Fish Community Changes in Lake Spokane (Long Lake), Washington, from 2001 to 2024

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Abstract

The Washington Department of Fish and Wildlife conducted three standardized surveys in 2001, 2015 and 2024 to track changes in the fish community of Lake Spokane (Long Lake) over the 23-year period. Over the course of the study, the relative abundance of all native species decreased 53% in total number and 23% in total biomass from 2001 to 2024. Conversely, the relative abundance of nonnative species increased 55% in total number and 74% in total biomass over the same period. The results of this study document large increases in two predator species, Smallmouth Bass and Walleye. The Smallmouth Bass population increased more than 2-fold during the first period of this study (2001-2015), which coincided with declines of Largescale Sucker, Largemouth Bass and Black Crappie. During the second period of this study (2015-2024), the Walleye population increased more than 9-fold and their proportional size distribution values increased in all size categories. The rapid and significant increase in the Walleye population corresponded to decreases in both native and nonnative species during the 2015-2024 time period. It appears the Smallmouth Bass population in Lake Spokane has matured and remains relatively constant, while the Walleye population continues to grow in both quantity and quality, and may be approaching maturity. There has been a succession of top predator species in Lake Spokane, where Smallmouth Bass and Walleye appear to be responsible for the reduction of the native species community and several nonnative species, in the process of biotic homogenization.

Acknowledgments

We would like to thank WDFW District 2 Fisheries Biologist Randy Osborne (who is responsible for the fisheries management of Lake Spokane) and the Warmwater Fisheries Program Manager Kenny Behen for their input on this report. We would also like to thank all of the Biologists and technicians from WDFW, as well as faculty and students from Eastern Washington University, who participated in various surveys during the course of this study.

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Introduction

The concept of species replacement at both the individual and community level is not new, particularly in aquatic environments (Mayer et al., 2024; Villéger et al., 2011). Nonnative species can replace native species under the dynamics of biological invasion theory (Blackburn et al. 2011; Sax et al., 2007). The introduction of nonnative species into new environments is often human-mediated and can lead to biotic homogenization (Mayer and Garrett., 2023; McKinney and Lockwood, 1999; Rahel, 2002). The end result is a reduction in the abundance and biomass of native species, with a corresponding increase in the abundance and biomass of nonnative species (Mayer et al., 2024; McKinney and Lockwood, 1999; Sax & Gaines, 2003).

Reservoirs promote a shift from native-dominated fish communities to invasive-dominated ones, where only a subset of native species, mainly large-bodied fishes, may survive (Clavero and Hermoso 2011; Nicholson et al, 2015). Predation is a main factor affecting the composition of fish communities (Jackson et al., 2001), by shifting them from small-bodied, soft-rayed, fusiform native species, to spiny-rayed, nonnative species, with a corresponding reduction in biomass from prey species (Mayer et al., 2024).

Lake Spokane, also known as Long Lake, is located in Spokane County, Washington (WA; Figure 1). The reservoir was created when Long Lake Dam was built on the Spokane River in 1915. Lake Spokane is 39 km (24 miles) long, with a surface area of 2,048 hectares (4,748 acres). Lake Spokane has three distinct sections: the upper 4 km is riverine with limited shoreline development, the middle 24 km characterized by gentle slope and shallow bays with significant development, and the lower 11 km has steep banks and rocky shorelines and little development (Osborne et al., 2003).

Lake Spokane is managed by the Washington Department of Fish and Wildlife (WDFW) as a ‘mixed species fishery’, which provides fishing opportunity for multiple game fish species (Randy Osborne, WDFW, personal communication). In addition to the established warmwater species community, WDFW and the Avista Corporation (Spokane, Washington), stock 155,000 Rainbow Trout *Oncorhynchus mykiss* annually in the reservoir, as part of mitigation for the operation of Long Lake Dam. Surveys of Lake Spokane between 1980-2000 documented that Yellow Perch *Perca flavescens* were the most abundant gamefish, along with a relatively high abundance of three non-game species: Northern Pikeminnow *Ptychocheilus oregonensis*, Largescale Sucker *Catostomus macrocheilus*, and Chiselmouth Chub *Acrocheilus alutaceus* (Osborne et al., 2003).

The Largemouth Bass *Micropterus salmoides* population in Lake Spokane was thought to be stable in the 1980s and early 1990s, but also appeared to be below its production capacity (Bennett and Hatch 1991). Smallmouth Bass *M. dolomieui* were first introduced into Lake Spokane in 1992 by WDFW, with additional releases between 1993 and 1995 (Osborne et al., 2003). As a result, Smallmouth Bass established a relatively new, self-sustaining population in Lake Spokane, especially in the lower section of the reservoir, and was “considered a successful introduction” (Osborne et al., 2003). Another game fish, Walleye, were illegally introduced into Lake Spokane sometime prior to 2001.

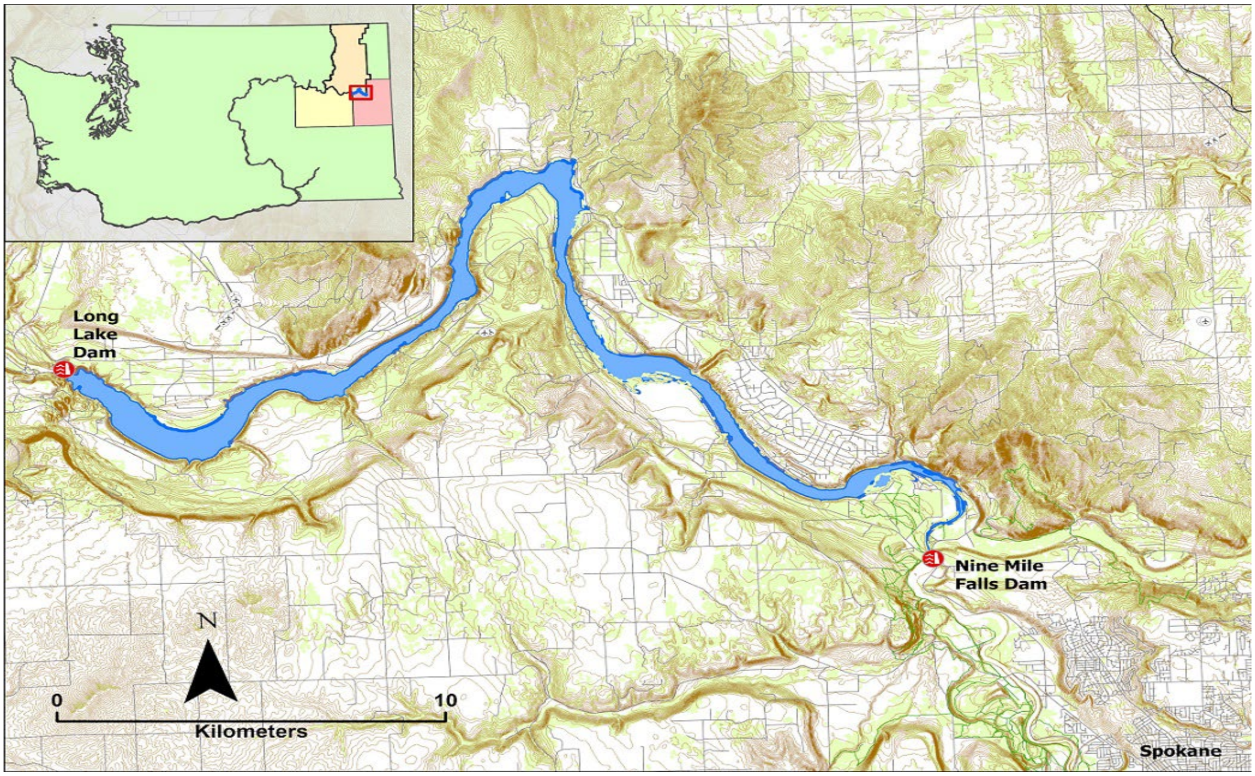

Figure 1. Lake Spokane (also known as Long Lake), Washington, formed by the creation of Long Lake Dam, below Nine Mile Falls Dam.

An apex predator, Northern pike, established a population in Lake Spokane around 2018. However, this period of time fell between survey dates. Therefore, Northern Pike were minimally represented in all surveys. A management action was taken to reduce the Northern Pike population in Lake Spokane using suppression netting. From 2020 and prior to our survey in 2024, a total of 1,089 Northern Pike were removed from Lake Spokane, resulting in a suppression efficiency of 99%, based on the CPUE from suppression netting (Parsons and Lee, 2024; WDFW unpublished data).

Between 2001-2024, WDFW conducted three standardized surveys in 2001, 2015 and 2024, to track changes in the fish community of Lake Spokane. The objectives of this study were to determine if there was a shift in the structure of the fish community in Lake Spokane, and, if so, determine which species were affected most.

Methods

Standardized fish surveys of Lake Spokane were performed by WDFW and Eastern Washington University in 2001 and 2015. The WDFW conducted the 2024 survey. The three surveys were performed on June 18-21, 2001, June 15-18, 2015, and June 10-13, 2024, respectively. The surveys followed the WDFW Standard Fish Sampling Guidelines (Bonar et al. 2000), using boat electro-fishing and gill netting.

Sampling locations were divided into five sections, and then randomly selected throughout the study area (Figure 2). Sampling effort was highest in 2015, with a similar level of effort in 2001, with fewer sites in 2024 (Table 1). After running a statistical power analysis to determine the level of effort needed to detect a 30% change with 80% certainty in the Smallmouth Bass population captured via electrofishing, the total number of sites was reduced by 14% in 2024.

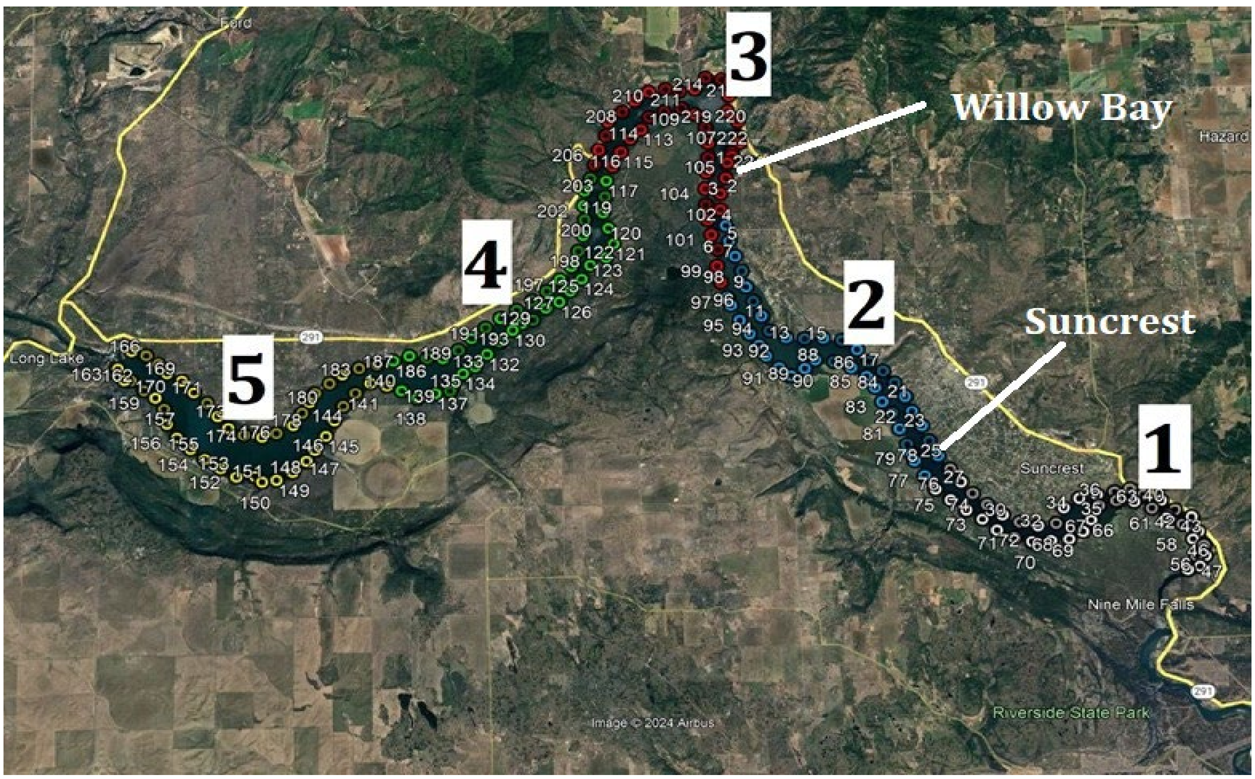

Figure 2. All 222 potential sampling sites, divided into five sections, for Lake Spokane, WA (between Nine Mile Falls Dam and Long Lake Dam) for the 2024 survey. The survey of Lake Spokane randomly sampled 140 of the sites in 2024.

