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Understanding the influence of predation by introduced fishes on juvenile salmonids in the Columbia River Basin: closing some knowledge gaps

Interim Report of Research 2010

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Project overview

Predation on juvenile salmonids by fish in the Columbia River Basin (CRB) has impacted salmon survival and is a topic that has received considerable attention over the last three decades. Some of the earliest and most detailed research focused on the food habits, consumption rates, abundance, and distribution of predaceous northern pikeminnow *Ptychocheilus oregonensis*, smallmouth bass *Micropterus dolomieu*, walleye *Sander vitreus*, and channel catfish *Ictalurus punctatus* in John Day Reservoir (Beamesderfer and Rieman 1991; Poe et al. 1991; Vigg et al. 1991). This group of researchers also estimated the loss of juvenile salmonids to predation by some of these predators (Rieman et al. 1991). Since this pioneering effort, others have evaluated various aspects of predation-related mortality on juvenile salmonids in the CRB, focusing mostly on northern pikeminnow and smallmouth bass (e.g., Tabor et al. 1993; Zimmerman 1999; Naughton et al. 2004).

Perhaps the most significant finding coming from this body of research was that the native northern pikeminnow was the dominant predator of juvenile salmonids in the CRB. Indeed, Beamesderfer et al. (1996) estimated that northern pikeminnow consumed about 16 million (8%) of the estimated 200 million juvenile salmonids emigrating annually in the CRB, far surpassing the consumption of smallmouth bass, walleye, and channel catfish combined. Because of this, large-scale management fisheries (i.e., the northern pikeminnow management program, or NPMP; see Rieman and Beamesderfer 1990; Beamesderfer et al. 1996) have been implemented in the CRB since 1990 to achieve a 10%–20% exploitation rate on northern pikeminnow and reduce predation on juvenile salmonids. The NPMP has been a success,

resulting in up to 38% potential reductions in predation (Friesen and Ward 1999; Knutsen and Ward 1999; Ward and Zimmerman 1999;).

In contrast to the NPMP, Oregon and Washington state fish and wildlife agencies manage and enhance recreational fisheries for smallmouth bass and walleye by implementing size and harvest limit regulations. Recently, many biologists and fish managers have become concerned about the impact of non-native predaceous fishes on juvenile salmonid survival. For example, Poe et al. (1994) warned that smallmouth bass, walleye, and channel catfish were expanding their populations in some areas, that these fish could be significant predators on juvenile salmonids, and that they may compete with northern pikeminnow for common prey items, resulting in higher consumption rates of salmonids by the native predator. Sanderson et al. (2009) reported that the impact of non-indigenous species (including piscivorous fishes) on salmon survival within the CRB can be severe and suggested that managing nonindigenous species may be imperative for salmon recovery. Assessing the current ecological impacts of introduced fishes throughout the CRB will fill information gaps associated with their impact on salmonid survival and contribute to the description of CRB food webs.

In response to these recent concerns about the potential predatory impact of non-native piscivores on salmon survival, the Bonneville Power Administration (BPA) and the Columbia Basin Fish and Wildlife Authority (CBFWA) co-hosted a workshop to address predation on juvenile salmonids in the CRB by non-native fish (Halton 2008). The purpose of the workshop was to review, evaluate, and develop strategies to reduce predation by non-native fishes on juvenile salmonids. In the end, discussion at the workshop and at subsequent meetings considered two potential ideas to reduce predation by non-native fish on juvenile salmonids; (1) understanding the role of juvenile American shad *Alosa sapidissima* in the diet of non-native

predators in the fall; and (2) the effects of localized, intense reductions of smallmouth bass in areas of particularly high salmonid predation. In this report, we describe initial efforts to understand the influence of juvenile American shad as a prey item for introduced predators in the middle Columbia River. Our first objective, addressed in Chapter 1, was to evaluate the efficacy of nonlethal methods to describe the physiological condition of smallmouth bass, walleye, and channel catfish from late summer through late fall. Such information will be used to understand the contribution of juvenile American shad to the energy reserves of predaceous fish prior to winter. In Chapter 2, we describe the results of some limited sampling to document the food habits of smallmouth bass, walleye, and channel catfish in three reservoirs of the middle Columbia River during late fall. Collectively, we hope to increase our understanding of the contribution of juvenile American shad to the diets of introduced predators and the contribution of this diet to their energy reserves, growth, and perhaps over-winter survival. Managers should be able to use this information for deciding whether to control the population of American shad in the CRB or for managing introduced predaceous fish in the CRB.

