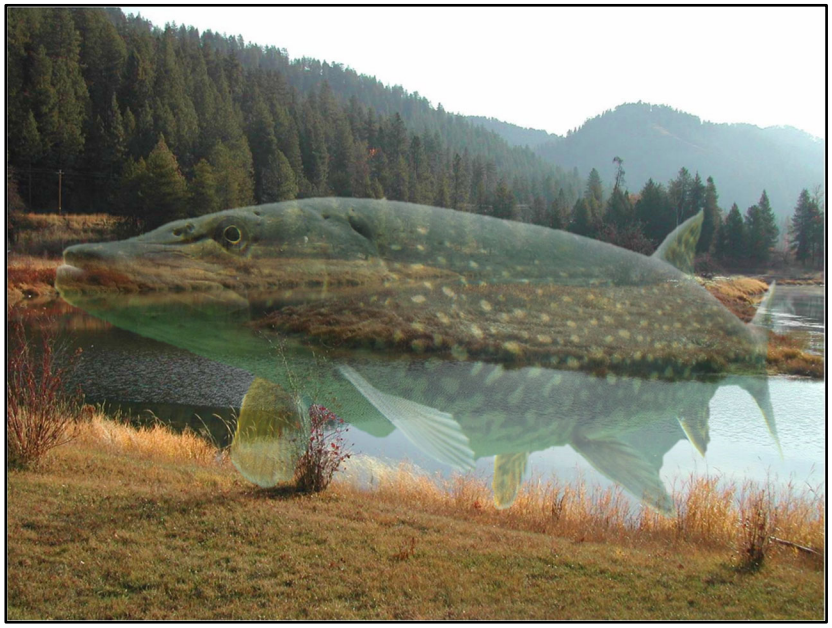
Fish Community Response to Rapid Colonization and Subsequent Suppression of Northern Pike: A 15-year Study of Box Canyon Reservoir, Washington



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FPT 23-03

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June 26, 2023

Abstract

The expansion of Northern Pike outside its native range into the western states of North America is a growing problem due to negative effects on fish communities. Illegally introduced Northern Pike were first detected in Box Canyon Reservoir (Pend Oreille River), in northeast Washington, in 2004. By 2010, the Northern Pike population was estimated at more than 10,000 individuals. Between 2012 to 2019, the Kalispel Tribe of Indians conducted gill net suppression, which reduced the Northern Pike population by 97.3% by number and 98% of their biomass by 2019. From 2004 to 2019, four standardized surveys were conducted to track changes in the Box Canyon Reservoir fish community. All but two species (Brown Trout and Smallmouth Bass) experienced significant declines in relative abundance during Northern Pike colonization and intensive suppression. There was a 55.5% reduction in native species biomass (primarily Northern Pikeminnow, Peamouth Chub, Largescale Sucker, Longnose Sucker) during the course of the 15 year study. Conversely, biomass of nonnative species (Largemouth Bass, Smallmouth Bass, Brown Bullhead, Black Crappie, Pumpkinseed Sunfish and Yellow Perch) increased 31% over the same period. While biomass of Northern Pike was reduced drastically by 2019, native species exhibited no signs of recovery. Most nonnative species declined from 2004-2011, during Northern Pike colonization, but rebounded during the response period following intensive Northern Pike suppression from 2014-2019. Brown Trout and Smallmouth Bass were present at low abundance in 2004, and continued to increase in abundance throughout the study. As an apex predator, Northern Pike had a significant impact on the fish community of Box Canyon Reservoir in a relatively short period of time (7 years) and likely acted as a catalyst to increase the rate of replacement of native species by nonnative species.

Acknowledgments

We would like to thank WDFW biologists Kenny Behen and Bill Baker for their input and extensive reviews of this report. We would also like to thank the Kalispel Tribe of Indians Natural Resources Department, especially Nick Bean, Jason Connor and Shane Harvey, for their efforts to co-develop the Spring Pike Index Netting (SPIN) surveys, continuing work to suppress Northern Pike in Box Canyon Reservoir, benefiting fish species downstream, and the on-going discussions about the management of NP in BCR. Finally, we acknowledge all of the Biologists and technicians from WDFW and the Kalispel Tribe, as well as faculty and students from EWU, who assisted with fish sampling in various years.

Table of Contents

List of Figures

List of Tables

Introduction

Box Canyon Reservoir (BCR), located on the lower Pend Oreille River in northeast Washington, spans 90 kilometers with an area of 2,983-3,556 hectares, depending on pool elevation (Figure 1). The impoundment was created in 1955, following the construction of Box Canyon Dam at river kilometer 54. The reservoir has two distinct reaches, differing in both flow and habitat characteristics: the southern portion consists of the river, sloughs, flooded islands and backwatered areas, while the northern portion is more riverine (Ashe and Scholz 1992, Harvey 2011).

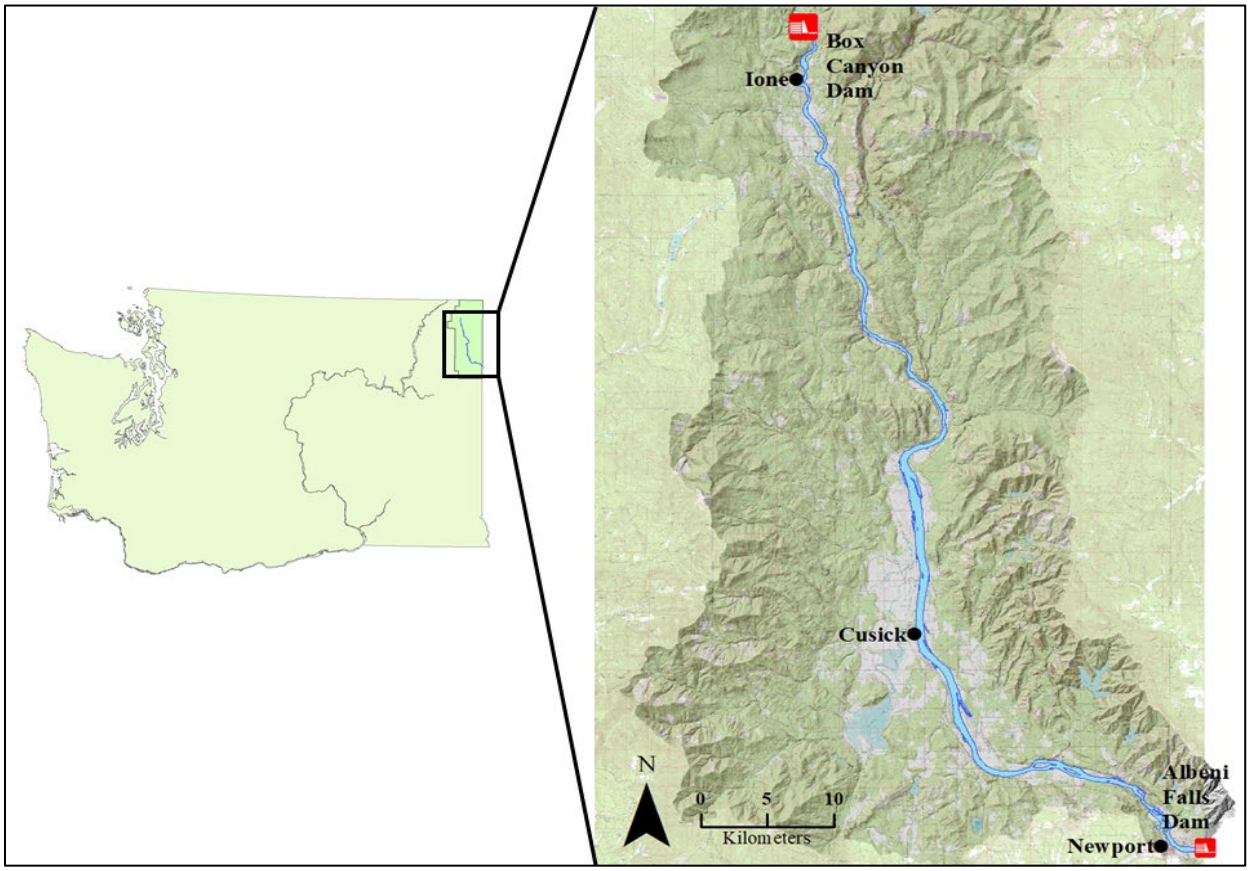

Figure 1. Box Canyon Reservoir, Pend Oreille River, WA.

Construction of Box Canyon Dam created a slower-flowing river, with warmer water temperatures, and inundated backwater sloughs in the southern portion, creating habitat more suitable for warmwater, nonnative fish species, such as Largemouth Bass *Micropterus salmoides*, Smallmouth Bass *Micropterus dolomieu*, Yellow Perch *Perca flavescens*, Black Crappie *Pomoxis nigromaculatus*, Pumpkinseed Sunfish *Lepomis gibbosus*, Tench *Tinca tinca*, and Northern Pike *Esox lucius* (Divens and Osborne 2010).

Prior to 2004, the long-standing fish community in the BCR was characterized as prey-heavy (dominated by overabundant forage species, including Yellow Perch and Pumpkinseed Sunfish, as well as native fish species, such as Northern Pikeminnow *Ptychocheilus oregonensis* and Peamouth Chub *Mylocheilus caurinus* (Bennett and Liter 1991; Ashe and Scholz 1992). The primary predator species, Largemouth Bass, was present prior to the invasion of Northern Pike, which were first documented in BCR in a 2004 standardized warmwater fish survey (Divens and Osborne 2010).

Box Canyon Reservoir provides excellent habitat for Northern Pike, with vegetated sloughs adjacent to riverine areas. Northern Pike have a number of life history traits which make them detrimental to aquatic ecosystems outside of their native range (Dunker et al., 2018). They grow quickly relative to other fish, reaching lengths over 1000 mm in just a few years; they are apex predators, capable of consuming prey outside the size range of most other freshwater fish predators; they are long-lived, with a life span of 8-12 years; and have a high fucundity with females >1000mm, capable of producing up to 200000 eggs (WDFW unpublished data).

The spread of nonnative Northern Pike into BCR is not unique. They have been introduced and are considered invasive in 38 of 50 states in the U.S. (Dunker et al. 2018). Expansion of Northern Pike into states in Western North America, outside its native range, is particularly concerning because of their status as an apex predator (Dunker et al. 2020; Nicholson et al. 2015). In response to the arrival and subsequent expansion of Northern Pike in BCR, the Washington Department of Fish and Wildlife (WDFW) and the Kalispel Tribe of Indians Natural Resources Department (KNRD) agreed that ”Northern Pike are a problem, not an opportunity” and were to be managed as such. In 2011, Northern Pike were reclassified from a game fish species to strictly a prohibited species in the State of Washington. In 2019, Northern Pike were reclassified again, this time as a Class 1 prohibited species.