Table 1. Level of effort (number of sites sampled), by year and gear type (electrofishing and gill net), for the three standardized surveys of Lake Spokane, WA, in 2001, 2015, and 2024.

Year	2001	2015	2024
Electrofishing	104	112	80
Gill net	56	54	60
Total sites	160	166	140

For electrofishing, we used SAA-6 electrofishing boats equipped with gas powered pulsators (Smith-Root, Inc. Vancouver, Washington). Electrofishing boats were operated in the downstream direction in 400 meter (m) sections, at an average speed of 0.66 m/second (2.38 km h-1), using a DC current of 4-5 amps for 600 seconds. Gill nets were 45.72 m long and 2.44 m deep, with four sinking monofilament panels (two panels 7.62 m long and two panels 15.24 m long) of variable mesh size (1.27 centimeter (cm), 1.91 cm, 2.54 cm and 5.08 cm, respectively). Gill nets were set overnight for 14-18 hours (i.e., net-night).

Fish were identified to the species level, measured for total length (mm; and inches [in]), and weighed to the nearest gram (g). Species composition was calculated based on the total number and weight (kg) of all fish caught, excluding Common Carp *Cyprinus carpio*.

Catch-per-unit effort (CPUE), by gear type (electrofishing and gill netting) were reported as the number of fish-per-hour for electrofishing and number of fish per net-night for gill netting, respectively. Eighty percent confidence intervals were calculated for mean CPUE. Two native species (Largescale Sucker and Northern Pikeminnow), five nonnative species (Yellow Perch, Smallmouth Bass, Black Crappie, and Largemouth Bass) represented >2.0% of the total biomass in 2001 and Walleye, were included in comparative analysis of mean CPUE across years. Largemouth Bass sample size was too small from gill netting to draw statistical conclusions with this gear type.

A comparative analysis was conducted to detect differences in CPUE for each species representing greater than 2.0% of the biomass in 2001 and Walleye, based on survey year. An Anderson-Darling test ($\alpha = 0.05$) was used to detect deviations of CPUE data from normality. Since data were non-normally distributed, comparisons were conducted with the Kruskal-Wallis test ($\alpha = 0.05$). When significant differences were detected, a Dunn test (Dunn 1964) for pairwise comparisons was used to specify where the differences occurred between years.

Proportional size distributions (PSD) for selected species were calculated using the number of quality-size (PSD), preferred-size (PSD-P), memorable-size (PSD-M) and trophy-size (PSD-T) fishes, divided by the number of the number of stock-size fish, multiplied by 100 (Neumann et al., 2012).

We evaluated changes in the mean length of two nonnative populations (Smallmouth Bass and Walleye) by analysing differences in the length distributions from 2001-2015, 2015-2024, and 2001-2024. A t-Test was used to determine if there were significant differences in mean length between surveys.

Relative weight (Wr) was used to evaluate the relative condition of selected species. The Wr index is defined as: $Wr = W/Ws \times 100$, where W is the weight (g) of individual fish and Ws is the standard weight of fish at the same length, which generally indicates the relative condition of fish of the same species (Neumann et al., 2012). The Washington state-wide average Wr values were used for comparative purposes for selected species using lengths above 80 mm.

During the 2015 survey of Lake Spokane, 16 Walleye scale samples were taken to assess the age structure of the Walleye population. In addition, 49 Walleye otoliths were collected from a stratified random sample of Walleye caught in 2021, during a carp netting project, to assess the growth rates. A von Bertalanffy growth curve was developed for female Walleye in 2021, as a separate analysis.

Results

Comparison of 2001, 201 and 2024 Survey Results from Lake Spokane

During the course of a 23-year study of Lake Spokane, 24 fish species were caught in three standardized warmwater surveys. A list of all native species and nonnative species caught and sample sizes, by year, are presented in Tables 2 and 3, respectively. A total of 16,433 fishes were caught during the entire study: 5,225 in 2001, 7,507 in 2015, and 3,701 in 2024.

Table 2. Total number of native species caught in standard surveys of Lake Spokane in 2001, 2015 and 2024. Asterisk (*) indicates species which were >2.0% of the total biomass in 2001 and were included in the statistical analyses.

Species	Scientific Name	2001 n	2015 n	2024 n
Bridgelip Sucker	*Catostomus columbianus*	43	66	8
Chiselmouth Chub	*Acrocheilus alutaceus*	97	53	8
Largescale Sucker *	*Catostomus macrocheilus*	1,639	1,197	627
Longnose Sucker	*Catostomus catostomus*	33	37	0
Mountain Whitefish	*Prosopium williamsoni*	74	39	0
Northern Pikeminnow *	*Ptychocheilus oregonensis*	705	598	217
Peamouth Chub	*Mylocheilus caurinus*	3	0	0
Redside Shiner	*Richardsonius balteatus*	0	0	3
Sucker: General	*Catostomus spp.*	47	0	0
Total individuals		**2,641**	**1,990**	**863**

Table 3. Total number of nonnative species caught in standard surveys of Lake Spokane in 2001, 2015 and 2024. Asterisk (*) indicates species which were >2.0% of the total biomass in 2001, plus Walleye, and were included in the statistical analyses.

Species	Scientific Name	2001 n	2015 n	2024 n
Black Crappie *	*Pomoxis nigromaculatus*	275	70	39
Brown Bullhead	*Ameiurus nebulosus*	84	135	32
Brown Trout	*Salmo trutta*	16	0	0
Channel Catfish	*Ictalurus punctatus*	1	0	0
Chinook Salmon	*Oncorhynchus tshawytscha*	0	0	9
Lake Whitefish	*Coregonus clupeaformis*	0	0	7
Largemouth Bass *	*Micropterus salmoides*	130	36	9
Northern Pike	*Esox lucius*	1	2	0
Pumpkinseed Sunfish	*Lepomis gibbosus*	12	29	36
Rainbow Trout (hatchery)	*Oncorhynchus mykiss*	4	357	50
Smallmouth Bass *	*Micropterus dolomieu*	651	1,765	1,196
Tench	*Tinca tinca*	32	52	14
Walleye *	*Sander vitreus*	1	71	755
Yellow Bullhead	*Ameiurus natalis*	107	206	23
Yellow Perch *	*Perca flavescens*	1,270	2,794	668
Total individuals		**2,584**	**5,517**	**2,838**

The majority of fishes were caught via electrofishing in all years: 58.4%, 54.0% and 61.0% in 2001, 2015 and 2024, respectively, with the balance caught by gill net: 41.6%, 46.0% and 39.0% in 2001, 2015 and 2024, respectively (Table 4). The greatest proportion (percentage of total catch) for both native species (range = 51.2%-60.2%) and nonnative species (range = 53.4%-64.0%) were caught via electrofishing. Gill nets were also effective for capturing both native (range = 39.8%-48.8%) and nonnative species (range = 37.3%-46.6%).

Native species, Largescale Sucker and Northern Pikeminnow, showed significant decreases in CPUE (Dunn Test $p<0.05$) over the entire 2001-2024 study period. The p-values for significant differences in CPUE for native species based on gear type (electrofishing and gill net) are presented in Table 5. The catch rate of Largescale Sucker and Northern Pikeminnow declined in both gear types throughout the study (Figures 3 and 4).

Nonnative species, Smallmouth Bass and Walleye, showed significant increases in CPUE (Dunn Test $p<0.05$) over the entire 2001-2024 study period, while Black Crappie and Largemouth Bass decreased significantly via electrofishing, and Yellow Perch decreased significantly via gill net. The p-values for significant differences in CPUE for nonnative species based on gear type (electrofishing and gill net) are presented in Table 5. The catch rate of Smallmouth Bass increased from 2001 to 2015, and then leveled off from 2015 to 2024 (Figures 5 and 6). The catch rate of Walleye increased over the entire study period (2001-2024); however only one Walleye was caught in 2001. The catch rate of Yellow Perch increased significantly from 2001 to 2015, and then decreased between 2015 and 2024. The catch rate of Black Crappie and Largemouth Bass decreased throughout the study.

The change in the relative proportion of a combined catch of four species: Smallmouth Bass, Yellow Perch, Black Crappie and Largemouth Bass, caught via electrofishing across the three surveys (2001, 2015, 2024) is presented in Figure 7. The proportion of Smallmouth Bass and Yellow Perch increased from 2001 to 2015. During the same period, the catch of Black Crappie and Largemouth Bass decreased, and then remained at a similar, lower level from 2015 to 2024.

The change in the relative proportion for a combined catch of two species, Walleye and Yellow Perch, via gill netting across the three surveys (2001, 2015, 2024) is presented in Figure 8. The proportion of Walleye increased from 2015 to 2024 (only one Walleye was caught in 2001), compared to Yellow Perch, which increased and then decreased significantly from 2015 to 2024.

The number of PSD stock size Black Crappie via electrofishing decreased each year throughout the study. However, larger size (PSD-P; Preferred) fish remained in the system. Largemouth Bass followed a similar trend as Black Crappie. Smallmouth Bass increased in stock size fish between 2001 and 2015, and then leveled off from 2015 to 2024, while PSD-P Smallmouth Bass increased throughout the study. The number of stock size Walleye increased throughout the study, with larger categories (PSD-P and PSD-M; Memorable size) increased from 2015 to 2024. Stock size Yellow Perch increased from 2001 to 2015, and then decreased from 2015 to 2024, with PSD (Quality) size fish increasing in all years.

The PSD number of stock size Black Crappie via gill net decreased throughout the study. However, larger PSD-M fish remained in the system. There were no PSD values for Largemouth Bass via gill net in 2015 or 2024. The number of stock size Smallmouth Bass increased between 2001 and 2015, and then leveled off, while larger fish (PSD, PSD-P and PSD-M) remained in the system. There was a large increase in the number of stock and larger size Walleye via gill net from 2015 to 2024, with the larger categories (PSD-P and PSD-M) increasing during the same period. The number of stock size Yellow Perch increased from 2001-2015, and then decreased from 2015-2024, while PSD-Q size fish trended in the opposite direction. The larger categories (PSD-P and PSD-M) of Yellow Perch increased in 2024, while the number of stock size fish decreased during this time.

