-
2002	1.31 (3)	1.08 (6)	-	1.19 (3)
2003	1.16 (3)	1.17 (7)	1.20 (1)	1.10 (20)
2004	1.24 (5)	1.29 (2)	-	1.34 (1)
2005	1.62 (4)	1.22 (26)	1.29 (6)	1.31 (6)
2006	1.16 (5)	1.20 (7)	1.21 (5)	1.36 (7)
2007	1.25 (25)	1.25 (7)	1.25 (2)	1.22 (8)
2008	1.23 (20)	0.94 (9)	1.27 (58)	1.33 (4)
2009	1.52 (18)	1.44 (13)	1.50 (22)	1.47 (15)
2010	1.41 (15)	1.24 (6)	1.13 (5)	1.31 (13)
2011	1.37 (36)	1.26 (12)	1.24 (21)	1.26 (4)
2012	1.34 (6)	1.25 (11)	1.40 (10)	1.33 (12)
2013	1.07 (2)	1.18 (1)	1.24 (3)	1.22 (6)
2014	1.69 (8)	1.23 (9)	1.17 (18)	1.30(31)
2015	1.27 (16)	1.34 (21)	1.16 (18)	1.25 (25)
2016	1.32 (4)	1.11 (13)	1.19 (9)	1.24 (18)
2017	1.43 (15)	1.24 (14)	1.28 (10)	1.28 (2)
2018	1.28 (7)	1.31 (2)	1.32 (4)	1.51 (8)
2019	1.14 (8)	1.11 (18)	1.13 (11)	1.30 (25)
MEANS	**1.32**	**1.22**	**1.26**	**1.28**

Channel Catfish:

Channel Catfish are a pre-impoundment species that continues to flourish in the reservoir. Although less than 1% of anglers list them as their target species they are usually the third most frequently caught species on Lake Powell, although in 2018 they were edged out by Bluegill Sunfish. During the 2018 creel survey a total of 33,204 (± 10,761) Channel Catfish were caught lake-wide. Down-lake anglers accounted for 60% of the catch and up-lake accounted for 40%. Lake-wide, Channel Catfish represented approximately 5% of the total survey catch.

The catch rate was the same as the previous survey conducted in 2015 at 0.11 fishes\hr. Anglers were more successful down-lake (0.12 fishes/hr) compared to up-lake (0.10 fishes/hr). The best fishing month was August with a catch rate of .19 fishes/hr.

Lake-wide, 40% of the catch (33,204 fishes; ± 10,761) were harvested compared with 33% during the previous survey. Up-lake anglers harvested a larger (48%) portion of their catch than down-lake anglers (35%). Striped Bass and Walleye were the only species that are harvested at a higher rate than Channel Catfish: a testimony to their exceptional taste borne by the clear waters of Lake Powell.

The catch of Channel Catfish in the annual fall gill-net survey largely depicts a stable population over the past 26-years with 1998 and 2005 being the exceptions (FIgure 72). The historical mean catch/station was 9.1 (SD = 3.2) compared with a mean catch/station of 9.8 (SD = 2.2) over the previous 4-years. No statistical evidence suggests shad abundance or water elevations are correlated with the catch of Channel Catfish in the annual fall gill-net survey. However, like many other species there is a positive relationship between water temperatures at the time of the annual gill-net survey and the Catfish catch for 1993-2019 (Pearson: $r = .41$, $p = .03$).