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Chapter 1

An Assessment of Nonlethal Techniques to Determine the Energy Reserves of Smallmouth Bass, Walleye, and Channel Catfish

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Abstract

Energy reserves are used by fish to fulfill many biological possesses and evaluating them is an important component of fisheries management and ecology. Typically, energy reserves have been measured by proximate body analysis (e.g., lipid, water, protein, and ash) or bomb calorimetry, which require fish to be sacrificed. Because of this and the logistics associated with these methods, we evaluated the effectiveness of several nonlethal techniques to estimate total body fat in smallmouth bass *Micropterus dolomieu*, walleye *Sander vitreus*, and channel catfish *Ictalurus punctatus*. The techniques included (1) the Fulton and relative condition factors; (2) relative weight; (3) blood plasma indicators of nutrition (alkaline phosphatase, calcium, cholesterol, protein, triglycerides, and glucose); and (4) a hand held, microwave energy meter. We found strong positive relations ($P<0.001$; $r^2=0.83$) between energy meter readings and total body fat in channel catfish, but not in smallmouth bass ($P=0.306$; $r^2=0.02$) or walleye ($P=0.010$; $r^2=0.17$). Significant relations ($P<0.05$) were also found between total body fat and the Fulton and relative condition factors, and levels of plasma calcium, cholesterol, protein, and triglycerides, depending on species. The r^2 values of these relations ranged from0.17 to 0.50 and no single approach was consistent among all species. Our results indicate that no single variable was an accurate and reliable indicator of fat content in our fish, except for the energy meter in channel catfish.

Introduction

The success of animals when food is scarce often depends on the availability of lipid reserves stored in their somatic tissues. The accumulation of lipid reserves in fish is often critical for their persistence because stored energy is needed to fulfill energetically demanding life

processes, such as overwintering, reproduction, and migration (Berg and Bremset 1998; Biro et al. 2004; Finstad et al 2004; Gardiner and Geddes 1980; Jonsson et al 1997). In temperate climates, animals have adapted to seasonal fluctuations in prey abundance by storing energy during summer to expend during winter when prey are scarce (Gardiner and Geddes 1980; Berg and Bremset 1998; Finstad et al. 2004; Næsje et al. 2006.). These reserves may be a direct indicator of the ability of animals to capture prey (Baker 1989) and animals with higher lipid reserves are expected to have greater survival and reproductive success (Kaufman et al. 2007 Gardiner and Geddes 1980; Berg and Bremset 1998). Because of the importance of lipid reserves to fish, the continued advancement and refinement of techniques to accurately measure them is necessary.

Energy reserves of fish have typically been measured by either an analysis of their proximate composition (i.e. lipid, water, protein, and ash) or by bomb calorimetry. One drawback of these methods is that they require fish to be sacrificed. However, many fish are either protected under the Endangered Species Act or are part of an economically valuable sport-fishery. Moreover, in many cases, the logistics of transporting fish from the field to the laboratory, the space requirements for storing fish, and the laborious and time consuming methods makes these procedures prohibitive.