Note for PSD analyses: The ability to track PSDs across all years was negatively affected by decreases in the CPUE of certain species (e.g. Black Crappie, Largemouth Bass); the recommended sample size of at least 50 stock size fish was not met in every survey. Therefore, the ability to track changes in size distribution (PSD values) of Black Crappie and Largemouth Bass was not certain.

There was a significant increase (t-Test $p<0.05$) in the mean length of Smallmouth Bass between 2015 and 2024, and across the entire study from 2001 to 2024 (Figures 9 and 10). While the mean length of Smallmouth Bass remained the same from 2001 to 2015, the overall range of lengths decreased by 36%, resulting in less variation in fish lengths between 2001 and 2015 (while the population was increasing). From 2015 to 2024, there was a significant increase in the length of Smallmouth Bass, with a mean increase of 50 mm (a 22% increase) in mean length.

There was a significant decrease (t-Test $p<0.05$) in the mean length of Walleye between 2015 and 2024 (Figures 11 and 12). Only one Walleye was caught in 2001, which precluded statistical analyses of Walleye lengths in the first survey. From 2015 to 2024, there was a significant decrease in the length of Walleye, with a mean decrease of 112 mm (a 36% decrease) in mean length.

There was a significant decrease ($p<0.05$) in Chiselmouth Chub CPUE via gill net across the entire study: from 1.9% of the relative abundance and 0.3% of the relative biomass in 2001, which decreased to 0.2% of the relative abundance and 0.0% of the relative biomass in 2024.

Table 4. The number of fishes caught by year and gear type, from surveys of Lake Spokane, WA, in 2001, 2015 and 2024.

Year	2001		2015		2024	
Species	**Electrofishing**	**Gill Net**	**Electrofishing**	**Gill Net**	**Electrofishing**	**Gill Net**
Black Crappie	227	48	40	30	11	28
Bridgelip Sucker	37	6	57	9	6	2
Brown Bullhead	71	13	84	51	10	22
Brown Trout	9	7	0	0	0	0
Channel Catfish	1	0	0	0	0	0
Chinook Salmon	0	0	0	0	0	9
Chiselmouth Chub	47	50	11	42	3	5
Lake Whitefish	0	0	0	0	4	3
Largemouth Bass	126	4	36	0	8	1
Largescale Sucker	1,144	495	813	384	388	239
Longnose Sucker	22	11	37	0	0	0
Mountain Whitefish	22	52	6	33	0	0
Northern Pike	0	1	0	2	0	0
Northern Pikeminnow	270	435	189	409	43	174
Peamouth Chub	1	2	0	0	0	0
Pumpkinseed Sunfish	11	1	27	2	31	5
Rainbow Trout	4	0	89	268	21	29
Redside Shiner	0	0	0	0	2	1
Smallmouth Bass	626	25	1,577	188	1,065	131
Sucker: General	47	0	0	0	0	0
Tench	16	16	21	31	2	12
Walleye	0	1	13	58	119	636
Yellow Bullhead	72	35	93	113	9	14
Yellow Perch	297	973	964	1,830	537	131
Total	**3,050**	**2,175**	**4,057**	**3,450**	**2,259**	**1,442**
Percent of catch	**58%**	**42%**	**54%**	**46%**	**61%**	**39%**

Table 5. Results of Dunn Test showing the differences in catch rates, by gear type (electrofishing and gill net), between the 2001 and 2015, 2015 and 2024, and 2001 to 2024 surveys of Lake Spokane, for the seven species >2.0% of total biomass in 2001, plus Walleye. Significant differences ($p<0.05$) are indicated by arrows showing the direction of change, as an increase (↑) or decrease (↓), in catch rate (CPUE).

Species	Gear Type	2001-2015	2015-2024	2001-2024	General Trend Statement
Black Crappie	Electrofishing	0.168	0.149	0.008 ↓	CPUE decreased significantly across the entire study period only: 2001-2024.
	Gill Net	0.835	0.673	0.714	No significant changes in CPUE; then remained at low abundance.
Largemouth Bass	Electrofishing	0.000 ↓	0.117	0.000 ↓	CPUE decreased significantly 2001-2015, then no change 2015-2024.
	Gill Net	-	-	-	Not enough samples to test (-).
Largescale Sucker	Electrofishing	0.001 ↓	0.018 ↓	0.000 ↓	CPUE decreased significantly in all three sampling events: 2001-2015-2024.
	Gill Net	0.023 ↓	0.005 ↓	0.000 ↓	CPUE decreased significantly in all three sampling events: 2001-2015-2024.
Northern Pikeminnow	Electrofishing	0.127	0.000 ↓	0.000 ↓	No change 2001-2015, then CPUE decreased significantly 2015-2024.
	Gill Net	0.330	0.000 ↓	0.000 ↓	No change 2001-2015, then CPUE decreased significantly 2015-2024.
Smallmouth Bass	Electrofishing	0.000 ↑	0.848	0.000 ↑	CPUE increased significantly 2001-2015, then no change 2015-2024.
	Gill Net	0.000 ↑	0.037 ↓	0.000 ↑	CPUE increased significantly in all three sampling events: 2001-2015-2024.
Walleye	Electrofishing	0.096	0.000 ↑	0.000 ↑	No change 2001-2015, then CPUE increased significantly 2015-2024.
	Gill Net	0.000 ↑	0.000 ↑	0.000 ↑	CPUE increased significantly in all three sampling events: 2001-2015-2024.
Yellow Perch	Electrofishing	0.143	0.480	0.510	No significant changes in CPUE; then remained at relatively low abundance.
	Gill Net	0.434	0.000 ↓	0.000 ↓	No change 2001-2015, then CPUE decreased significantly 2015-2024.

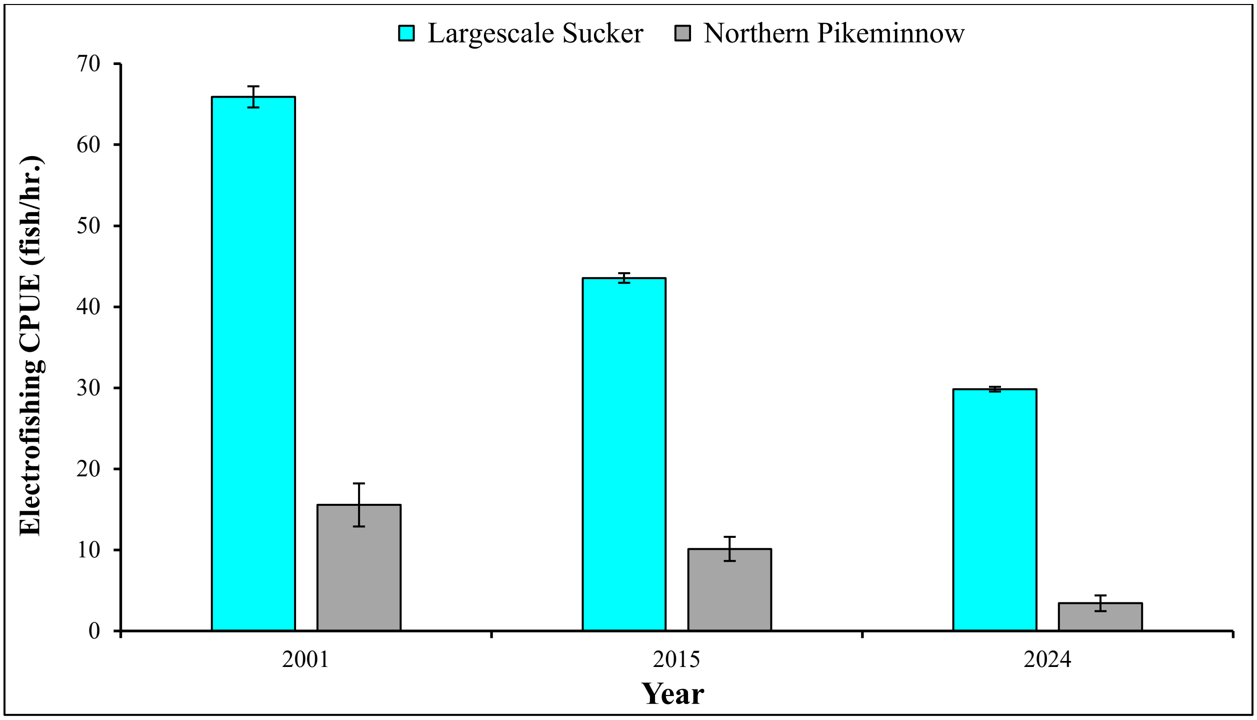

Figure 3. Catch rates (with 80% CI) of native species, Largescale Sucker and Northern Pikeminnow, via electrofishing, over a 23-year period, from surveys of Lake Spokane, WA, in 2001, 2015 and 2024.

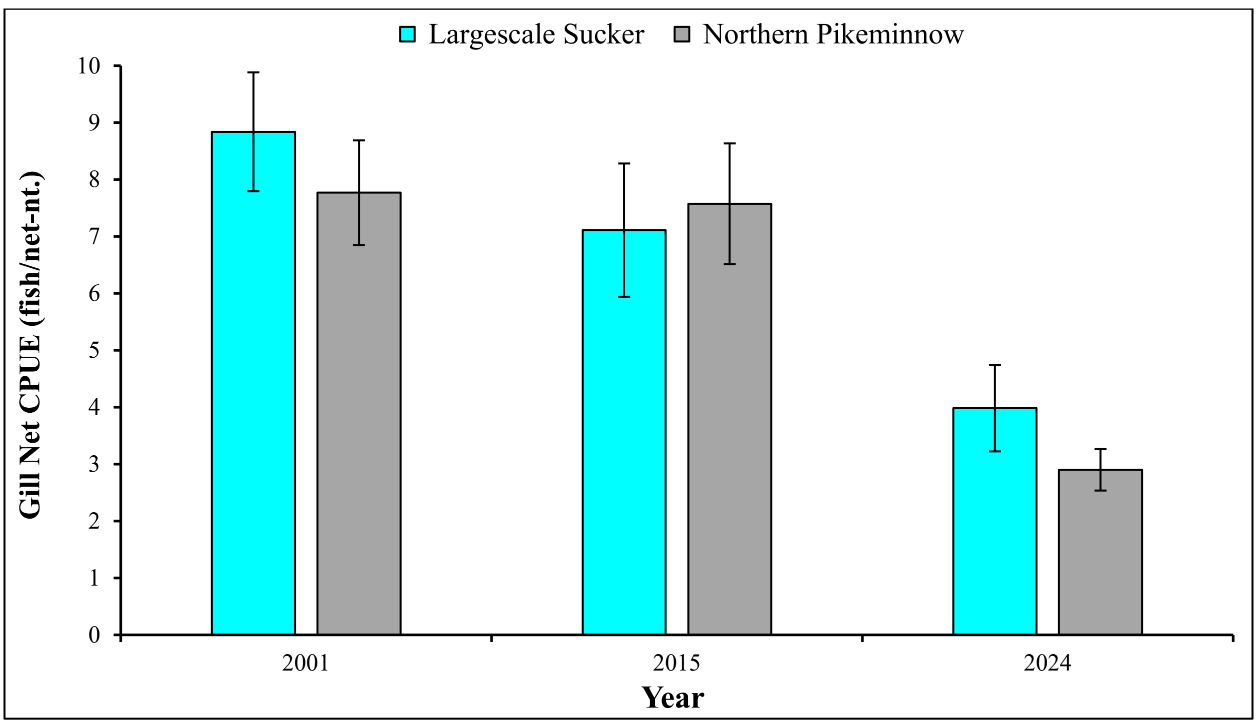

Figure 4. Catch rates (with 80% CI) of native species, Largescale Sucker and Northern Pikeminnow, via gill net, over a 23-year period, from surveys of Lake Spokane, WA, in 2001, 2015 and 2024.