Following the initial detection of Northern Pike in BCR, it was commonly believed that they had emigrated downstream from populations in the Lake Pend Oreille/Clark Fork River basins in Idaho (Divens and Osborne 2010). However, recent genetic data indicate that the Northern Pike in Box Canyon Reservoir are most closely related to populations from the Coeur d'Alene River basin, specifically the “Chain Lakes” area, suggesting that they were introduced into BCR as a result of human transport (Carim et al. 2022). Further, while genetically similar to populations in the Coeur d'Alene basin, those NP in BCR are genetically less diverse, lending credence to the hypothesis that the population was founded and colonized by a small number of illegally introduced individuals, which created a genetic "founder effect."

From 2004 through 2011, Northern Pike abundance increased rapidly and coincided with sharp declines in the abundance of many fish species in BCR, including native species, such as Northern Pikeminnow, Peamouth Chub, Largescale Sucker *Catostomus macrocheilus*, and Longnose Sucker *Catostomus catostomus* (Bean 2015). In 2006, Andersen and Bean (2013) estimated the population of Northern Pike at 400 adults. Just seven years following initial detection, the exponentially growing population was estimated to have exceeded 10,000 individuals by 2010 (Kalispel Tribe of Indians 2017).

In 2010, WDFW and KNRD developed a monitoring program termed “Spring Pike Index Netting” (SPIN) to estimate the annual relative abundance of Northern Pike in BCR (Andersen Bean 2013; WDFW 2012). In 2012, KNRD initiated an intensive three-year Northern Pike suppression program, with support from WDFW. Between 2012 and 2014, 16,227 Northern Pike (>17,240 kg) were removed from BCR in 3,965 gill net sets (Bean and Harvey 2015). Following the initial effort, an additional five years (2015-2019) of less-intensive suppression occurred. Over the 8-year period, from 2012-2019, the Northern Pike population was reduced by 97.3% (Figure 2; Harvey and Bean 2019). Annual SPIN and suppression summaries, which document Northern Pike population trends in BCR from 2010 to present, can be found at https://wdfw.wa.gov/species-habitats/invasive/esox-lucius#invasive.

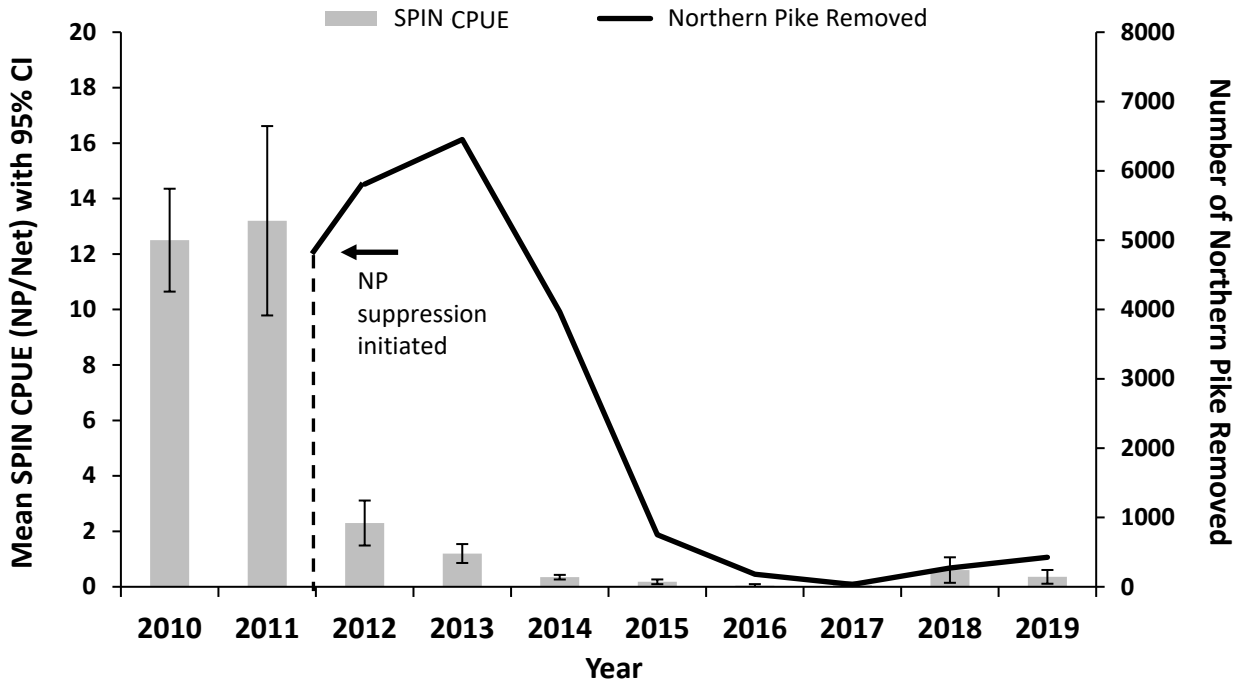

Figure 2. Northern Pike Spring Pike Index Netting surveys (SPIN) CPUE before and after intensive suppression efforts between 2012 and 2019 in Box Canyon Reservoir, WA. Confidence intervals (95%) are indicated by vertical bars (Kalispel Natural Resource Department 2019).

Between 2004-2019, WDFW conducted four standardized surveys of the fish community in BCR to track changes in the fish community. The surveys coincided with the periods of Northern Pike colonization (2004-2011), intensive suppression of Northern Pike (2011-2014) and fish community response following suppression of Northern Pike (2014-2019). Specific objectives of the surveys were to (1) evaluate which species were affected by the colonization of Northern Pike, (2) evaluate which species rebounded following Northern Pike suppression, and (3) determine whether an overall shift in the fish community structure occurred as a result of rapid colonization by Northern Pike.

Methods

Standardized fish surveys of Box Canyon Reservoir were performed jointly by WDFW, KNRD, and Eastern Washington University (EWU), on the following dates: May 10-14, 2004; May 16-19, 2011; May 19-23, 2014; and May 13-16, 2019. The surveys followed a modified version of WDFW warmwater survey protocols (Bonar et al. 2000), consisting of boat electrofishing and gill netting. Fyke nets were not used, due to their limitations under higher flows in riverine conditions.

Sampling locations were randomly selected in both river and slough sections based on pool elevation of the reservoir. Sampling effort was highest in 2004 (which was about 30% more sites were sampled than in subsequent years), and then effort was similar in the 2011, 2014, and 2019 surveys (Table 1).

Table 1. Level of effort (number of sample sites), by year and gear type (electrofishing and gill netting), for standardized surveys of Box Canyon Reservoir, WA.

Year	2004	2011	2014	2019
Electrofishing	126	92	96	95
Gill net	56	41	48	51
Total sites	182	133	144	146

Fish were identified to species, measured for total length (mm) and weighed to the nearest gram (g). Species composition was calculated based on the total number and weight (kg) of all fish captured.

Catch-per-unit effort (CPUE), by gear type (electrofishing or gill netting) and habitat type (river or slough), was calculated for species representing greater than 0.5% of the biomass in BCR, reported as number of fish-per-hour for electrofishing and number of fish per net-night for gill netting. Mean CPUE was calculated separately for riverine and slough habitats to account for differences in gear efficiency and habitat types. Eighty percent confidence intervals were calculated for mean CPUE. To avoid committing a Type I error (i.e., rejecting the null hypothesis when it is true) or Type II error (i.e., accepting the null hypothesis when it is false), conclusions were not drawn from statistically significant results which had very low sample sizes, and therefore less statistical power to detect change.

A comparative analysis was conducted to detect differences in CPUE for each species using two factors: survey year and habitat type. 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 survey years.

The population status of Northern Pike in 2004 was determined using CPUE based on standardized warmwater survey methodology (Bonar et al. 2000). The abundance of NP in 2011, 2014 and 2019 was based on SPIN survey results. Northern Pike CPUE derived from SPIN surveys (2010-2019) is displayed on CPUE graphs of selected species (see Results) from standardized surveys, to elucidate the apparent causal effects of the rapid colonization of Northern Pike, especially during the period of rapid population increase between 2004 and 2011, and the subsequent suppression efforts beginning in 2012.

Results

During the course of the 15-year study, 24 fish species were captured in Box Canyon Reservoir. A list of all native species and nonnative species captured are presented in Tables 2 and 3, respectively, including sample size by year. A total of 30,072 fish were captured during the 15-year study period: 13,836 in 2004, 4,108 in 2011, 5,617 in 2014, and 6,688 in 2019.

Table 2. All native species captured in standard surveys of Box Canyon Reservoir, WA, from 2004 to 2019, including sample sizes (n). Asterisk (*) denotes species <0.5% of the biomass in BCR.

Common Name	Species / Genus	n 2004	n 2011	n 2014	n 2019
Largescale Sucker	*Catostomus macrocheilus*	446	295	217	122
Longnose Sucker	*Catostomus Catostomus*	89	16	29	12
Mountain Whitefish*	*Prosopium* williamsoni	64	9	19	10
Northern Pikeminnow	*Ptychocheilus oregonensis*	1625	442	259	137
Peamouth Chub	*Mylocheilus caurinus*	1072	65	14	4
Redside Shiner*	*Richardsonius balteatus*	22	0	0	0
Westslope Cutthroat Trout*	*Oncorhynchus clarkii lewisi*	2	2	1	2
	Total number of individuals	3320	829	539	287

Table 3. All nonnative species captured in standard surveys of Box Canyon Reservoir, WA, from 2004 to 2019, including sample sizes (n). Asterisk (*) denotes species <0.5% of the biomass in BCR.

Common Name	Species / Genus	n 2004	n 2011	n 2014	n 2019
Black Crappie	*Pomoxis nigromaculatus*	774	130	55	144
Brown Bullhead	*Ameiurus nebulosus*	114	80	59	192
Brown Trout	*Salmo trutta*	41	82	84	129
Eastern Brook Trout*	*Salvelinus fontinalis*	5	2	6	8
Grass Pickerel*	*Esox americanus*	0	1	5	68
Kokanee*	*Oncorhynchus nerka*	0	4	0	2
Lake Trout*	*Salvelinus namaycush*	0	0	1	3
Lake Whitefish*	*Coregonus clupeaformis*	2	3	3	8
Largemouth Bass	*Micropterus salmoides*	1122	137	226	273
Northern Pike	*Esox lucius*	27	199	7	5
Pumpkinseed Sunfish	*Lepomis gibbosus*	3859	322	342	677
Rainbow Trout*	*Oncorhynchus mykiss*	9	2	11	42
Smallmouth Bass	*Micropterus dolomieu*	30	62	198	461
Tench	*Tinca tinca*	740	692	639	820
Walleye*	*Sander vitreus*	1	7	10	37
Yellow Perch	*Perca flavescens*	3792	1379	3432	3532
	Total number of individuals	10516	3102	5078	6401

Four native species (Northern Pikeminnow, Peamouth Chub, Largescale Sucker, Longnose Sucker) and nine nonnative species (Northern Pike, Largemouth Bass, Brown Bullhead *Ameiurus nebulosus*, Black Crappie, Pumpkinseed Sunfish, Smallmouth Bass, Yellow Perch, Tench, Brown Trout *Salmo trutta*

represented >0.5% of the total biomass 2004 to 2019, and were then included in comparative analysis of mean CPUE across all years.