As alternatives to the methods described above, there are other non-lethal ways to estimate the lipid reserves of fish, including morphometric indices, blood chemistry variables, and handheld microwave meters. The underlying assumption behind various morphometric indices is that a heavier fish at a given length has more fat and may be healthier. The more common of these indices are derived either by describing the weight to length relation (i.e., Fulton's condition factor; *K*), or by comparing the length-specific weight of an individual to

either the length-specific mean weight for the population under study (i.e., the relative condition factor; *Kn*), or to the length-specific standard weight derived for a species (i.e., the relative weight; *Wr*). These indices are popular with biologists because they are simple, require no specialized equipment, and are useful for monitoring mass-at-length trends over time. Despite their simplicity, these indices have been reliable indicators of proximate composition for a variety of fish species, including adult walleye *Sander vitreus*, juvenile muskellunge *Esox masquinongy*, and juvenile Atlantic salmon *Salmo salar* (Kaufman et al. 2007; Salam and Davies 1994; Sutton et al. 2000).

Blood chemistry indicators—including plasma nutrients, enzyme activities, and metabolites—have long been used as nutritional indicators in warm blooded animals (Rea et al. 1998; Jenni-Eierman and Jenni 1998; Hollmén et al. 2001) and have recently been used in fish. Congleton and Wagner (2006) showed decreases in alkaline phosphatase, total protein, total cholesterol, and total calcium in the blood plasma of rainbow trout (*Oncorhynchus mykiss*) and Chinook salmon (*Oncorhynchus tshawytscha*) that were fasted for 21–35 days. The fat content of fish that were fasted was consistently lower than those fed during the experiment and may have indicated that plasma variables correlated with fat content. However, more work is needed to explore the efficacy of blood chemistry variables for predicting the lipid reserves of wild fish.

Handheld microwave meters are commonly used for estimating the lipid content of market fish and are widely used in the aquaculture industry. These meters work by measuring the water content of fish muscle and using pre-determined regression equations to estimate lipid content of the sample (for more details, go to www.distell.com). The meters are commercially available, relatively inexpensive, and have been used in fisheries research to estimate the lipid content of adult and juvenile Pacific salmon (Colt and Shearer 2001; Crossin and Hinch 2005).

Although there are currently over one dozen custom calibration equations available for a variety of fish, none currently exist for smallmouth bass *Micropterus dolomieu*, walleye, or channel catfish *Ictalurus punctatus*—the species of interest in this study.

For this work, we collected smallmouth bass, walleye, and channel catfish from various locations in the middle Columbia River and subjected them to a whole body proximate analysis. We then regressed several morphometric indices, blood chemistry variables, and readings from a microwave meter against the lipid content of each fish. Our objective was to evaluate the efficacy of these non-lethal indicators for predicting the lipid content of these species. Ultimately, we hope to use this information to increase our understanding of the importance of juvenile American shad in the late summer and fall diet of these introduced predators. In upcoming years of study, monitoring temporal trends in lipid reserves, or correlates thereof, may provide insight into the contribution of juvenile American shad to the general health of these predators prior to the onset of winter.

Methods

From September 27 to October 21 2010, we collected adult smallmouth bass, walleye, and channel catfish via angling, gillnets, trammel nets, and boat electrofishing in various areas of the lower and middle Columbia River (river km 194 – 469). We also collected some fish in the spring of 2011, when we joined Oregon Department of Fish and Wildlife staff during their annual electrofishing surveys for northern pikeminnow assessments. We sampled the lower Columbia River near Camas WA (RKM 194) because the area where fish collection occurred was not critical and we knew it to contain high concentrations of walleye, which minimized the time needed to catch fish.

After collection, fish were placed in a lethal dose (200 mg/L) of buffered MS-222 and measured for fork length (mm) and weight (g). We then collected a blood sample from the caudal vasculature of each fish using a heparinized Vacutainer or heparin-coated syringe and needle. Blood samples were lightly shaken, placed in a centrifuge at 3,000 × g for 3 min, and the resulting plasma aspirated off, placed in a new tube, and stored on ice. At the end of each day, plasma samples were frozen at -80°C until analysis. Plasma samples were shipped frozen to the Gritman Medical Center, University of Idaho (Moscow) and assayed for concentrations of nutritional indicators, including alkaline phosphatase, calcium, cholesterol, total protein, total triglycerides, and glucose via an auto-analyzer. To ensure accuracy and reproducibility, all assays followed guidelines for standardization and quality control established by the Joint Commission for Accreditation of Health Care Organizations and by the College of American Pathologists