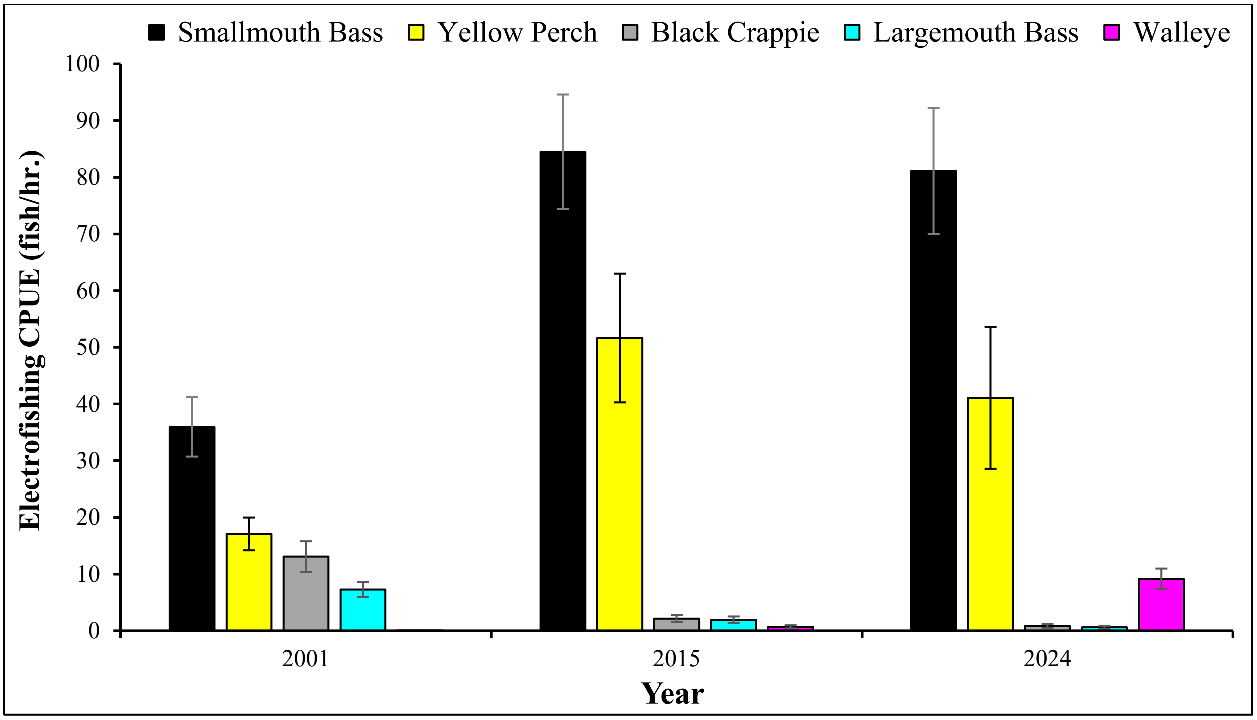

Figure 5. Catch rates (with 80% CI) of nonnative species, Smallmouth Bass, Yellow Perch, Black Crappie, Largemouth Bass and Walleye, via electrofishing, over a 23-year period, from surveys of Lake Spokane, WA, in 2001, 2015 and 2024.

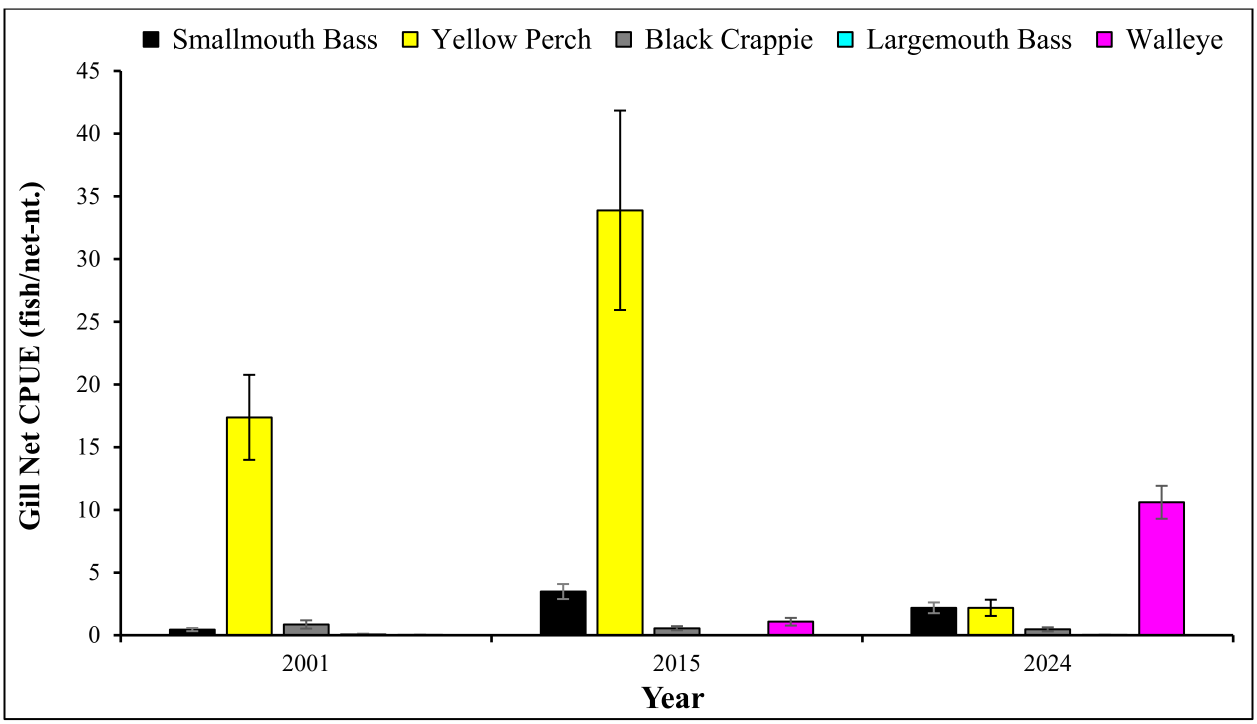

Figure 6. Catch rates (with 80% CI) of nonnative species, Smallmouth Bass, Yellow Perch, Black Crappie, Largemouth Bass and Walleye, via gill net, over a 23-year period, from surveys of Lake Spokane, WA, in 2001, 2015 and 2024.

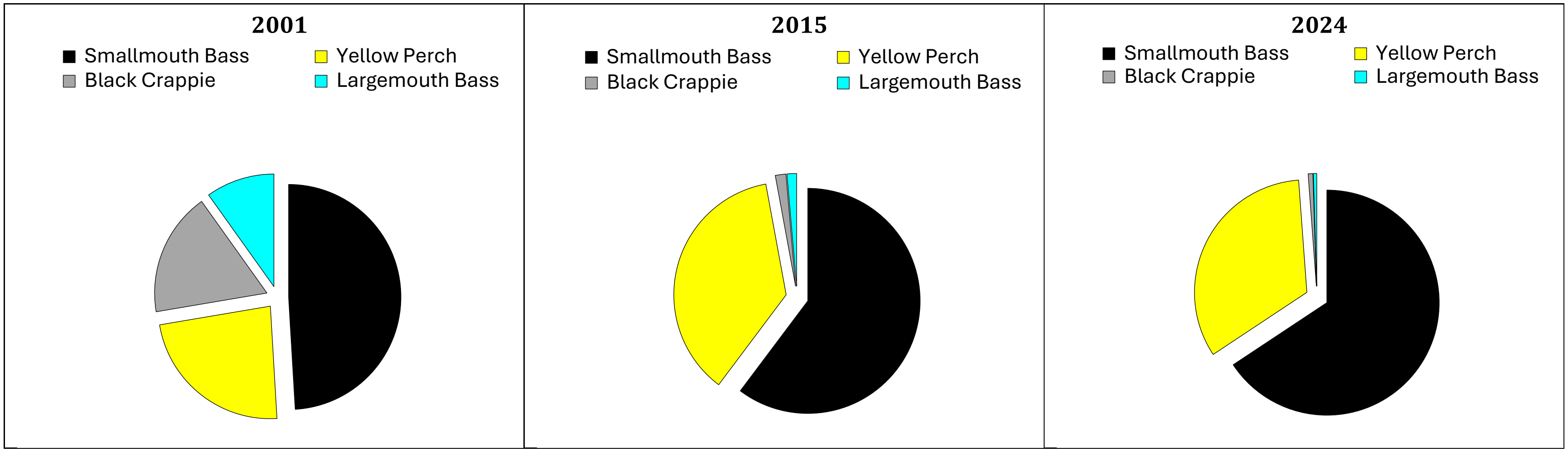

Figure 7. Change in relative proportions of a combined catch of Smallmouth Bass, Yellow Perch, Black Crappie and Largemouth Bass via electrofishing over a 23-year period, from surveys of Lake Spokane, WA, in 2001, 2015 and 2024.

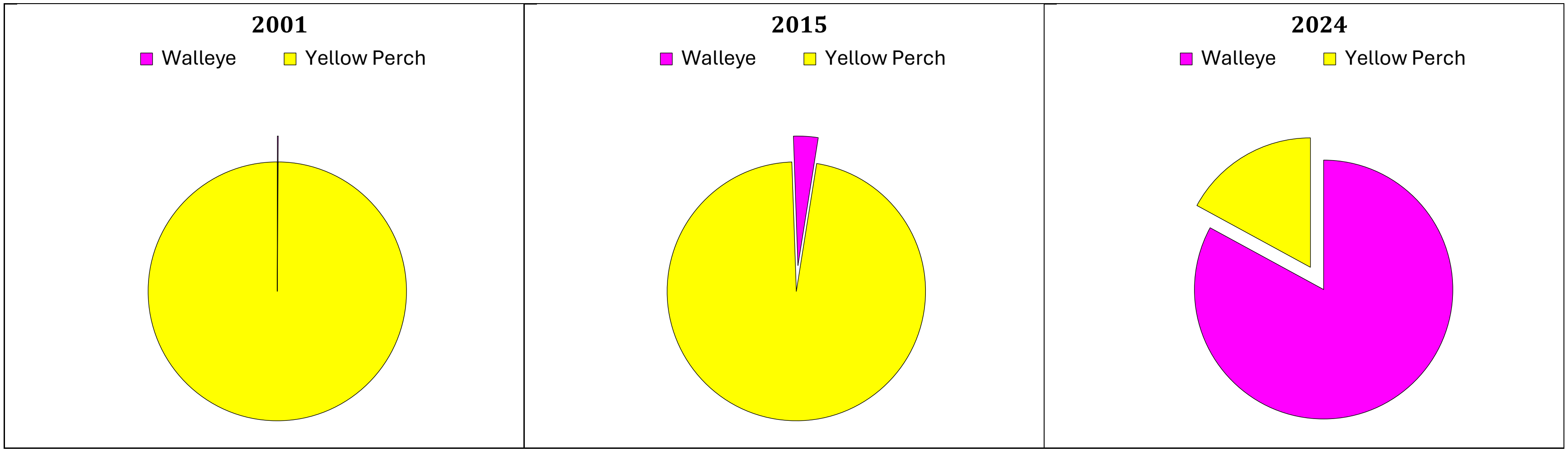

Figure 8. Change in relative proportions of a combined catch of Walleye and Yellow Perch via gill net over a 23-year period, from surveys of Lake Spokane, WA, in 2001, 2015 and 2024.