Electrofishing was the most effective gear type for monitoring native species, based on sample sizes (Table 4). Gill netting was also useful for monitoring changes in CPUE in some circumstances. All native species showed significant declines in CPUE over the 2004-2019 study period (Figures 3-6). P-values for significant differences in CPUE based on gear and habitat types are presented in Appendix 1.

During the colonization period (2004-2011), Northern Pikeminnow and Peamouth Chub CPUE declined significantly in all gear and habitat types. Longnose Sucker gill net CPUE declined significantly in the river, but sample size was low (n=18 combined, for all surveys). Longnose Sucker electrofishing CPUE in the river indicated no change (n=93). During the same period, Largescale Sucker showed no change across gear and habitat types.

During the intensive suppression period (2011-2014), native species showed no significant change in electrofishing CPUE across habitat types. Gill net CPUE for Peamouth Chub declined significantly in the river, but sample size was low (n=27). Similarly, Largescale Sucker declined significantly in gill nets set in sloughs, but sample size was also low (n=18).

During the response period (2014-2019), native species showed no significant change in CPUE across gear or habitat type, with the exception of Northern Pikeminnow, which declined significantly in electro-fishing in slough habitat, but sample size was low (n=32) compared to electrofishing in the river (n=318) where no change was observed.

Table 4. Results of comparative analyses (Dunn test) of CPUE for electrofishing (EB) and gill netting (GN) in river and slough habitats between years for native species. Sample size is the total for each species across all years combined (2004, 2011, 2014, 2019). Arrows (↑↓) indicate where significant differences occurred and the direction of change.

Species	Variables: Gear type Habitat type	Total Sample Size (N)	Colonization (2004-2011)	Intensive Suppression (2011-2014)	Response (2014-2019)	15-Year Study Period (2004-2019)
Northern Pikeminnow	EB-River	1931	↓	-	-	↓
	EB-Slough	85	↓	-	↓	↓
	GN-River	368	↓	-	-	↓
	GN-Slough	85	↓	-	-	↓
Peamouth Chub	EB-River	347	↓	-	-	↓
	EB-Slough	39	↓	-	-	↓
	GN-River	393	↓	↓	-	↓
	GN-Slough	381	↓	-	-	↓
Largescale Sucker	EB-River	830	-	-	-	↓
	EB-Slough	60	-	-	-	↓
	GN-River	135	-	-	-	-
	GN-Slough	46	-	↓	-	↓
Longnose Sucker	EB-River	104	-	-	-	-
	EB-Slough	15	-	-	-	-
	GN-River	18	↓	-	-	↓
	GN-Slough	2	-	-	-	-

Electrofishing was also the most effective gear type for monitoring nonnative species, based on sample sizes (Table 5), except for Northern Pike, which were more effectively monitored with gill nets. Gill netting was useful for monitoring changes in CPUE in some circumstances. All nonnative species showed a significant difference in CPUE over the entire study period, from 2004 to 2019 (Figures 7-14). P-values for significant differences in CPUE based on gear and habitat types are presented in Appendix 1.

During the colonization period (2004-2011), Largemouth Bass and Pumpkinseed Sunfish electrofishing CPUE declined significantly in both river and slough habitats. Gill net CPUE for Pumpkinseed Sunfish declined for both habitat types, while Largemouth Bass declined in slough habitat only (Table 5). Black Crappie CPUE declined significantly across gear types in river habitat, but not in slough habitat. Yellow Perch CPUE declined significantly in gill nets in the river, but showed no change among other gear and habitat types. Tench CPUE declined significantly in gill nets in sloughs, but showed no change for other gear and habitat types. Brown Trout CPUE increased significantly in river habitats. Brown Bullhead and Smallmouth Bass CPUE showed no change during the colonization period across all gear and habitat types.

During the intensive suppression period (2011-2014), Largemouth Bass, Brown Bullhead, Black Crappie, Pumpkinseed Sunfish, and Brown Trout CPUE showed no significant change across all gear and habitat types (Table 5). Yellow Perch electrofishing CPUE increased significantly in slough habitat, but gill net CPUE decreased significantly in river habitat. Smallmouth Bass electrofishing CPUE increased significantly based in slough habitat. Tench gill net CPUE declined significantly in river habitat, but while no changes were observed in electrofishing CPUE.

During the response period (2014-2019), the CPUE of all nonnative species, except for Brown Trout, increased significantly for at least one gear and habitat type (Table 5).

Over the entire study period (2004-2019), CPUE of Largemouth Bass, Black Crappie, and Pumpkinseed Sunfish decreased significantly, while Smallmouth Bass and Brown Trout CPUE increased significantly. Yellow Perch experienced both significant decreases and increases in CPUE throughout the study, under different gear and habitat types. While there was a significant decrease in Yellow Perch gill net CPUE in river habitat, other gear and habitat combinations indicated an increase in Yellow Perch CPUE at the end of the study in 2019. Tench also experienced significant CPUE decreases and increases, but ultimately increased in relative abundance by 2019.

Table 5. Results of comparative analyses (Dunn test) of CPUE for electrofishing (EB) and gill netting (GN) in river and slough habitats between years for nonnative species. Sample size is the total for each species across all years combined (2004, 2011, 2014, 2019). Arrows (↑↓) indicate where significant differences occurred and the direction of change.

Species	Variables: Gear type Habitat type	Total Sample Size (N)	Colonization (2004-2011)	Intensive Suppression (2011-2014)	Response (2014-2019)	15-Year Study Period (2004-2019)
Largemouth Bass	EB-River	817	↓	-	-	↓
	EB-Slough	883	↓	-	-	↓
	GN-River	79	↓	-	↑	-
	GN-Slough	132	-	-	↑	↓
Brown Bullhead	EB-River	120	-	-	↑	-
	EB-Slough	186	-	-	-	-
	GN-River	76	-	-	↑	↑
	GN-Slough	64	-	-	-	-
Black Crappie	EB-River	346	↓	-	↑	↓
	EB-Slough	435	-	-	-	↓
	GN-River	170	↓	-	↑	-
	GN-Slough	207	-	-	-	↓
Pumpkinseed Sunfish	EB-River	2440	↓	-	-	↓
	EB-Slough	1907	↓	-	-	↓
	GN-River	538	↓	-	↑	-
	GN-Slough	332	↓	-	↑	-
Smallmouth Bass	EB-River	522	-	↑	-	↑
	EB-Slough	225	-	-	↑	↑
	GN-River	21	-	-	↑	↑
	GN-Slough	41	-	-	-	↑
Yellow Perch	EB-River	4989	-	-	-	-
	EB-Slough	5556	-	↑	-	-
	GN-River	1380	↓	↓	↑	↓
	GN-Slough	1131	-	-	-	-
Tench	EB-River	919	-	-	-	-
	EB-Slough	905	-	-	-	-
	GN-River	577	-	↓	↑	↑
	GN-Slough	535	↓	-	-	↑
Brown Trout	EB-River	295	↑	-	-	↑
	EB-Slough	13	-	-	-	-
	GN-River	18	-	-	-	-
	GN-Slough	10	-	-	-	-

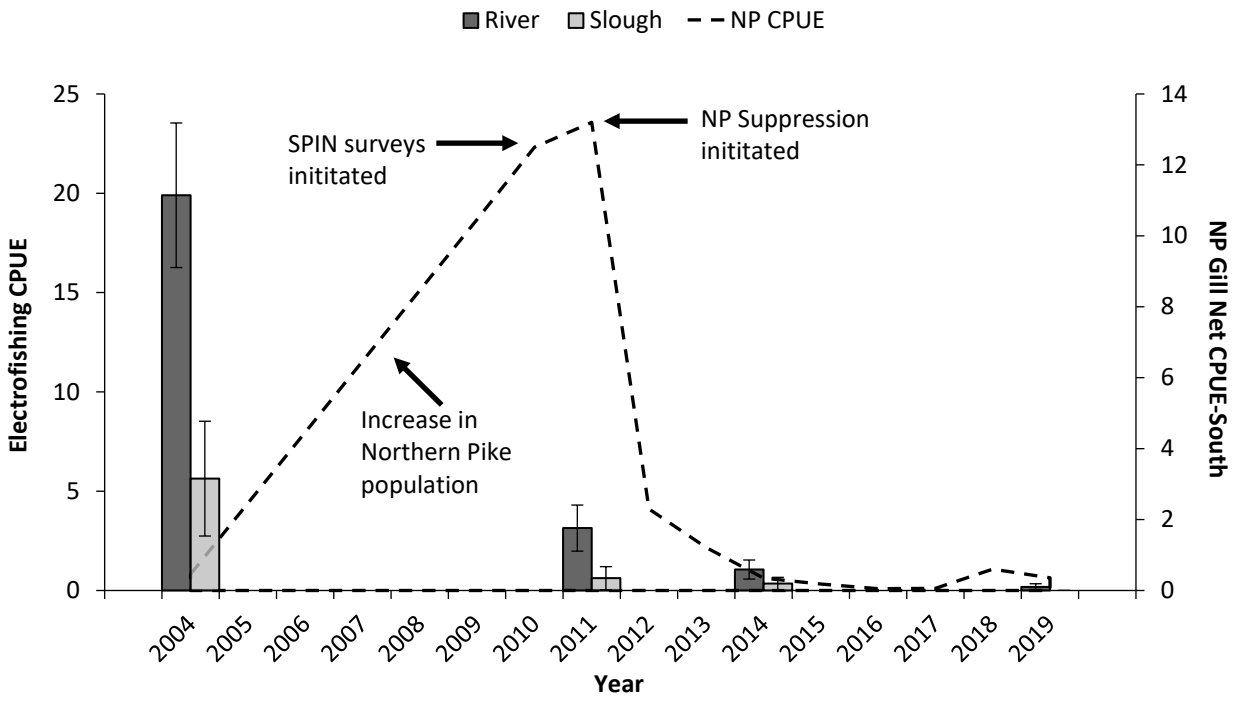

Figure 3. Mean electrofishing CPUE (±80% CI) of Peamouth Chub by year and habitat type in surveys of Box Canyon Reservoir, WA, in 2004, 2011, 2014 and 2019. Northern Pike CPUE in 2004 (-- dashed line) is based on a standard survey in 2004. Northern Pike CPUE from 2010-2019 is based on Spring Pike Index Netting surveys.