After a blood sample was removed, we interrogated each fish at four positions along the left and right side with a Distell Model 692 Fish Fatmeter (Distell Inc., West Lothian, Scotland), hereinafter referred to as the energy meter (Figure 1). Thus, for each fish, we obtained eight energy meter readings. Finally, the stomach contents of each fish were removed by gastric lavage (smallmouth bass and walleye only) with a modified Seaburg sampler (Seaburg 1957) or by removing the stomach, opening it with a scalpel or scissors, and removing the contents with a dissecting spoon. All stomach contents were placed in labeled plastic bags and placed on ice. When finished, fish were placed singly in a labeled plastic bag, placed on ice, and transported to our laboratory, where they were frozen (along with the stomach contents) for later analysis. Results of the stomach contents analysis are presented in Chapter 2.

At the laboratory, the carcasses were slightly thawed and individually homogenized (without gonads) by first cutting them into pieces with a knife and then blending in a commercial food processor (Robot Coupe Blixer™, Model BX4V). A subsample of each homogenate (ca. 25 g) was placed in an airtight plastic bag and frozen at -80°C until analysis. Samples were shipped frozen to the Washington State University Wildlife Habitat Laboratory, where they were analyzed for their proximate composition (i.e., lipids, water, and ash; Table 1). Protein content was calculated by subtracting the sum of lipid, water, and ash content from 100% (Berg and Bremset 1998, Crossin and Hinch 2005).

Statistical analysis— We used the length and weight measurements to calculate a Fulton condition factor (*K*), a relative condition factor (*Kn*), and a relative weight (*Wr*) for each fish (Blackwell et al. 2000). We then used simple-linear regressions to assess the relations of each morphometric index, the blood variables, and the mean energy meter readings of each fish to their somatic lipid content, as measured by proximate analysis (Zar 1999). Our goal was to determine if one or more of these metrics could be used as a surrogate for energy reserves in these fish. Somatic lipid values were analyzed as percentages to account for size specific variations in the lipid content of fish and any differences between the sexes were not considered because of low sample sizes and the difficulty of distinguishing genders in the field outside of the spawning period (Scott and Crossman 1973). For each regression model, we tested whether the slopes differed significantly ($P < 0.05$) from zero using *F*-tests and evaluated the goodness of fit for each model via their coefficients of determination (r^2 values).

Results

Positive significant relations ($P < 0.05$) were found between somatic lipid levels and all morphometric indices for smallmouth bass, Fulton condition factor for walleye, and relative

condition for channel catfish (Table 2). The models for all other morphometric relations were not significant. The models with the best-fit were for somatic lipid content and Fulton condition factor and relative weight for smallmouth bass (r^2=0.42). The r^2 values for all other significant models were relatively small (<0.24).

Positive significant relations ($P < 0.05$) were found between lipid content and cholesterol, triglycerides, and protein for smallmouth bass, cholesterol and triglycerides for channel catfish, and calcium levels for walleye (Table 3). However, the fits of the models were generally poor ($r^2 < 0.27$), except those for lipid content and cholesterol ($r^2 = 0.50$) and protein ($r^2 = 0.47$) in smallmouth bass. The slopes of the relations between lipid content and all other blood constituents were not significant.

Lipid content was strongly correlated (P<0.0001) with water content in all species (Table 4). However, significant ($P < 0.05$) positive correlations between energy meter readings and lipid content were found only for walleye and channel catfish (Table 4); the explanatory power of the model was high for channel catfish ($r^2 = 0.83$) and low for walleye ($r^2 = 0.17$).