Table 6. Proportional size distribution of fish caught via electrofishing in surveys of Lake Spokane in 2001, 2015 and 2024. Confidence intervals (CI) are at the 80% level.

Species - 2001	Stock	PSD	80%CI	PSD-P	80%CI	PSD-M	80%CI	PSD-T	80%CI
Black Crappie	226	90	3	4	2	1	1	-	-
Largemouth Bass	125	97	2	80	5	7	3	-	-
Smallmouth Bass	261	23	3	4	2	1	1	-	-
Walleye	0	-	-	-	-	-	-	-	-
Yellow Perch	138	75	5	4	2	0	-	-	-
2015	**Stock**	**PSD**	**80%CI**	**PSD-P**	**80%CI**	**PSD-M**	**80%CI**	**PSD-T**	**80%CI**
Black Crappie	40	35	10	10	6	8	5	-	-
Largemouth Bass	22	100	0	100	0	41	13	-	-
Smallmouth Bass	647	14	2	7	1	3	1	-	-
Walleye	8	75	20	0	-	-	-	-	-
Yellow Perch	947	17	2	0	-	-	-	-	-
2024	**Stock**	**PSD**	**80%CI**	**PSD-P**	**80%CI**	**PSD-M**	**80%CI**	**PSD-T**	**80%CI**
Black Crappie	2	100	0	100	0	50	45	0	-
Largemouth Bass	3	67	35	67	35	0	-	-	-
Smallmouth Bass	629	49	3	23	2	9	1	0	-
Walleye	34	21	9	12	7	9	6	3	4
Yellow Perch	35	26	9	9	6	0	-	-	-

Table 7. Proportional size distribution of fish caught via gill net in surveys of Lake Spokane in 2001, 2015 and 2024. Confidence intervals (CI) are at the 80% level.

Species - 2001	Stock	PSD	80%CI	PSD-P	80%CI	PSD-M	80%CI	PSD-T	80%CI
Black Crappie	48	94	4	4	4	0	-	-	-
Largemouth Bass	4	100	0	100	0	-	-	-	-
Smallmouth Bass	20	65	14	60	14	10	9	0	-
Walleye	1	100	0	0	-	-	-	-	-
Yellow Perch	971	87	1	2	1	-	-	-	-
2015	**Stock**	**PSD**	**80%CI**	**PSD-P**	**80%CI**	**PSD-M**	**80%CI**	**PSD-T**	**80%CI**
Black Crappie	30	33	11	10	7	3	4	-	-
Largemouth Bass	0	-	-	-	-	-	-	-	-
Smallmouth Bass	150	33	5	31	5	9	3	0	-
Walleye	55	56	9	5	4	4	3	-	-
Yellow Perch	1823	31	1	0	-	-	-	-	-
2024	**Stock**	**PSD**	**80%CI**	**PSD-P**	**80%CI**	**PSD-M**	**80%CI**	**PSD-T**	**80%CI**
Black Crappie	4	50	32	50	32	50	32	0	-
Largemouth Bass	0	-	-	-	-	-	-	-	-
Smallmouth Bass	113	59	6	53	6	18	5	2	2
Walleye	499	23	2	6	1	0	-	-	-
Yellow Perch	66	73	7	18	6	0	-	-	-

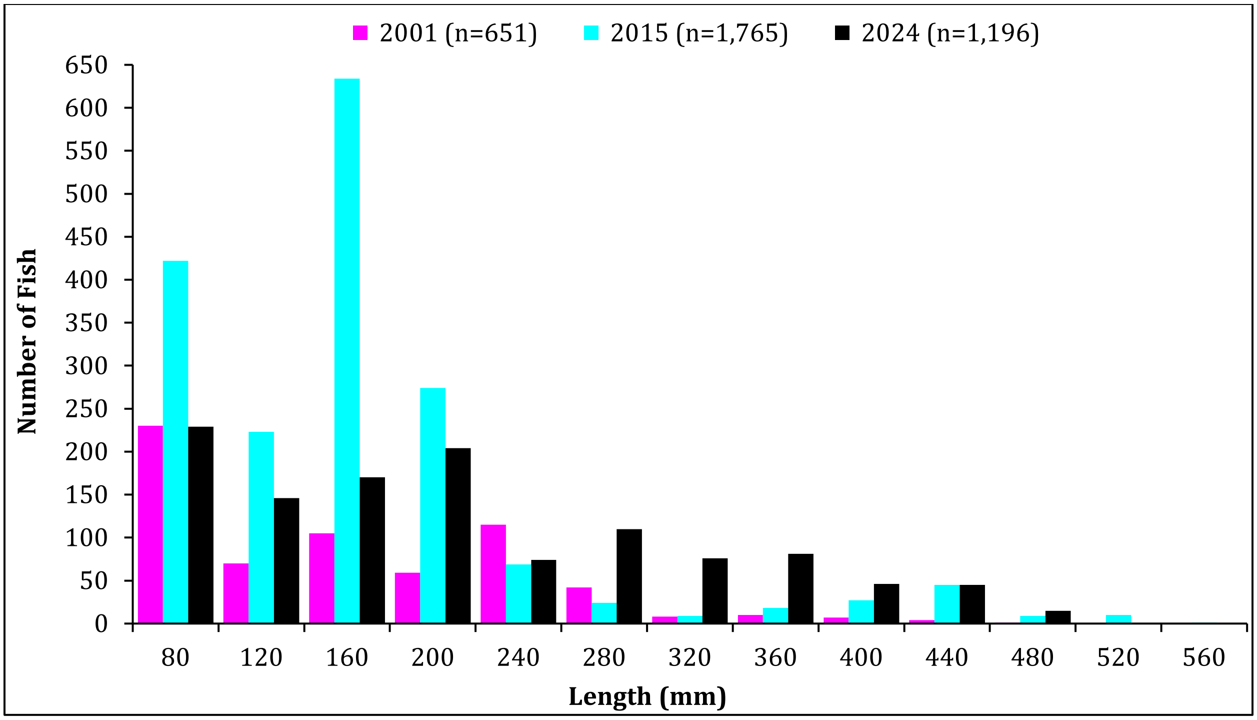

Figure 9. Distribution of Smallmouth Bass lengths in 2001 (n=651), 2015 (n=1,765), and 2024 (n=1,196) from surveys of Lake Spokane, WA. Unit conversions: 102 mm = 4 inches, 203 mm = 8 inches, 406 mm = 16 inches, 610 mm = 24 inches, 800 mm = 31.5 inches.

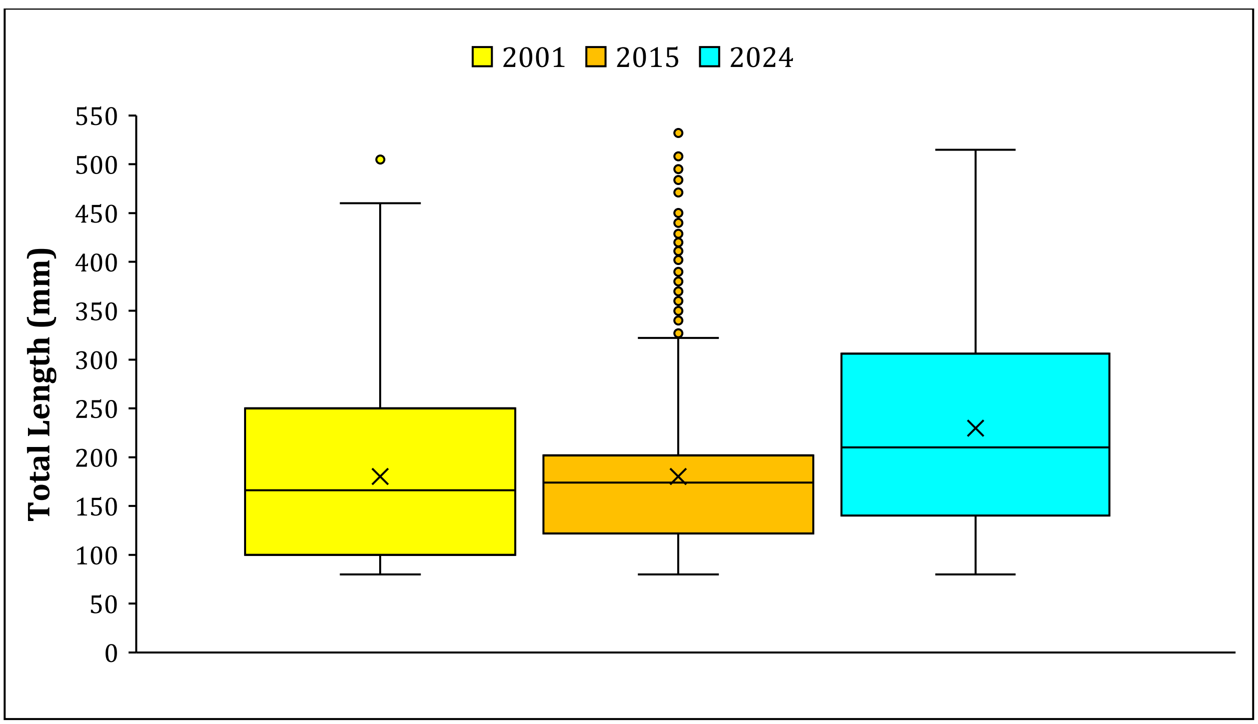

Figure 10. Box-and-whisker plots showing distribution of Smallmouth Bass lengths in 2001 (n=651), 2015 (n=1,765), and 2024 (n=1,196) from surveys of Lake Spokane, WA. Unit conversions: 102 mm = 4 inches, 203 mm = 8 inches, 406 mm = 16 inches, 610 mm = 24 inches, 800 mm = 31.5 inches.