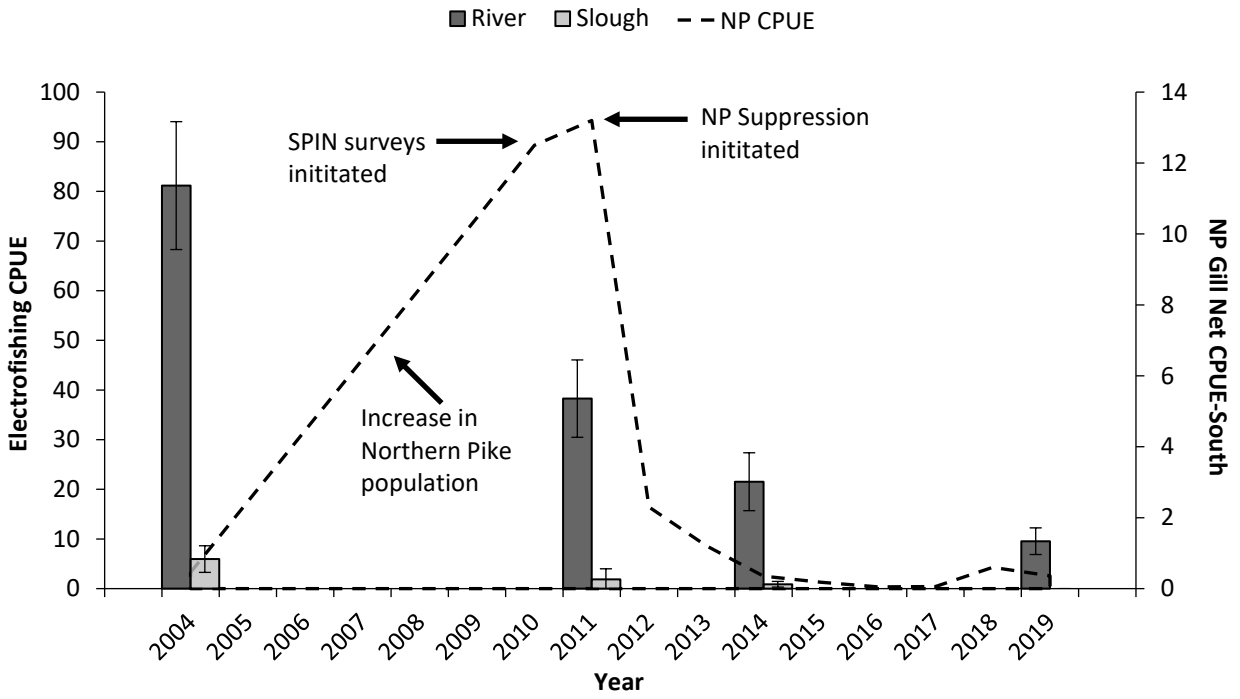

Figure 4. Mean electrofishing CPUE (±80% CI) of Northern Pikeminnow by year and habitat type in surveys of Box Canyon Reservoir, WA, in 2004, 2011, 2014 and 2019. Northern Pike CPUE in 2004 (-- dashed line) is based on a standard survey in 2004. Northern Pike CPUE from 2010-2019 is based on Spring Pike Index Netting surveys.

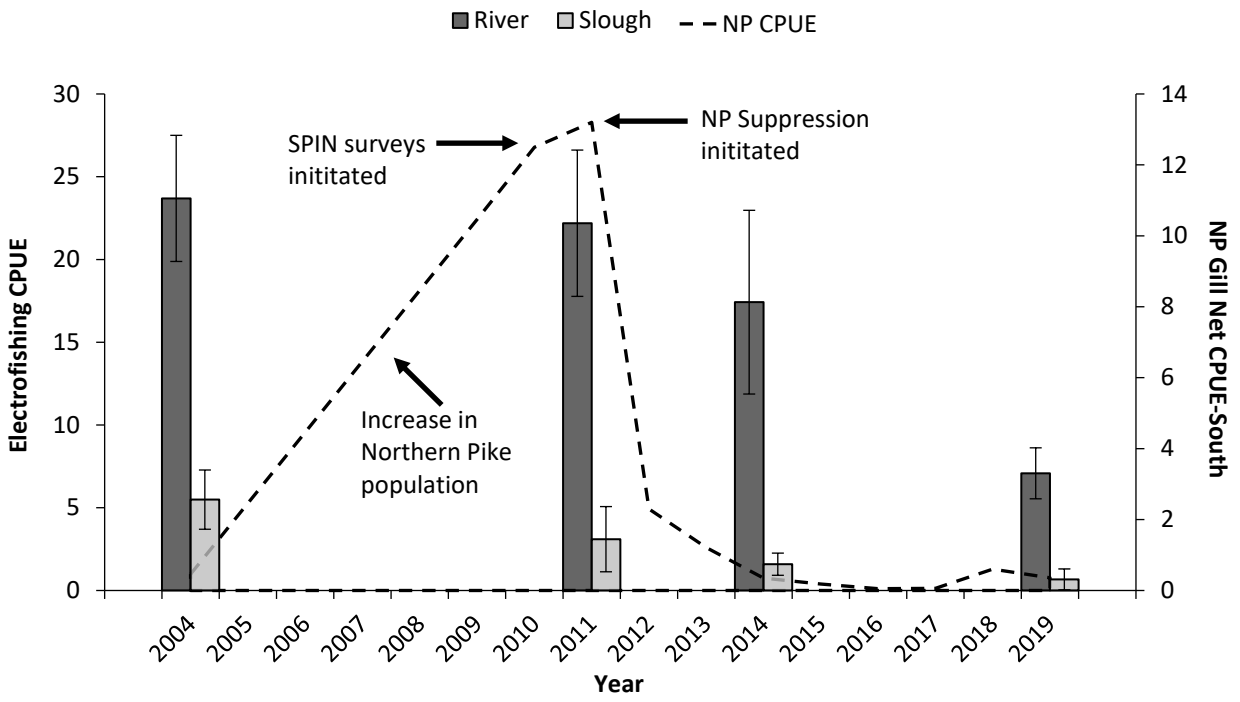

Figure 5. Mean electrofishing CPUE (±80% CI) of Largescale Sucker by year and habitat type in surveys of Box Canyon Reservoir, WA, in 2004, 2011, 2014 and 2019. Northern Pike CPUE in 2004 (-- dashed line) is based on a standard survey in 2004. Northern Pike CPUE from 2010-2019 is based on Spring Pike Index Netting surveys.

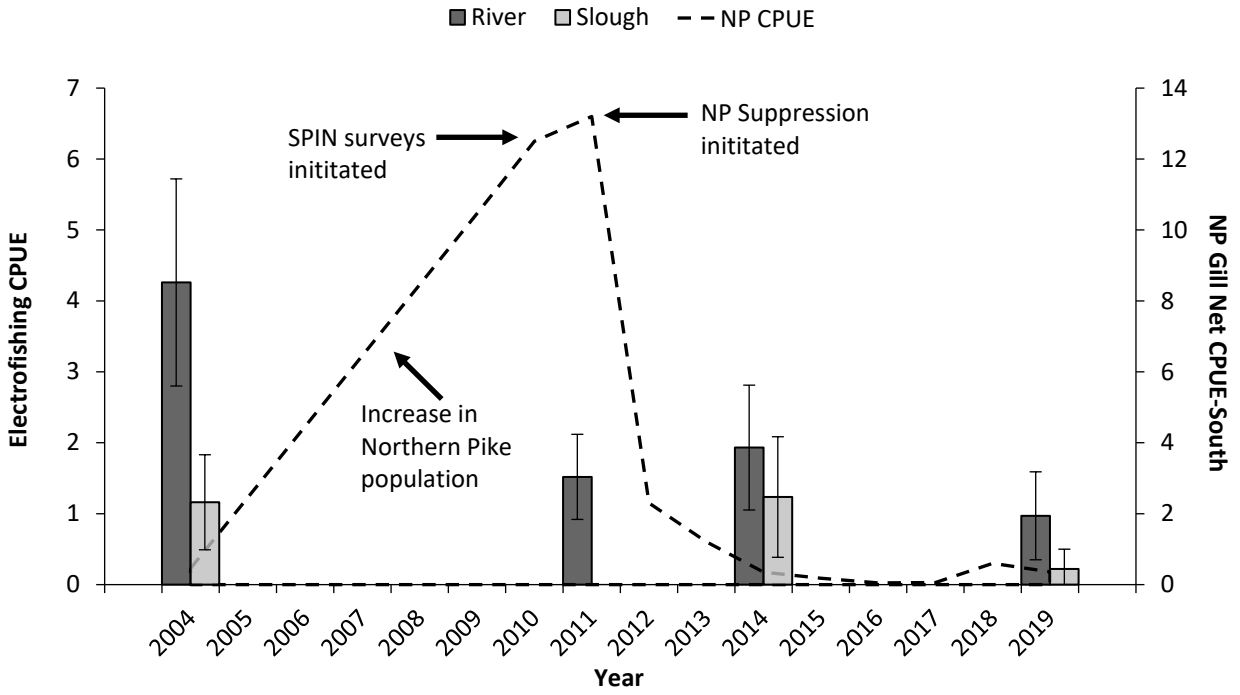

Figure 6. Mean electrofishing CPUE (±80% CI) of Longnose Sucker by year and habitat type in surveys of Box Canyon Reservoir, WA, in 2004, 2011, 2014 and 2019. Northern Pike CPUE in 2004 (-- dashed line) is based on a standard survey in 2004. Northern Pike CPUE from 2010-2019 is based on Spring Pike Index Netting surveys.

The CPUE of Nonnative species (Largemouth Bass, Smallmouth Bass, Brown Bullhead, Black Crappie, Pumpkinseed Sunfish, Yellow Perch) also decreased significantly between 2004 and 2011 coinciding with the expansion of Northern Pike (Figures 7-15). However, nonnative species subsequently increased in overall abundance beginning in 2014, following the intensive suppression of NP. The greatest increase in the CPUE of nonnative species was documented in 2019, except for Northern Pike, which were significantly reduced by suppression. The gill net CPUE results for Northern Pike mirror the results from annual SPIN surveys (Figure 7).