Discussion

The purpose of our research was to determine whether common mass-at-length indices, blood chemistry constituents, and a handheld energy meter could be used to predict the whole body lipid content of smallmouth bass, walleye, and channel catfish. Such information could allow researchers to quickly and effectively assess the nutritional condition of an animal without having to euthanize it for proximate analysis, making these techniques useful for studying species protected under the Endangered Species Act or when lethally sampling large numbers of fish is not feasible. In addition, the techniques presented here pose little risk of injury and mortality to test fish beyond that associated with routine anesthesia and handling procedures and

could allow for repeated measurements on individuals over time. Our results showed that, although we produced significant relations between somatic lipid content and several predictor variables, almost all of the models had low explanatory power—indicating that other, unknown variables were influencing the lipid content of our study fish. In fact, only one model—between energy meter readings and lipid content in channel catfish—had an r^2 value (0.83) high enough to justify using it as a predictive tool. All of the other significant models we produced had r^2 values ranging from 0.17–0.50. Our results indicate that the energy meter may be a useful tool for estimating lipid content in channel catfish and that proximate analysis or perhaps a dry weight index (e.g., residualized dry weight—see Sutton et al. 2000) are probably the best ways of measuring lipid content in smallmouth bass and walleye.

Morphometric indices have been used to describe the general health of fish by assuming that heavier fish at a given length are in better condition (Sutton et al. 2000). Further, "better" condition generally implies increased fat reserves that result in good physiological condition. However, the relation between morphometric indices and lipid reserves in fish has been equivocal, with some researchers reporting relatively strong correlations between the variables in adult walleyes (Kaufman et al. 2007), juvenile cisco *Coregonus artedi* (Pangle and Sutton 2005), northern pike *Esox lucius* (Salam and Davies 1994), juvenile striped bass *Morone saxatilis* and hybrid striped bass *M. saxatilis* × *M. chrysops* (Brown and Murphy 1991), and juvenile Atlantic salmon *Salmo salar* (Herbinger and Friars 1991), and others observing only weak correlations in ship sturgeon *Acipenser nudiventris* (Gershanovich et al. 1994), adult Atlantic salmon (Kadri et al. 1995), juvenile walleyes (Copeland and Carline 2004), and juvenile Pacific salmon (Trudel et al. 2005). In part, these conflicting results are probably due to variation in the condition indices used, methods, species, and size and age of fish. For our fish, the highest r^2 value we observed

was 0.42 for the relations between percent lipid and *K* and *Wr* in smallmouth bass. For us, these relations are simply too weak to be used reliably as predictive tools. Perhaps we would have produced somewhat stronger models had we explored the relations between morphometric indices and residualized lipid weight, as per Sutton et al. (2000). In the end, however, we agree with the conclusion of Sutton et al. (2000) that morphometric indices have a weak to moderate direct link to fat reserves—depending on species. As such, we believe that morphometric indices will be ineffective for predicating changes in lipid reserves in fish.

There were no reliable blood chemistry predictors of lipid content in our fish. In fact, the two highest r^2 values we observed were 0.42 and 0.50 for the relations between percent lipid and plasma protein and cholesterol in smallmouth bass. All other models had r^2 values less than 0.27. The use of plasma constituents as indicators of nutritional condition in fish is rare, particularly in wild fish. Wagner and Congleton (2004) used a multivariate approach to derive two factors that were correlated with nutritional condition in juvenile Chinook salmon—one "nutritional" factor composed of total protein, cholesterol, calcium, and alkaline phosphatase, and a "lipid metabolism" factor composed of triacylglycerol lipase and triglycerides. Perhaps if we had taken a similar multivariate approach, our results would have been more definitive. However, because so many variables can influence the blood chemistry of free-living fish, including environmental conditions, feeding status (i.e., recently fed or fasted), stage of sexual maturity, and exposure to exogenous stressors, analysis of single point samples of blood probably had a low probability of reliably predicting lipid reserves. Thus, even though plasma constituents such as cholesterol, triglycerides, protein, calcium, and alkaline phosphatase are related to the nutritional condition of fish (Sheridan 1988; Wagner and Congleton 2004; Congleton and Wagner 2006), they may be more responsive to changes in food intake and growth, rather than lipid reserves per se (Wagner

and Congleton 2004). As such, we cannot recommend the use of single blood chemistry variables for predicting the lipid reserves of smallmouth bass, walleye, and channel catfish.