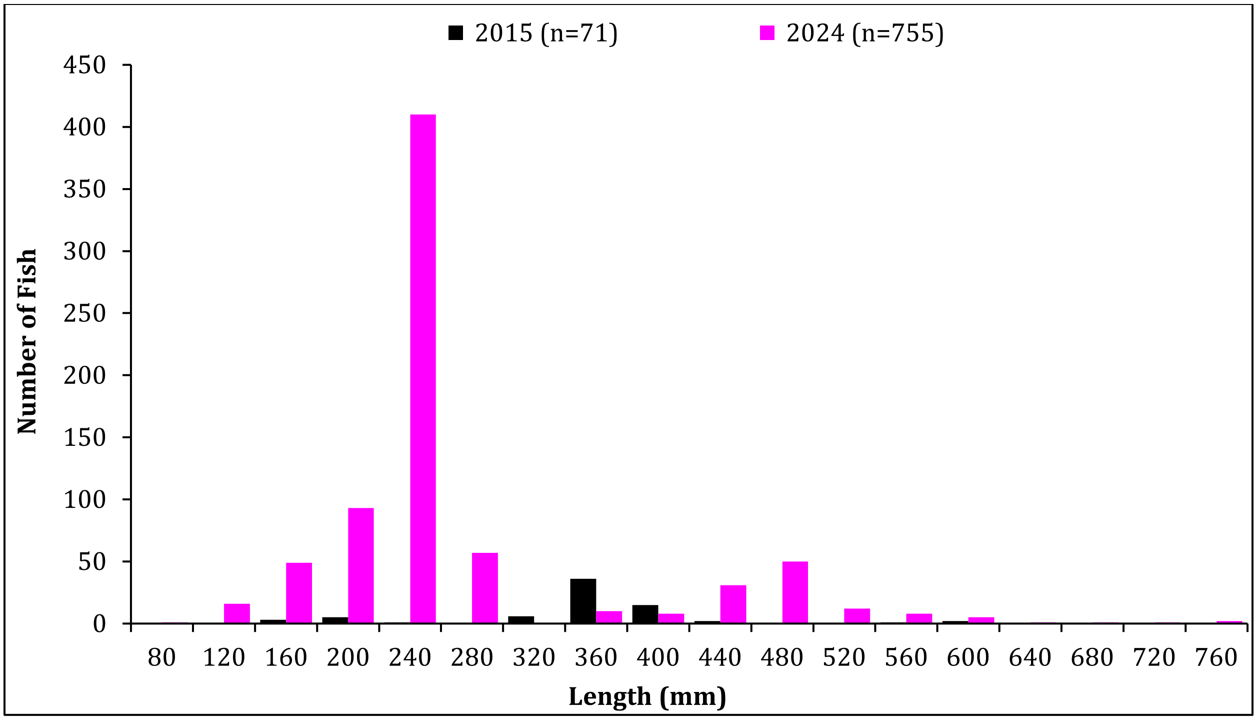

Figure 11. Distribution of Walleye lengths in 2015 (n=71) and 2024 (n=755) from surveys of Lake Spokane, WA. Only one Walleye was caught in 2001. Unit conversions: 102 mm = 4 inches, 203 mm =8 inches, 406 mm = 16 inches, 610 mm = 24 inches, 800 mm = 31.5 inches.

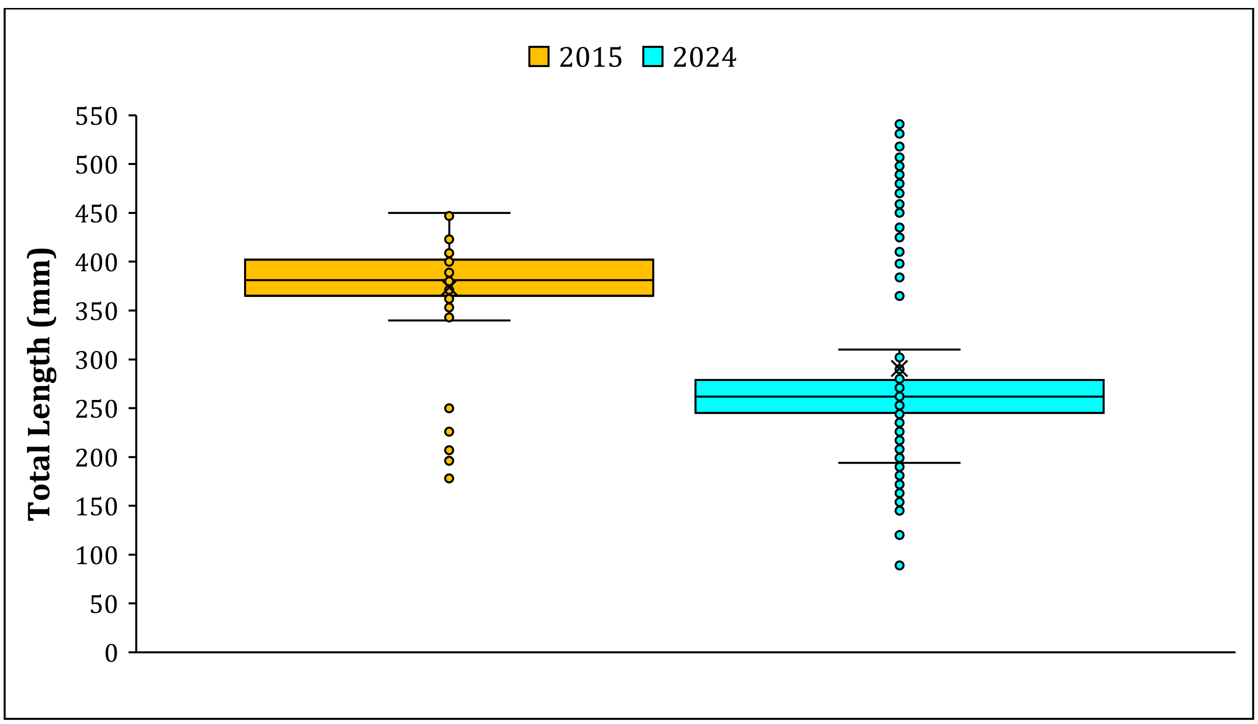

Figure 12. Box-and-whisker plots showing distribution of Walleye lengths in 2015 (n=71) and 2024 (n=755) from surveys of Lake Spokane, WA. One Walleye was caught in 2001. Unit conversions: 102 mm = 4 inches, 203 mm = 8 inches, 406 mm = 16 inches, 610 mm = 24 inches, 800 mm = 31.5 inches.

Changes in the relative abundance of native species compared to nonnative species over time is presented in Figure 13. From 2001 to 2015, the relative abundance of the native species community decreased from 51% to 28% (45% decrease), and then decreased again to 24% of the relative abundance (14% decrease) from 2015 to 2024, resulting in a total decrease of 53% in abundance across the entire study. Largescale Sucker and Northern Pikeminnow accounted for a combined 88.8%, 90.2% and 97.8% of the relative abundance of all native species in 2011, 2015 and 2024, respectively. Conversely, the relative abundance of the nonnative species community increased from 49% in 2001 to 72% in 2015 (32% increase), which increased again to 76% of the relative abundance (5% increase) in 2024, resulting in a total increase of 64% in relative abundance across the entire study.

Changes in relative biomass over time of native species compared to nonnative species is presented in Figure 14. From 2001 to 2015, the relative biomass of the native species community decreased from 76% to 67% (12% decrease), and then decreased again to 59% of the relative biomass (another 12% decrease) from 2015 to 2024, resulting in a total decrease of 22% in biomass across the entire study. Largescale Sucker and Northern Pikeminnow accounted for a combined 97.3%, 97.9% and 99.8% of the relative biomass of all native species in 2001, 2015 and 2024, respectively. Conversely, the relative biomass of the nonnative species community increased from 24% in 2001 to 33% in 2015 (27% increase), which increased again to 41% of the relative biomass (20% increase) in 2024, resulting in a total increase of 41% in relative biomass across the entire study.

During the increase in the Smallmouth Bass population from 2001-2015, there was a large decrease in the relative abundance of native species with a corresponding increase in the relative abundance of nonnative species. The relative abundance of both native and nonnative species remained at similar levels from 2015 to 2024, during the increase in the Walleye population.

During the increase of the Smallmouth Bass population from 2001-2015 and the increase in the Walleye population from 2015-2024, there was a constant 12% decrease in the relative biomass of native species, with a corresponding 12% increase in the biomass from nonnative species, during both the 2001-2015 and 2015-2024 time periods.

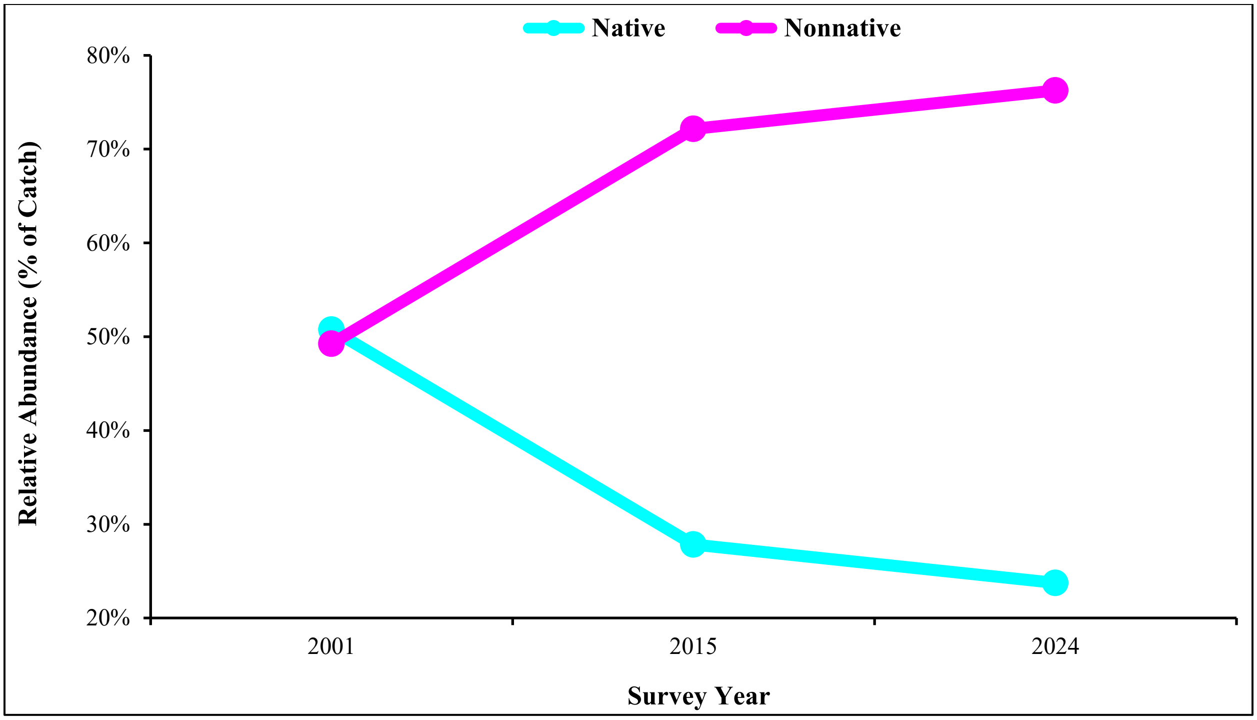

Figure 13. Change in relative abundance (% of catch) of the native species community compared to the nonnative species community over a 23-year period, from surveys of Lake Spokane, WA, in 2001, 2015 and 2024.