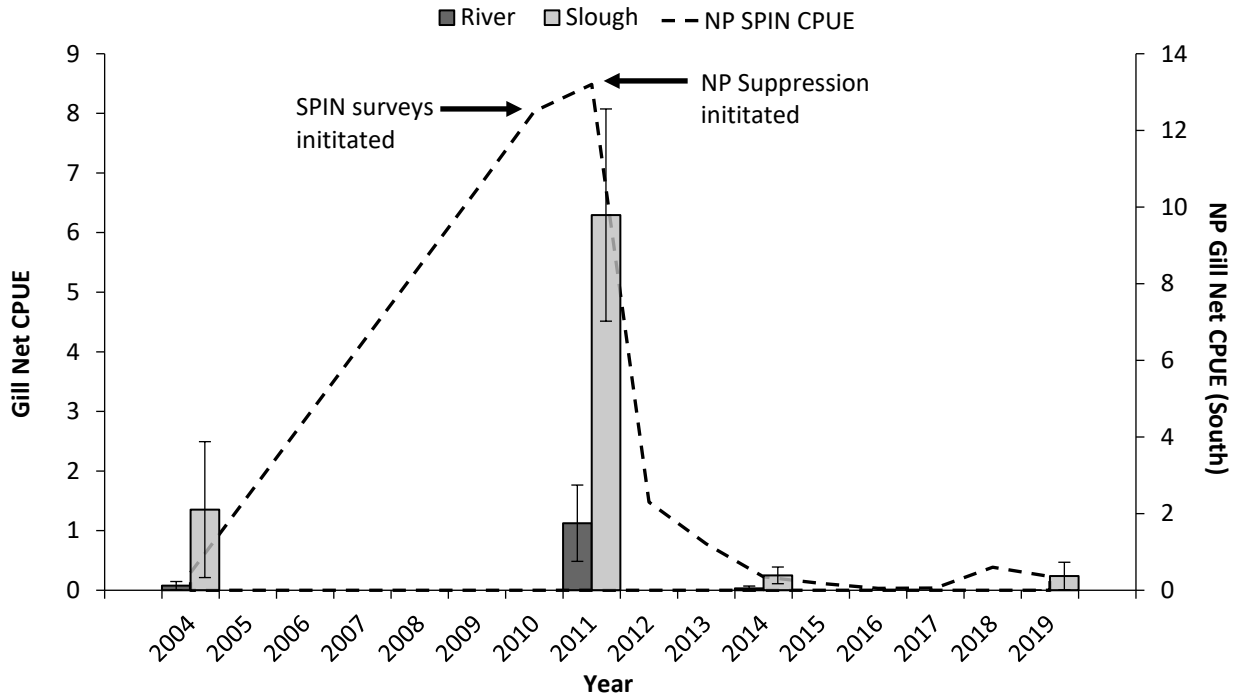

Figure 7. Mean gill netting CPUE (±80% CI) of Northern Pike by year and habitat type in surveys of Box Canyon Reservoir, WA, in 2004, 2011, 2014 and 2019. The Northern Pike CPUE in 2004 (-- dashed line) is based on a standard survey in 2004 and the CPUE from 2010-2019 is based on Spring Pike Index Netting (SPIN) surveys.

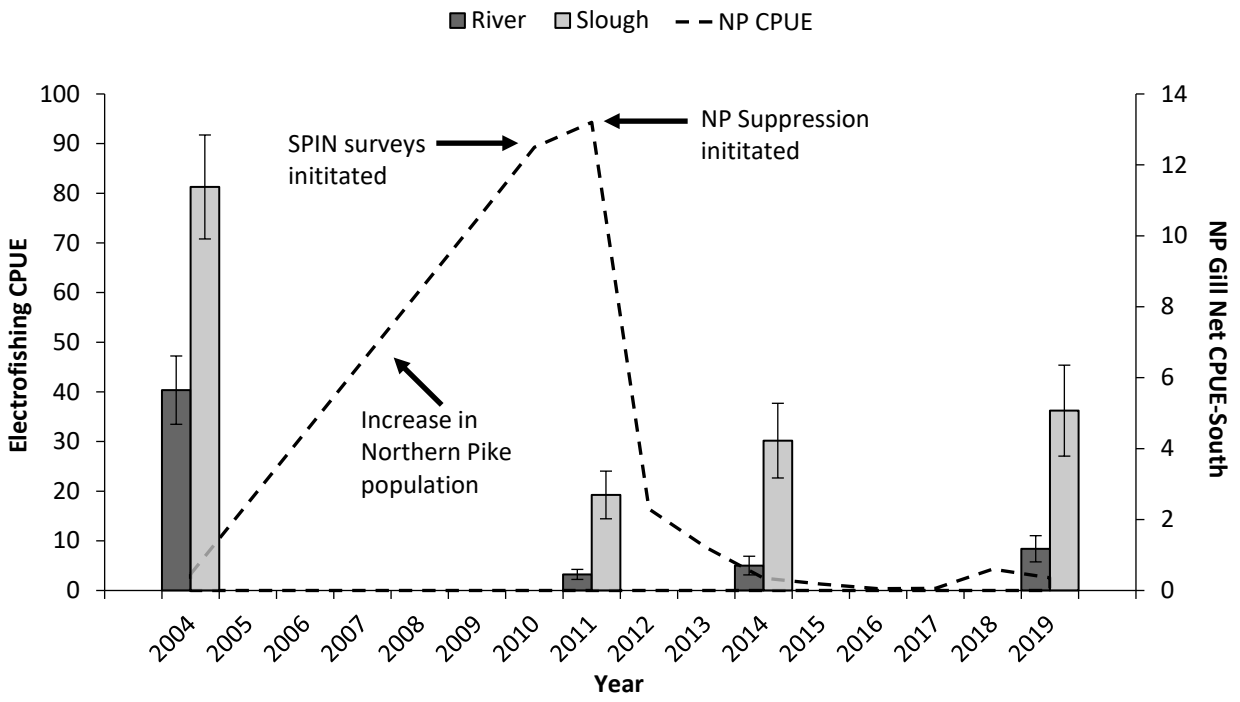

Figure 8. Mean electrofishing CPUE (±80% CI) of Largemouth Bass by year and habitat type in surveys of Box Canyon Reservoir, WA, in 2004, 2011, 2014 and 2019. Northern Pike CPUE in 2004 (-- dashed line) is based on a standard survey in 2004. Northern Pike CPUE from 2010-2019 is based on Spring Pike Index Netting surveys.

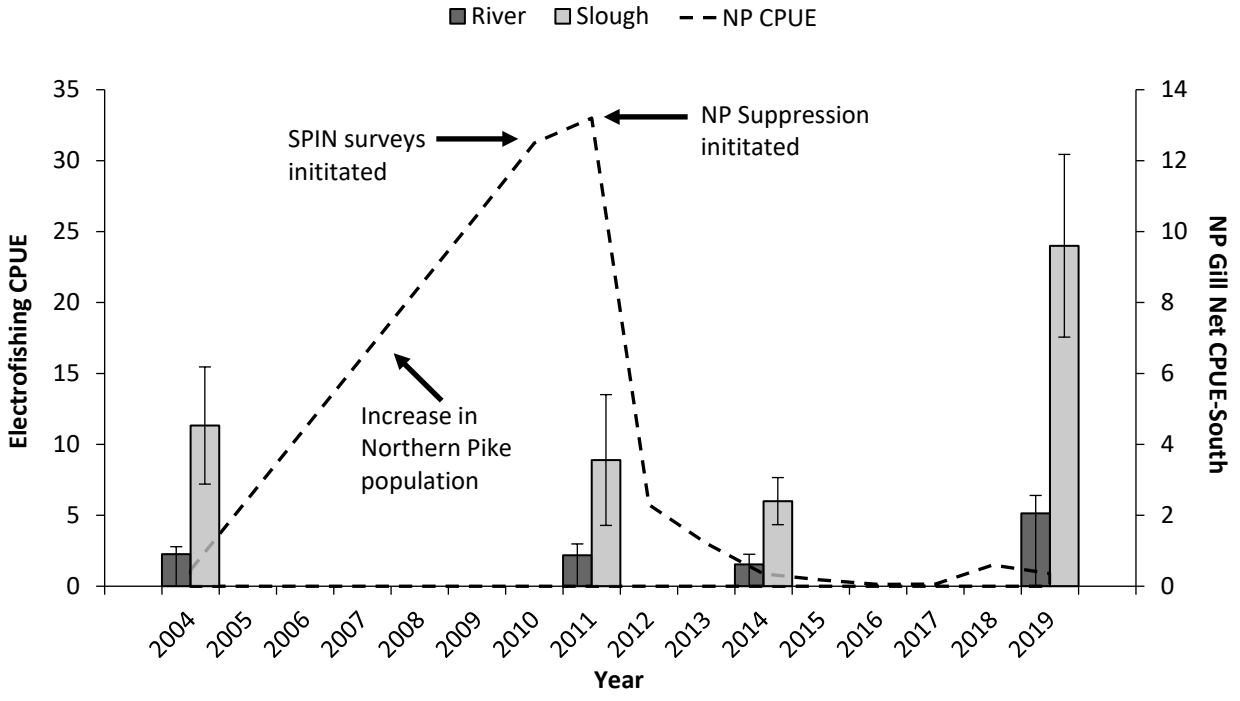

Figure 9. Mean electrofishing CPUE (±80% CI) of Brown Bullhead by year and habitat type in surveys of Box Canyon Reservoir, WA, in 2004, 2011, 2014 and 2019. Northern Pike CPUE in 2004 (-- dashed line) is based on a standard survey in 2004. Northern Pike CPUE from 2010-2019 is based on Spring Pike Index Netting surveys.