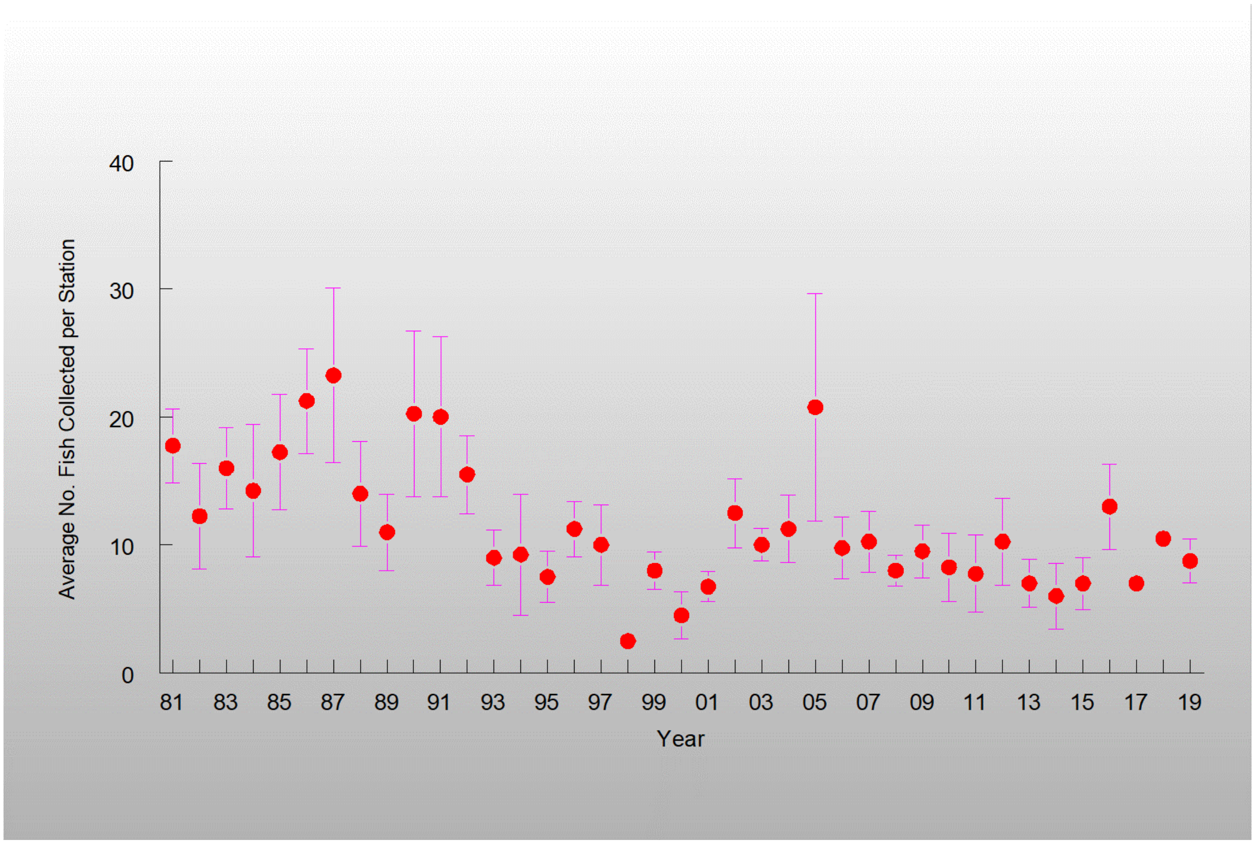


Figure 72. Average catch of Channel Catfish per station from the annual fall gill-net survey with SE, Lake Powell, 1981-2019.

Lake Powell produces a lot of moderate sized catfish, perfect for the pan and table. The mean sizes of catfish captured in the annual fall gill-nets were somewhat larger from 2016-2019 when compared with 2013-2015, averaging 390mm TL lake-wide. Wahweap had the largest average fish at 453mm TL, followed by Rincon, San Juan and Good Hope at 447mm, 352mm and 351mm respectively. The mean condition (Ktl) of these gill-net caught catfish increased for 2017-2019 (mean Ktl = .87, SD = .03) over the historical mean of .79 (SD= .03) (Figure 73). There also has been a slight increase in condition following the establishment of Gizzard Shad.

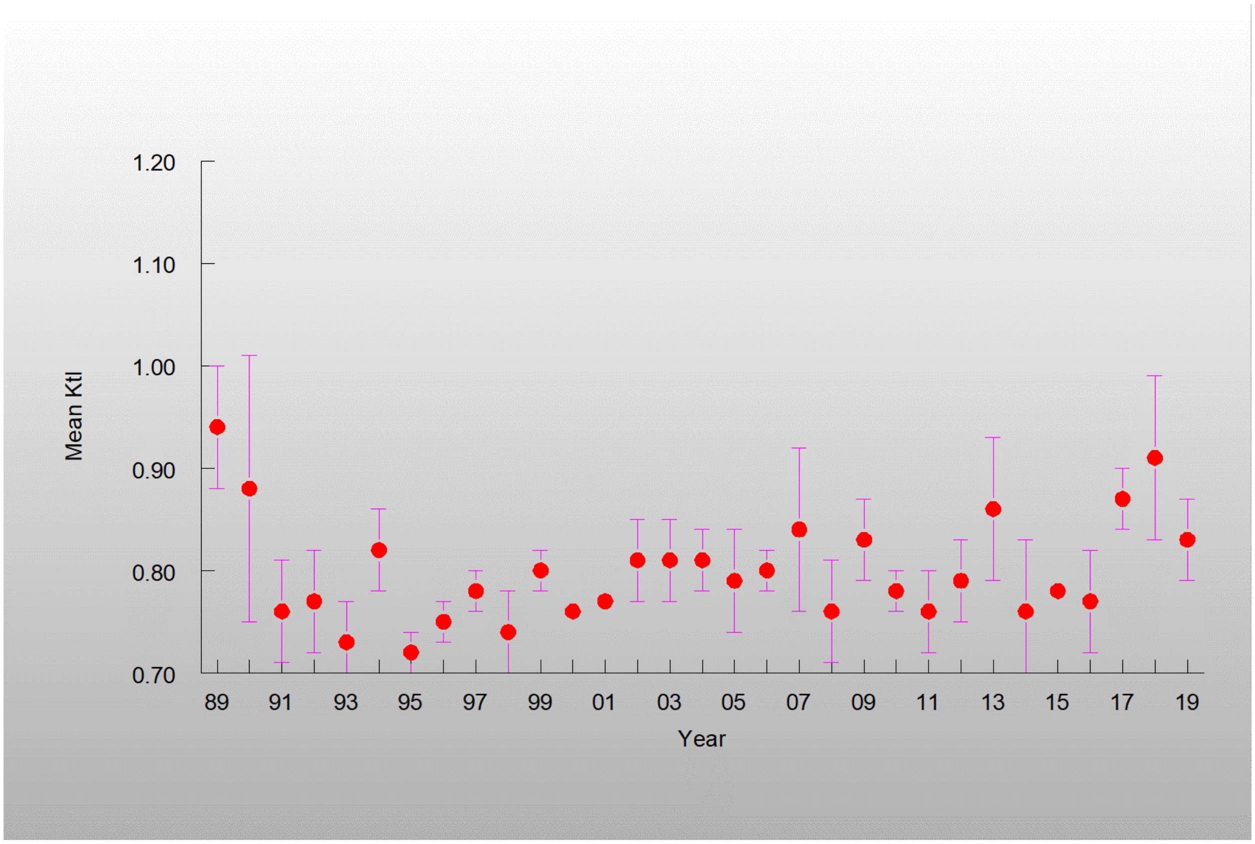


Figure 73. Mean Condition (Ktl) of Channel Catfish per station from the annual fall gill-net survey with SE, Lake Powell, 1989-2019.

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