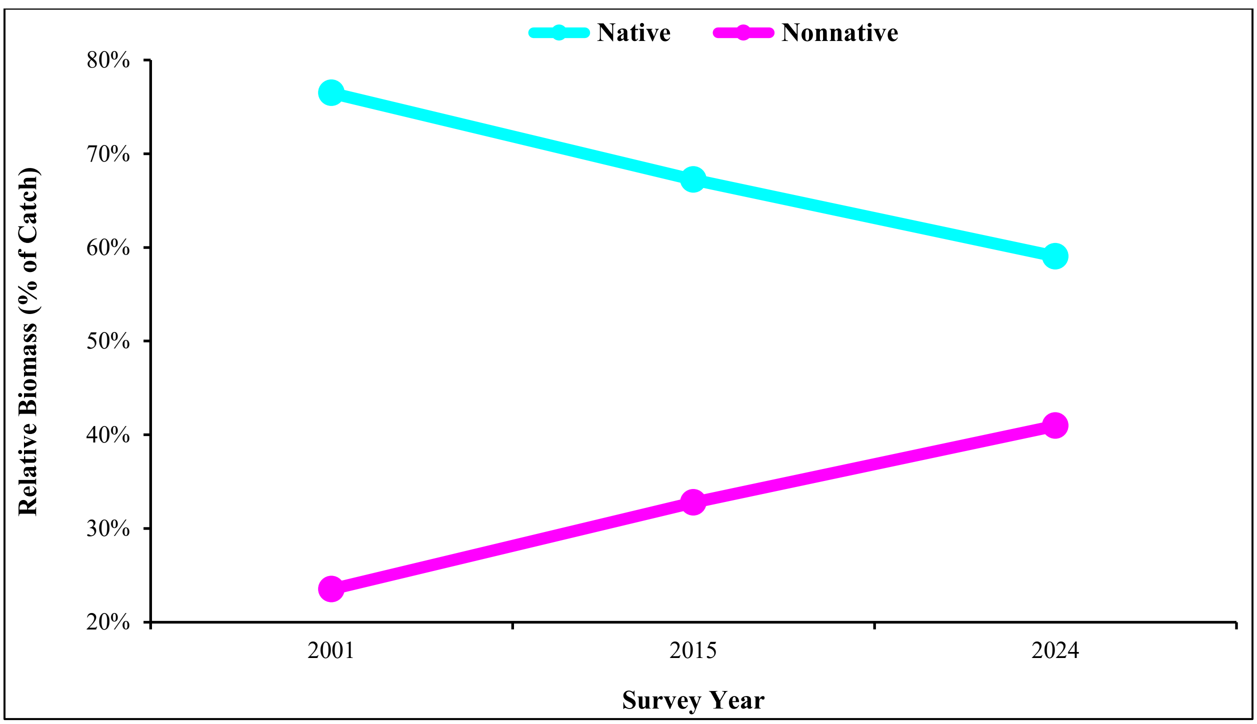

Figure 14. Change in relative biomass (% of catch) of the native species community compared to the nonnative species community over a 23-year period, from surveys of Lake Spokane, WA, in 2001, 2015 and 2024.

2024 Lake Spokane Survey Results

Summary results from the 2024 survey of Lake Spokane of the numbers of fish caught, catch rates, PSD values, and combinations of relative proportions analyzed for selected species, are presented in their respective Tables (3-6) and Figures (13 and 14) in the Results above.

The length distributions of Smallmouth Bass, Walleye, Yellow Perch and Black Crappie from the 2024 survey of Lake Spokane is presented in Figure 15, which also includes the state-wide average length for each species. Specifically, the mean length of Smallmouth Bass in Lake Spokane was 230 mm (9.0 inches), with a median length of 210 mm (8.3 inches); compared to the state-wide average length of 255 mm (10.0 inches) and 271 mm median length (10.7 inches), respectively. For Walleye, there was a 55 mm (2.2 inch) gap in length between 310-365 mm (12.2-14.4 inches) in 2024.

The relative weight values of Smallmouth Bass, Walleye, Yellow Perch and Black Crappie from the 2024 survey of Lake Spokane is presented in Figure 16, which also includes the state-wide average relative weight for each species.

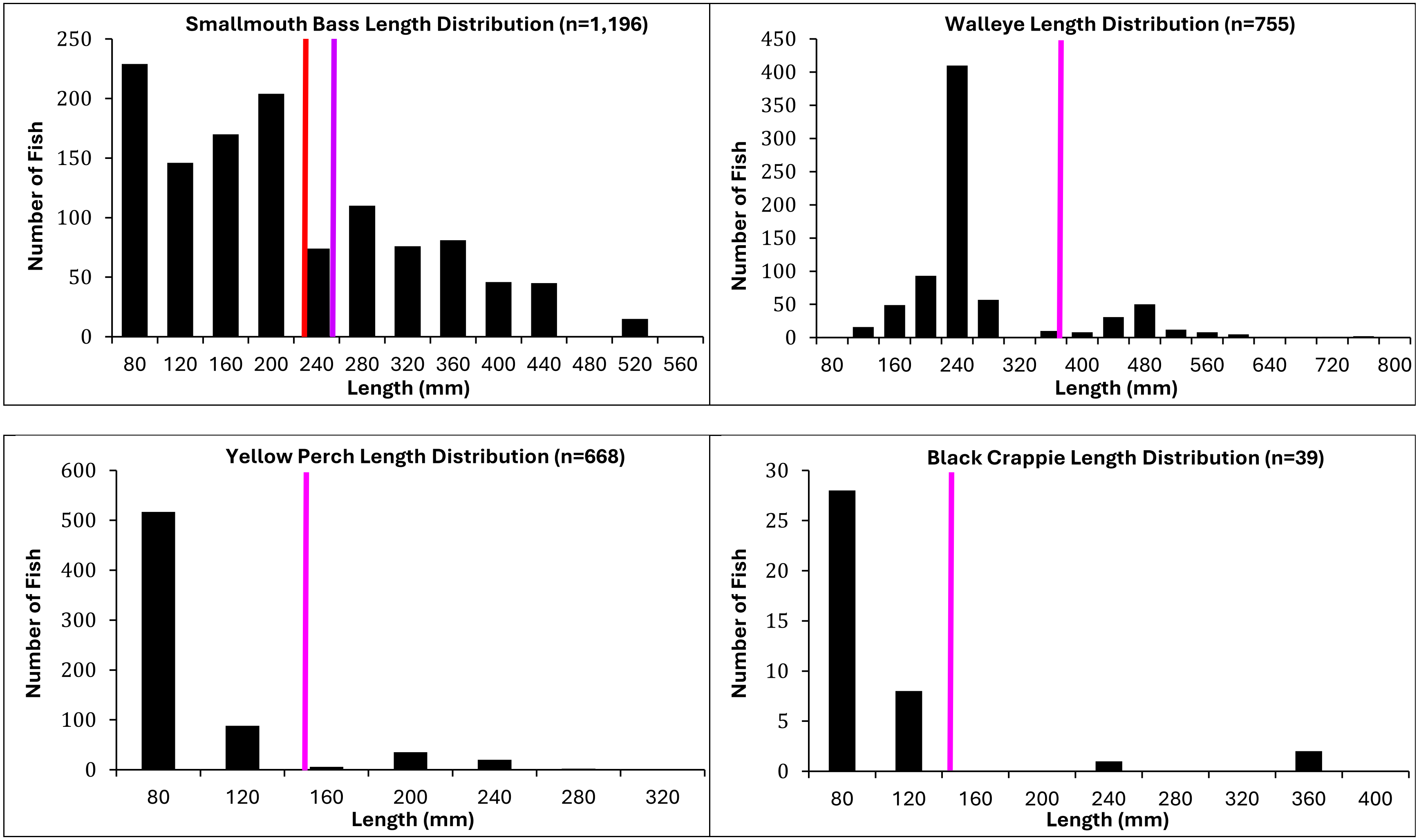

Figure 15. Length distributions of Smallmouth Bass, Walleye, Yellow Perch and Black Crappie, from a survey of Lake Spokane, WA, in 2024. The vertical purple line represents the Washington state-wide average length (255 mm for Smallmouth Bass, 368 mm for Walleye, 155 mm for Yellow Perch, 145 mm for Black Crappie, compared to the state-wide average for that species and length. In the Smallmouth Bass (SMB) graph, the vertical red line is the 230 mm mean length of SMB in Lake Spokane. Unit conversions: 102 mm = 4 inches, 203 mm = 8 inches, 406 mm = 16 inches, 610 mm = 24 inches, 800 mm = 31.5 inches.

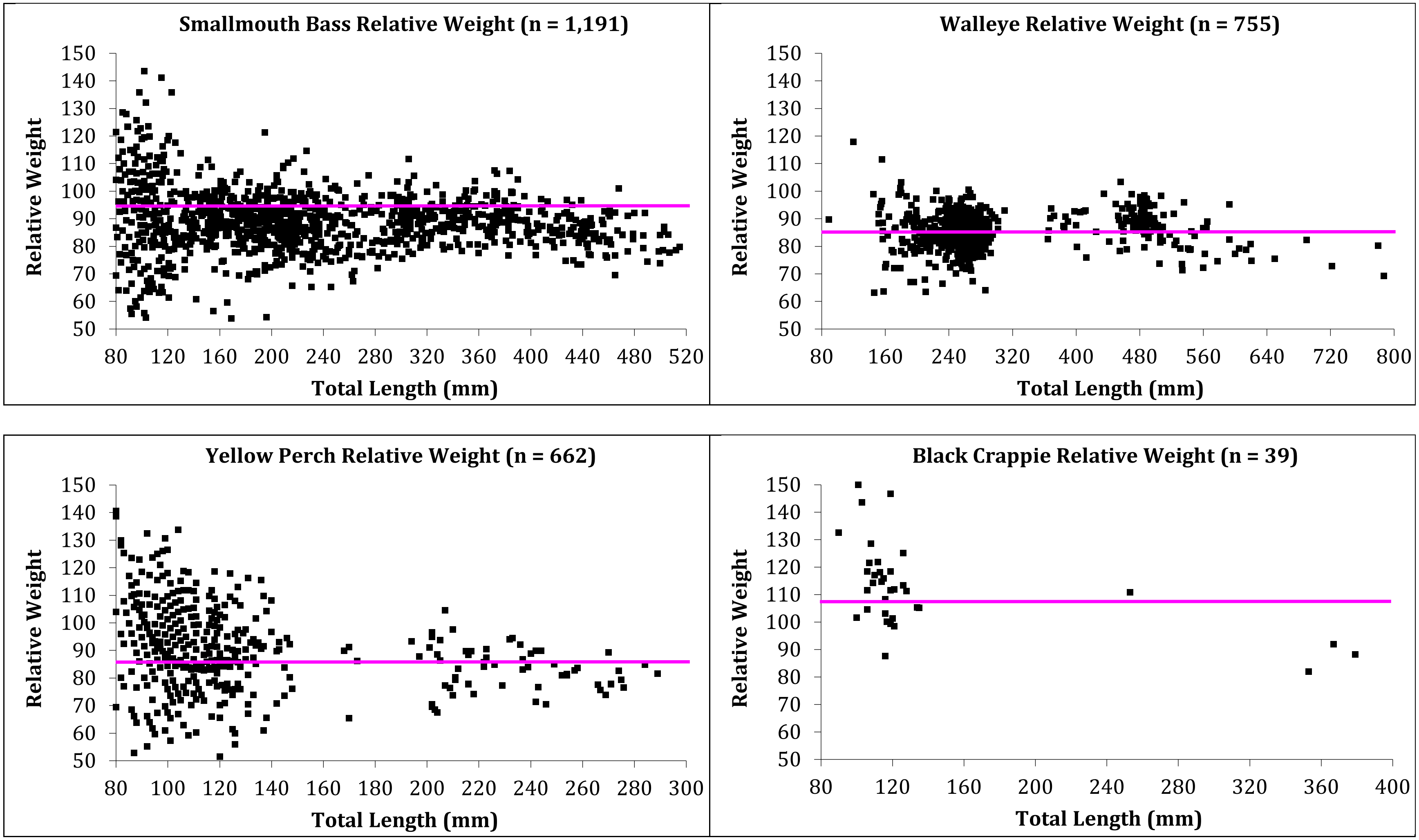

Figure 16. Relative weights (Wr) of Smallmouth Bass, Walleye, Yellow Perch and Black Crappie, from a survey of Lake Spokane, WA, in 2024. The horizontal purple line represents the Washington state-wide average Wr value (93.2 for Smallmouth Bass, 84.8 for Walleye, 85.1 for Yellow Perch, 106.9 for Black Crappie), which indicates fish in good condition compared to the state-wide average for that species and length. Unit conversion: 102 mm = 4 inches, 203 mm = 8 inches, 406 mm = 16 inches, 610 mm = 24 inches, 800 mm = 31.5 inches.