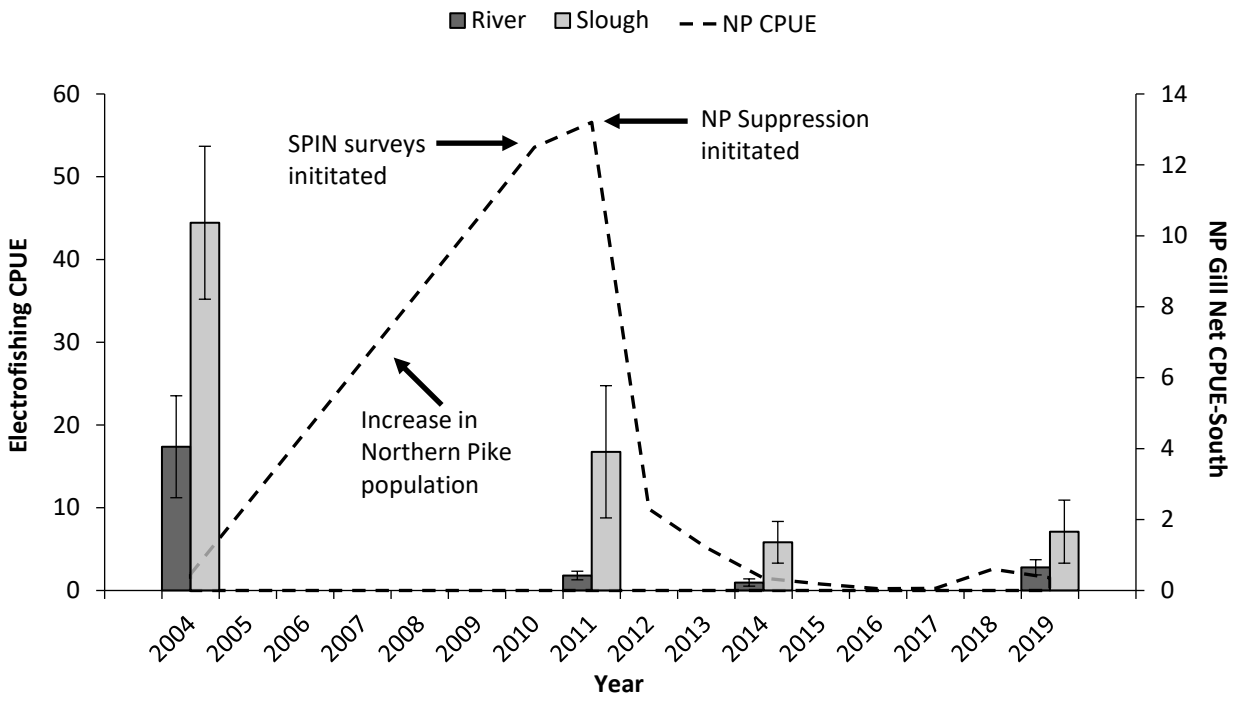

Figure 10. Mean electrofishing CPUE (±80% CI) of Black Crappie by year and habitat type in surveys of Box Canyon Reservoir, WA, in 2004, 2011, 2014 and 2019. Northern Pike CPUE in 2004 (-- dashed line) is based on a standard survey in 2004. Northern Pike CPUE from 2010-2019 is based on Spring Pike Index Netting surveys.

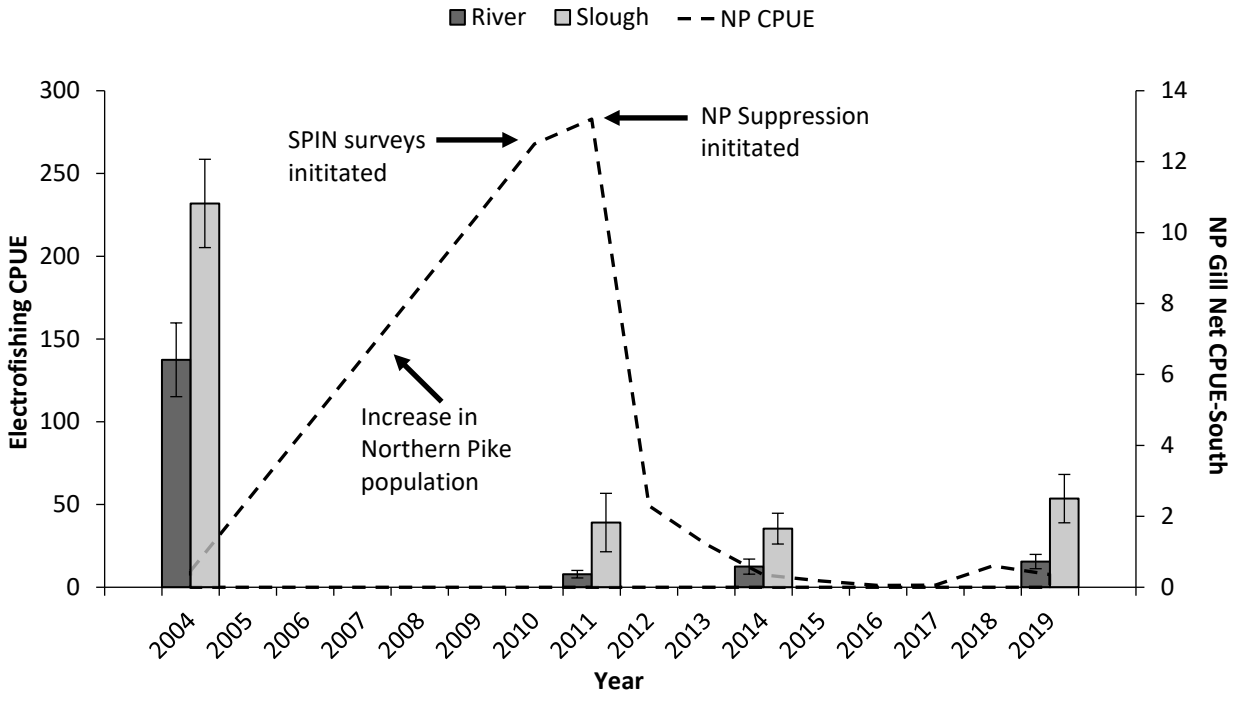

Figure 11. Mean electrofishing CPUE (±80% CI) of Pumpkinseed Sunfish by year and habitat type in surveys of Box Canyon Reservoir, WA, in 2004, 2011, 2014 and 2019. Northern Pike CPUE in 2004 (-- dashed line) is based on a standard survey in 2004. Northern Pike CPUE from 2010-2019 is based on Spring Pike Index Netting surveys.

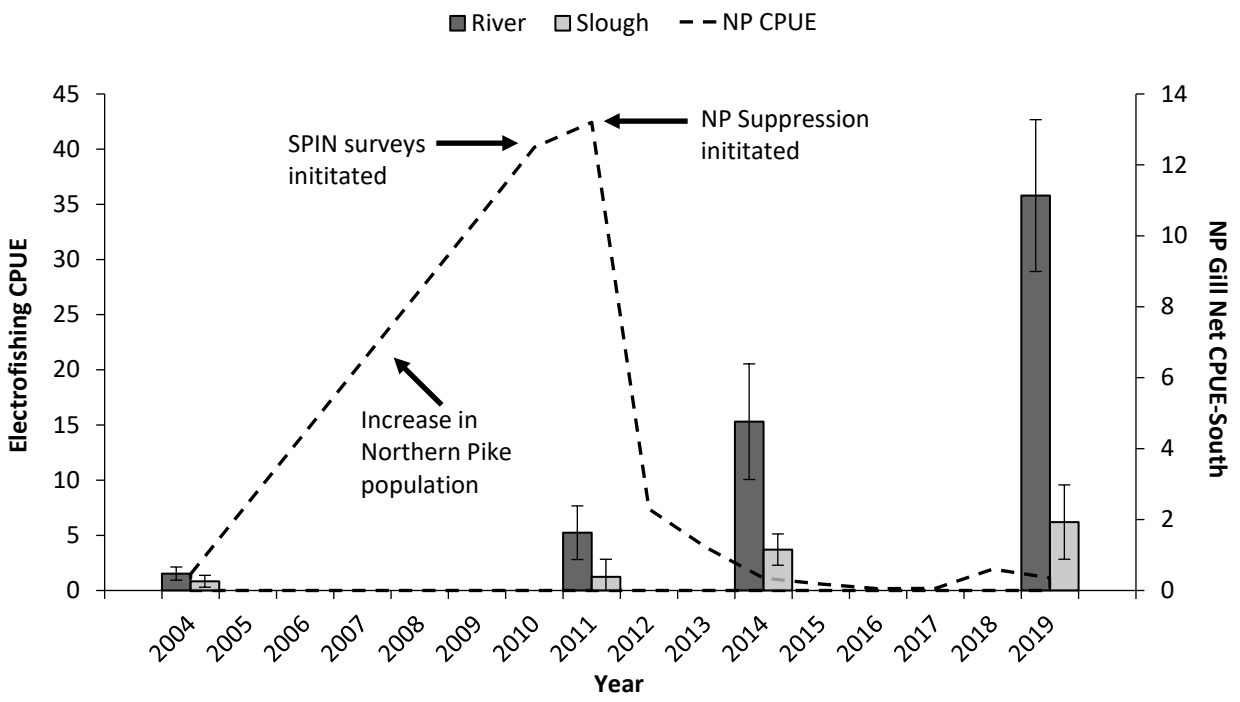

Figure 12. Mean electrofishing CPUE (±80% CI) of Smallmouth Bass by year and habitat type in surveys of Box Canyon Reservoir, WA, in 2004, 2011, 2014 and 2019. Northern Pike CPUE in 2004 (-- dashed line) is based on a standard survey in 2004. Northern Pike CPUE from 2010-2019 is based on Spring Pike Index Netting surveys.