2015 and 2021 Age and Length Distributions of Walleye in Lake Spokane

During the 2015 survey of Lake Spokane, scale samples were taken from 16 Walleye to assess the age structure of the Walleye population. Of the 16 scale samples taken in 2015, two (12%) were age-1 and 14 (88%) were age-2. The age-1 Walleye ranged from 196 to 226 mm (7.7 to 8.9 inches), respectively, and the age-2 Walleye lengths ranged from 343 mm to 423 mm (13.5 to 16.7 inches).

In 2021, otoliths were collected from a stratified random sample of 49 Walleye, caught during a carp netting project, to assess the length-at-age of Walleye in Lake Spokane (six years after scales samples were taken in 2015). Of the 49 otolith samples taken in 2021, 24% were age-1 and 16% were age-2. A von Bertalanffy growth curve developed for female Walleye using otolith data from 2021 is presented in Figure 17.

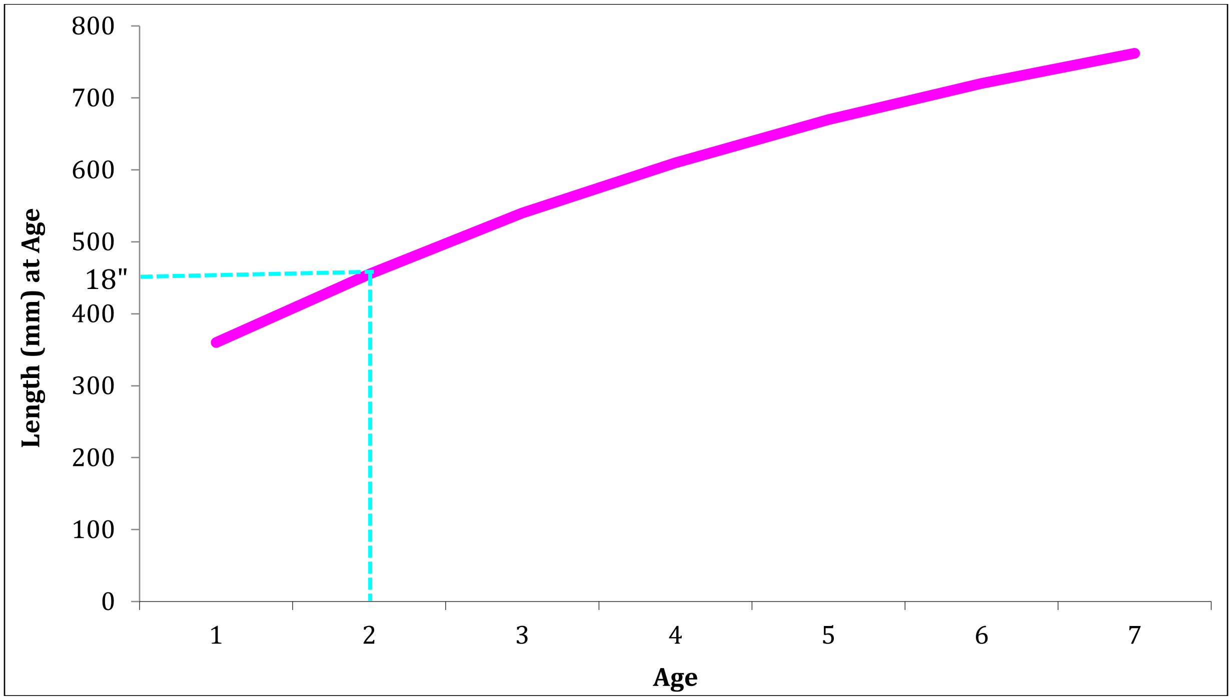

Figure 17. A von Bertalanffy growth curve for female Walleye in Lake Spokane in 2021. The blue dashed lines highlight the mean length of age-2 Walleye, which was 457 mm (18 inches) in 2021.

A comparison of age-2 Walleye lengths between 2015 and 2021 in Lake Spokane is presented in Table 8. There was a significant difference (t-Test P<0.05) in the length of age-2 Walleye between 2015 and 2021, with an increase in mean length of age-2 Walleye of 68 mm (2.7 inches) in 2021. The smallest age-2 Walleye sampled in 2021 were the almost same size (-2 mm less) than the largest Walleye sampled in the 2015 standard survey.

Table 8. Comparison of the age-2 Walleye lengths from Lake Spokane between 2015 and 2021. Unit conversions: 406 mm = 16 inches, 457 mm = 18 inches.

Statistic	2015 (n=14)	2021 (n=8)	Change
Mean	387	455	↑ 68 mm
Median	389	457	↑ 68 mm
Minimum	343	421	-
Maximum	423	484	-
95% Conf. Interval	13.2	18.8	↑ 5.6

Discussion

The spread of nonnative species, whether intentional or not, in Lake Spokane is not unique. Nonnative species have spread throughout Washington, with recent studies documenting changes in both native and nonnative species communities (Mayer et al., 2024; Mayer and Garrett, 2023). Mayer et al. (2024) documented a dramatic increase of nonnative species with a corresponding decrease of native species in Box Canyon Reservoir (~50 miles away), in the biotic homogenization process (McKinney and Lockwood, 1999; Rahel, 2002). The replacement of native species with nonnative species indicates that biotic homogenization is occurring in the reservoir.

Relative abundance of native species compared to nonnative species was equal (+/- 2%) in 2001. However, the proportion of native species caught via electrofishing decreased consistently throughout the study (from 2001 to 2015, and 2015 to 2024). The proportion of native species caught via gill net also decreased, with the largest decline between 2015 and 2024, especially for Largescale Sucker and Northern Pikeminnow. Native species showed no signs of recovery in Lake Spokane during this study (2001 to 2024).

There was a large increase in the proportion of nonnative species caught by both gear types from 2001 to 2015. However, the proportion of nonnative species caught decreased from 2015 to 2024, especially in gill nets, mainly due to the large decrease in the number of Yellow Perch, while nonnative Walleye increased in abundance more than 10-fold in both gear types at the same time. This overall trend of decreases in the catch rate of both native and nonnative species was similar to what we have seen in other predator-dominated systems (Mayer et al., 2024).

The rapid and significant increase of the Smallmouth Bass population during the first period of this study (2001-2015) coincided with significant decreases in Largescale Sucker and Largemouth Bass abundance. The habitat characteristics of Lake Spokane (i.e., thermal regime, flow characteristics, and rocky substrate) favor the life history characteristics and feeding ecology of Smallmouth Bass. And, although the habitat characteristics of Lake Spokane is not ideal for Largemouth Bass (Osborne et al. 2003), the sharp decline in their abundance coincided with the increase in the Smallmouth Bass population, which suggests that competition with Smallmouth Bass was detrimental to Largemouth Bass.

The rapid and significant increase in the Walleye population during the second period of this study (2015-2024) coincided with additional decreases in native and nonnative species: Northern Pikeminnow, Chiselmouth Chub, Bridgelip Sucker, and Yellow Perch. The larger sized Yellow Perch and Northern Pikeminnow sampled in gill nets likely experienced the greatest impact from Walleye predation. However, we can only postulate about causal relationships among fish species without direct diet studies.

Two metrics, catch-per-unit effort (CPUE) and proportional size distribution (PSD), may be used to assess the past and present trajectories of the Smallmouth Bass and Walleye populations in Lake Spokane. From 2001 to 2015, the Smallmouth Bass population increased more than 2-fold via electrofishing (the principal estimator of Smallmouth Bass abundance in this study) and their PSD values increased in the stock, preferred, and memorable size categories at the same time. From 2015 to 2024, the Smallmouth Bass CPUE leveled off and their stock PSD values decreased, while all quality and larger size categories roughly tripled in value during this period. However, on average, the relative weight of Smallmouth Bass in lake Spokane are generally below the state-wide average. These metrics appear to indicate that the Smallmouth Bass population in Lake Spokane remains constant, and has probably peaked and matured.

From 2015 to 2024, the Walleye population increased more than 9-fold via gill net (the principal estimator of Walleye abundance in this study) and their PSD values increased in all size categories at the same time. Further, length-at-age data of Walleye in Lake Spokane showed they grow considerably faster compared to Walleye in nearby Lake Roosevelt. For example, an age-2 Walleye in Lake Spokane has a mean length of 457 mm (18 in.), while it takes five years for an age-2 Walleye in Lake Roosevelt to grow to 457 mm. In addition, the relative weight of Walleye in Lake Spokane are generally above the state-wide average. Taken together, these metrics appear to indicate that the Walleye population in Lake Spokane is healthy and growing, and may be approaching maturity.

Northern Pikeminnow, a native species, may be considered the first top predator in Lake Spokane. Chronologically, the succession of top predator species in Lake Spokane is as follows: Northern Pikeminnow, followed by Largemouth Bass, Smallmouth Bass, and Walleye. This succession of predators in Lake Spokane may be a primary reason for the large declines of selected species in this formerly prey-heavy system. Large decreases of these species, in chronological order, include Largemouth Bass, followed by Black Crappie, Chiselmouth Chub, Yellow Perch, and Northern Pikeminnow. Lake Spokane may now be considered a predator-dominated system, as of 2024.

There are multiple reasons for the decline of native species and nonnative game fish, including Largemouth Bass, Black Crappie and Yellow Perch in Lake Spokane. Predation combined with the loss of habitats: both in-water (macrophytes and weed beds) and external (shoreline development), may play a role in their decline. Conversely, the rocky, flowing in-water habitat is more suitable for Smallmouth Bass and Walleye, than for Largemouth Bass and Black Crappie. The sharp decline in Yellow Perch, which co-evolved with Walleye as their primary prey, was probably due to the introduction, proliferation and predation by Walleye.

The results of this study document large increases in two predator species, Smallmouth bass and Walleye. These two predators are likely responsible for the overall reduction in native species and multiple nonnative species (Largemouth Bass, Black Crappie, and Yellow Perch) as well, over the last 23 years in Lake Spokane. Although we cannot account for the effects of habitat changes over time, competition with and predation by these two predators has played a large role in shaping the fish community in Lake Spokane.

Next steps to improve our understanding of the Lake Spokane fish community

In order to better understand the fish community in Lake Spokane, the following steps can be taken:

1) Periodic standard warmwater surveys every five years, to determine if the fish community in Lake Spokane has stabilized and/or if (and how) the predator:prey ratio continues to change.

2) Conduct Fall Walleye Index Netting (FWIN) surveys every three years, to develop a long-term dataset to monitor the emerging walleye population and how it changes over time – and if it follows similar population dynamics of other Walleye waters in Washington State.

3) Diet surveys of Walleye and Smallmouth Bass would provide a better understanding of how these two predators are impacting both native and nonnative species.

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