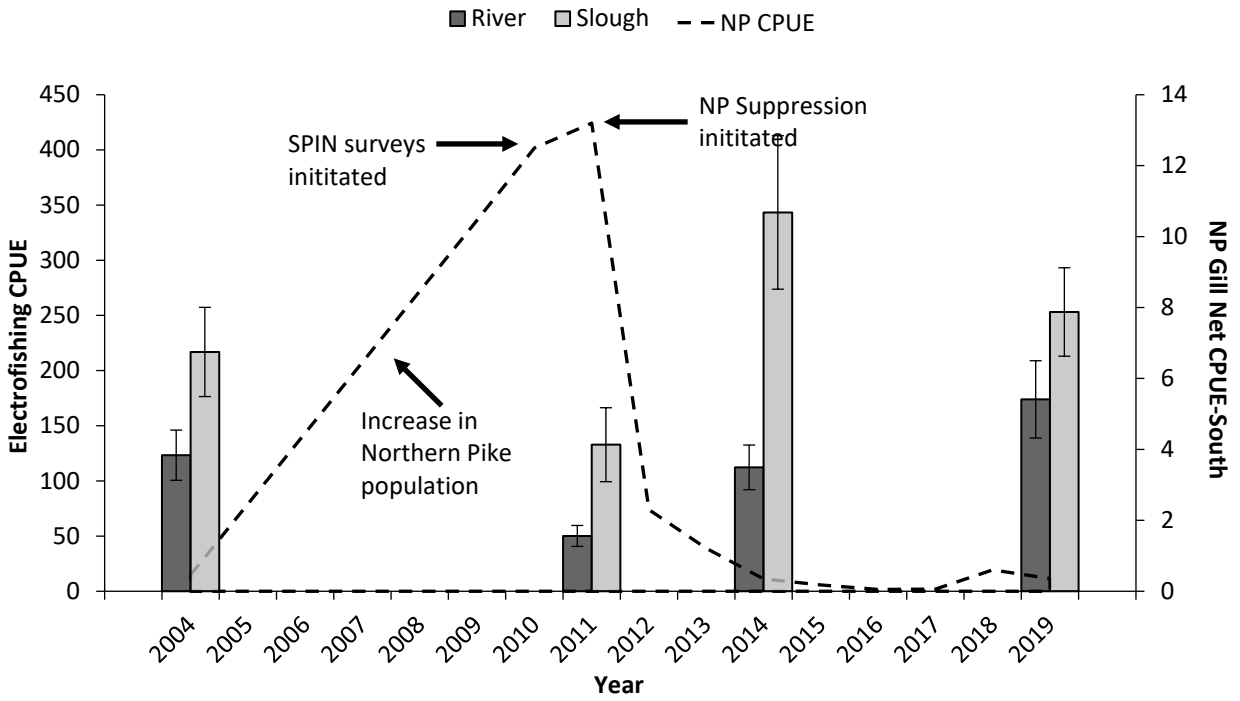

Figure 13. Mean electrofishing CPUE (±80% CI) of Yellow Perch by year and habitat type in surveys of Box Canyon Reservoir, WA, in 2004, 2011, 2014 and 2019. Northern Pike CPUE in 2004 (-- dashed line) is based on a standard survey in 2004. Northern Pike CPUE from 2010-2019 is based on Spring Pike Index Netting surveys.

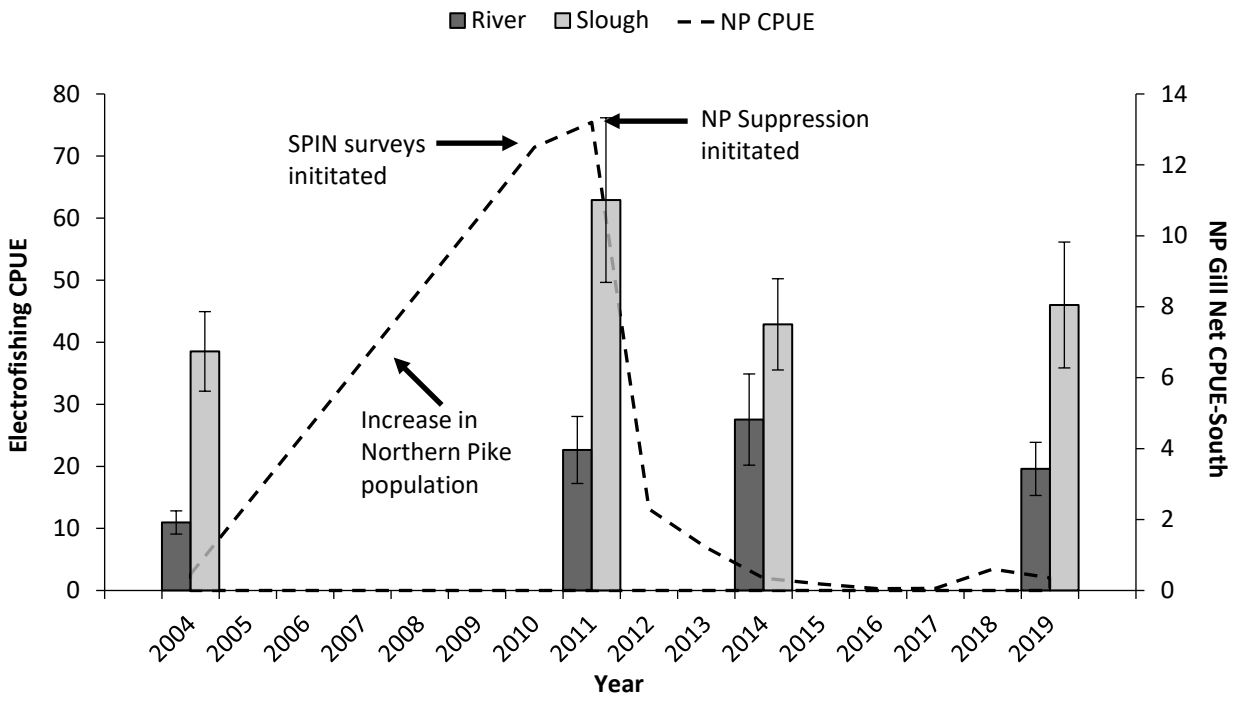

Figure 14. Mean electrofishing CPUE (±80% CI) of Tench by year and habitat type in surveys of Box Canyon Reservoir, WA, in 2004, 2011, 2014 and 2019. Northern Pike CPUE in 2004 (-- dashed line) is based on a standard survey in 2004. Northern Pike CPUE from 2010-2019 is based on Spring Pike Index Netting surveys.

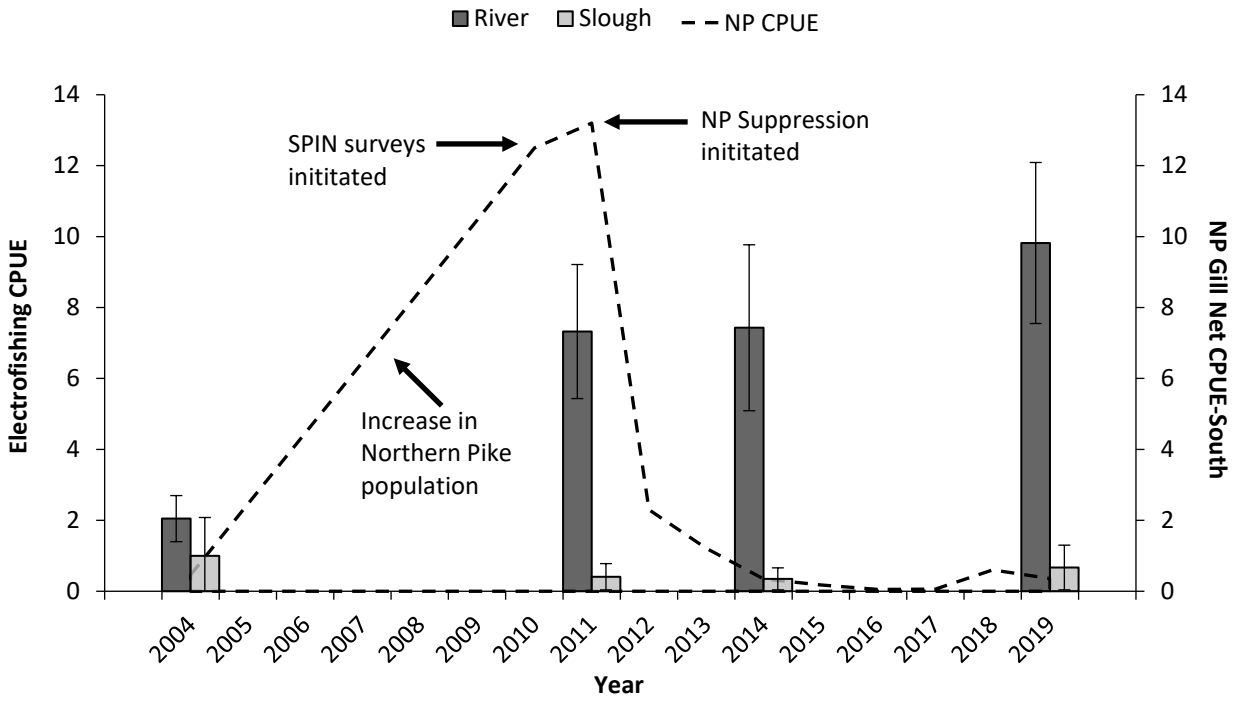

Figure 15. Mean electrofishing CPUE (±80% CI) of Brown Trout by year and habitat type in surveys of Box Canyon Reservoir, WA, in 2004, 2011, 2014 and 2019. Northern Pike CPUE in 2004 (-- dashed line) is based on a standard survey in 2004. Northern Pike CPUE from 2010-2019 is based on Spring Pike Index Netting surveys.

Between 2004 and 2019, native species biomass declined from 35.9% to 16.1% (Figure 16). Conversely, the percentage of nonnative biomass increased over the same time period from 64.1% to 83.9%. The biomass of Northern Pike peaked in 2011 at 24%, but was reduced to 1.2% by 2014 and just 0.5% by 2019. By 2019, Tench represented the greatest proportion (44.4%) of all biomass in the reservoir.

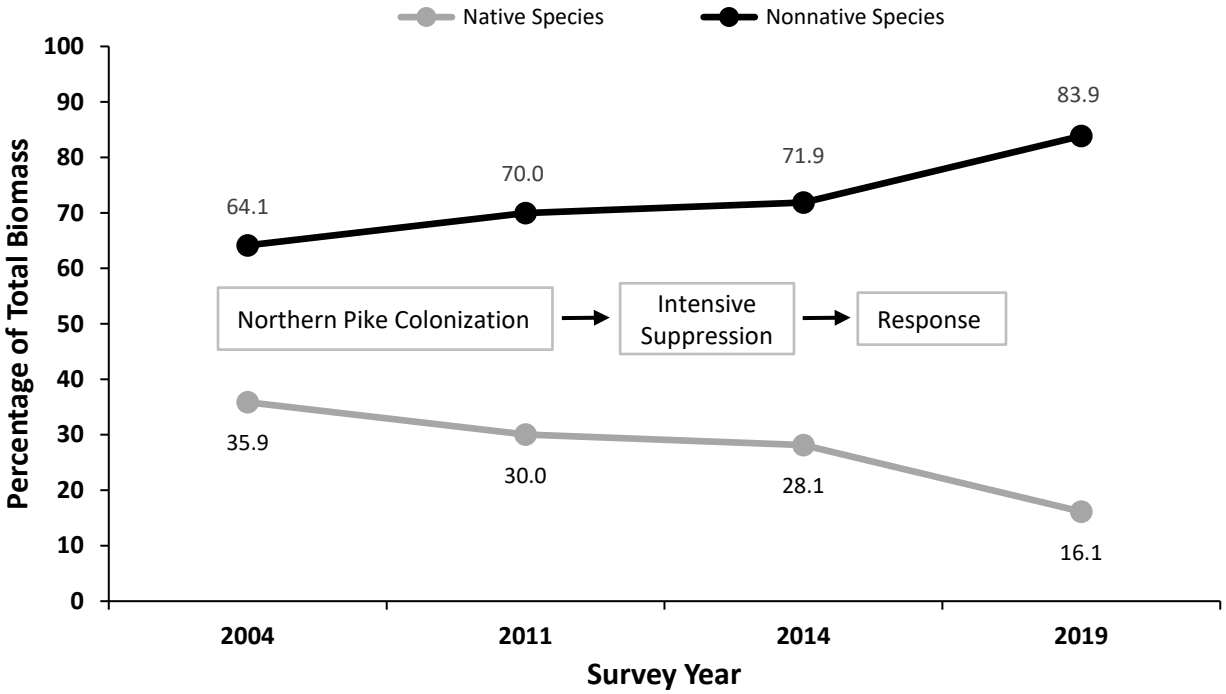

Figure 16. Percentage of biomass comprised of native species and nonnative species in standardized surveys of Box Canyon Reservoir, WA, in 2004, 2011, 2014 and 2019.

Discussion

The results of this study document the impact of Northern Pike population expansion and predation on the fish community in BCR. Almost all fish species, both native and nonnative, experienced significant declines in abundance during the colonization of Northern Pike in BCR (2004-2011). Species that represented the greatest potential prey source for Northern Pike during colonization were Peamouth Chub and Northern Pikeminnow (Bean 2010; Bennet and Liter 1991), which declined significantly. During the intensive suppression period (2011-2014), abundance of both native and nonnative species remained relatively stable, with the exception of Smallmouth Bass which increased significantly. Nonnative species (e.g., Largemouth Bass, Black Crappie, and Pumpkinseed Sunfish) increased in abundance by 2019, following intensive suppression of Northern Pike, while native species showed no signs of recovery.

During the response period following intensive suppression (2014-2019), abundance of native species continued to decline while abundance of nonnative species increased. This outcome may be due to a combination of reasons. First, the process for this replacement probably began when BCR was created, because slower waters are more suitable to nonnative species and less suitable for native, riverine species (Harvey 2011; Clavero and Hermoso 2011). Second, nonnative species continued to be introduced (intentionally or illegally) in BCR over decades (Bennett and Liter 1991, Ashe and Scholz 1992). Third, Northern Pike, although greatly reduced in abundance following intensive suppression, likely continued to preferentially consume native species, categorized as their preferred prey (i.e., soft-rayed fusiform native fishes) of Northern Pike in BCR (Bean 2010; Bean et al. 2011), and as evidenced elsewhere (Dunker et al. 2020; Nicholson et al. 2015; Sepulveda et al. 2013).

Jackson et al. (2001) concluded that piscivory is the main factor affecting fish community composition. Bean (2010) showed that mature Northern Pike (>400mm) in BCR preferentially consumed Peamouth Chub, Northern Pikeminnow and Mountain Whitefish, which were responsible for 33%, 25% and 20% of their diet, respectively. Once native fish populations had been greatly reduced by Northern Pike, predation by other nonnative fish, such as Smallmouth Bass, Brown Trout, and Largemouth Bass, may also have played a role in preventing their potential recovery. As native species declined throughout this study, the ratio of biomass between native to nonnative species in BCR changed from a 36:64 ratio in 2004 to a ratio of 16:84 in 2019.

During the course of this study, there was a near total loss of native Peamouth Chub, which declined 99.6% (from 1,072 individuals in 2004 to just 4) by 2019. Twenty-two Redside Shiners were caught in the first survey in 2004, but none were caught in the 2011, 2014 or 2019 surveys. For newer nonnative species in the system, the relative abundance of Grass Pickerel increased from zero in 2004 to 68 individuals in 2019, and Northern Pike CPUE increased significantly between 2004 and 2011, until they were intensively suppressed, beginning in 2012.

The only species which appeared to show little effect from the introduction and colonization of Northern Pike were Brown Trout and Smallmouth Bass, both of which increased in abundance throughout the 15-year study. Smallmouth Bass CPUE increased significantly in every survey from 2004 to 2019.

During suppression netting, the observed survival of bycatch was estimated at greater than 90% (i.e., there was less than 10% mortality of species other than Northern Pike during suppression; Bean and Harvey 2015). Without a formal creel survey, we are uncertain to what degree the changes in the fish community in Box Canyon Reservoir affected anglers. However, data collected from bass fishing tournaments held at Box Canyon Reservoir indicated that catch rates of bass (fish/hour) dropped from 0.36 fish/hr in 2009 to 0.26 fish/hr in 2010, then remained low from 2012 to 2015 (range 0.19-0.28 fish/hr), until they rebounded to 0.37 fish/hr in 2016 (see WDFW database at https://wdfw.wa.gov/fishing/contests/results/bass). The decline in catch rates between 2010 and 2015 is likely a reflection of the decrease in the Largemouth Bass population during Northern Pike colonization, and the increase in their abundance after suppression.

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; Jackson et al. 2001; Nicholson et al, 2015): in a process where riverine species are replaced with more cosmopolitan species (Rahel 2002; Sax and Gaines 2003). This loss of distinctiveness of native fish species is known as biotic homogenization, which promotes the geographic expansion of some species ('winners') and the geographic reduction of others ('losers') (McKinney and Lockwood 1999). "Pike-driven homogenization" is one consequence of the introduction and colonization by Northern Pike in non-salmonid fish communities in shallow, low-flow, vegetated habitat (Dunker et al. 2020; Spens and Ball 2008), similar to BCR.

As of 2018, seven Western states (Alaska, Arizona, Colorado, Idaho, Montana, New Mexico and Washington) and British Columbia (Canada) have implemented Northern Pike suppression programs in selected waters, in an effort to manage nonnative Northern Pike (Dunker et al. 2018). In comparison to other suppression programs (Dunker et al. 2020, Kuzmenko et al. 2010, Zelasko et al. 2016, Walrath et al. 2015, Muhlfeld 2008, Okanagan Nation Alliance 2021), the suppression results from Box Canyon Reservoir are striking, with a 97.3% reduction in Northern Pike CPUE over an eight year period (Bean and Harvey 2019). The ability to manage invasive Northern Pike could depend on an understanding that invasive Northern Pike populations may be controlled by intensive suppression in invaded waters similar to BCR. Our surveys, before, during and after the Northern Pike invasion, not only describe the related changes in the fish community in BCR – they also describe a human-mediated "boom-and-bust" cycle of Northern Pike (Blackburn et al. 2011), with the bust in this case caused by highly effective suppression.

According to the concept of invasion biology, the invader must go through a series of stages in order to be considered successful: (1) transport, (2) introduction, (3) establishment, (4) spread, and (5) negative impacts (Blackburn et al. 2011). In this case, Northern Pike were successful in all stages until the population was drastically reduced via intensive suppression. Ricciardi and Atkinson (2004) define "high-impact" invaders as those that displace native species, and, in all likelihood, belong to genera not already present in the system. This was the case in BCR, as there were no fishes of the *Esox* genus detected in BCR prior to 2004. This study documented that illegally introduced Northern Pike had a significant impact on the fish community in BCR in a relatively short period of time (seven years) and likely acted as a catalyst to increase the rate of replacement of native species by nonnative species.

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Appendix 1

Appendix Table 1. Dunn test p-values between standardized surveys of Box Canyon Reservoir, WA, for native species, based on gear type (EB electrofishing and GN gill netting) and habitat type (river and slough). Sample size is the total for each species across all years combined (2004, 2011, 2014, 2019).

Species	Variable: gear-habitat	Sample Size (n)	2004-2011	2011-2014	2014-2019	2004-2019
Northern Pikeminnow	EB-River	1931	<0.0001	-	-	<0.0001
	EB-Slough	85	0.0300	-	0.0210	<0.0001
	GN-River	368	<0.0001	-	-	<0.0001
	GN-Slough	85	<0.0001	-	-	0.0010
Peamouth Chub	EB-River	347	<0.0001	-	-	<0.0001
	EB-Slough	39	0.0050	-	-	0.0010
	GN-River	393	<0.0001	0.0150	-	<0.0001
	GN-Slough	381	<0.0001	-	-	<0.0001
Largescale Sucker	EB-River	830	-	-	-	<0.0001
	EB-Slough	60	-	-	-	0.0040
	GN-River	135	-	-	-	-
	GN-Slough	46	-	-	-	0.0030
Longnose Sucker	EB-River	104	-	-	-	-
	EB-Slough	15	-	-	-	-
	GN-River	18	0.0004	-	-	0.0001
	GN-Slough	2	-	-	-	-

Appendix Table 2. Dunn test p-values between standardized surveys of Box Canyon Reservoir, WA, for nonnative species, based on gear type (EB electrofishing and GN gill netting) and habitat type (river and slough). Sample size is the total for each species across all years combined (2004, 2011, 2014, 2019).

Species	Variable: gear-habitat	Sample Size (n)	2004-2011	2011-2014	2014-2019	2004-2019
Largemouth Bass	EB-River	817	<0.0001	-	-	-
	EB-Slough	883	<0.0001	-	-	-
	GN-River	79	0.0220	-	<0.0001	<0.0001
	GN-Slough	132	-	-	0.0010	0.0010
Brown Bullhead	EB-River	120	-	-	0.0160	0.0160
	EB-Slough	186	-	-	-	-
	GN-River	76	-	-	<0.0001	<0.0001
	GN-Slough	64	-	-	-	-
Black Crappie	EB-River	346	<0.0001	-	0.0260	0.0260
	EB-Slough	435	-	-	-	-
	GN-River	170	0.0010	-	<0.0001	<0.0001
	GN-Slough	207	-	-	-	-
Pumpkinseed Sunfish	EB-River	2440	<0.0001	-	-	-
	EB-Slough	1907	<0.0001	-	-	-
	GN-River	538	<0.0001	-	<0.0001	<0.0001
	GN-Slough	332	0.0270	-	0.0030	0.0030
Smallmouth Bass	EB-River	522	-	0.0000	-	-
	EB-Slough	225	-	-	<0.0001	<0.0001
	GN-River	21	-	-	0.0010	0.0010
	GN-Slough	41	-	-	-	-
Yellow Perch	EB-River	4989	-	0.0150	0.0160	0.0160
	EB-Slough	5556	-	0.0000	-	-
	GN-River	1380	0.0090	-	<0.0001	<0.0001
	GN-Slough	1131	-	-	-	-
Tench	EB-River	919	-	-	-	-
	EB-Slough	905	-	-	-	-
	GN-River	577	-	0.1000	<0.0001	<0.0001
	GN-Slough	535	0.0300	-	-	-
Brown Trout	EB-River	295	0.0030	-	-	-
	EB-Slough	13	-	-	-	-
	GN-River	18	-	-	-	-
	GN-Slough	10	-	-	-	-

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