Our results indicate that the energy meter can be used to accurately estimate whole body lipid reserves in channel catfish, but not in smallmouth bass and walleye. This finding was similar to that of Crossin and Hinch (2005) for adult Pacific salmon and those of Sang et al. (2009) for river catfish *Pangasianodon hypophthalmus.* We suspect that the poor performance of the meter for smallmouth bass and walleye was primarily due to their relatively thick skin with ctenoid scales and their limited range of lipid content. Technical specifications for the meter warn that skin thickness can affect accuracy in some fishes. Although we did not measure the skin thickness on our fish, the epidermal layer on yellow perch *Perca flavescens*—a similar Perciform fish—is about 7–10 times thicker than salmonids of similar size (Wilkins and Jancsar 1979; Chivers et al. 2007). We surmise that the skin and scale complex of smallmouth bass and walleye is thicker than that of the scaleless channel catfish, which contributed to the variable performance of the meter. In addition, technical specifications for the energy meter state that the microwave sensor can saturate when lipid levels are low and the meter has a level of accuracy of about 0.5% to 4% depending on the lipid content of the fish. For example, calibrations provided by the manufacture for sea bass *Dicentrarchus labrax* and to a lesser extent Atlantic salmon *Salmo salar* show the reader saturating when fat levels in fish range from about 2% to 8%.Thus, these constraints may limit the meter's effectiveness on fish with low fat content, such as smallmouth bass or walleye. Indeed, Crossin and Hinch (2005) cautioned against using the energy meter on spawning salmon when somatic energy levels were are low. In the end, regardless of the reasons, the meter did not work well for smallmouth bass and walleye and we cannot recommend its use for estimating the fat content of these fishes

The purpose of measuring the lipid content of these important Columbia River piscivores was to increase our understanding of the importance of juvenile American shad in their diets during the late summer and fall. We thought that monitoring trends in lipid reserves, or correlates thereof, would provide insight into the contribution of juvenile American shad to the general health of these predators prior to the onset of winter. Our results indicate that reliable, accurate, and non-lethal predictors of lipid content in smallmouth bass, walleye, and channel catfish seem untenable—except for perhaps the energy meter for channel catfish. We are currently conducting detailed analyses of the diets of these fish in the late summer and fall and will use this information to document the extent of juvenile American shad to their diets. Further explorations of the contribution of this diet item to the physiological health of these introduced predators may require some lethal sampling, new techniques, or could involve bioenergetics approaches.

Disclaimer

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TABLE 1— Summary of size and proximate constituents for smallmouth bass, walleye, and channel catfish collected from the middle Columbia River.

	Smallmouth Bass (*N*=43)			Walleye (*N*=38)			Channel Catfish (*N*=31)		
Metric	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range
Fork Length (mm)	352	66	249–530	431	84	321–707	301	103	179–580
Mass (g)	787	489	235–2,495	1,050	823	330–4,715	524	702	70–2,980
Moisture (%)	71	1	69–73	69	3	63–74	64	5	57–76
Fat (%)	5	2	1–8	9	3	3–15	16	5	5–24
Ash (%)	5	1	3–7	4	1	2–5	4	1	1–7
Protein (%)	20	1	18–22	19	1	17–22	15	1	12–18

TABLE 2.—Results of linear regressions of common morphometric indices to crude fat (%) content determined through proximate analysis for smallmouth bass, walleye, and channel catfish. Bold text indicates that the intercept or slope of the line differed significantly from zero (P<0.05).

Method	Intercept (b; SE)	Slope (m; SE)	R^2	F	P
Smallmouth bass					
Fulton condition factor	**-5.79 (1.95)**	6.50 (1.20)	0.42	29.43	**<0.001**
Relative condition	-2.89 (2.41)	7.61 (2.41)	0.19	9.97	**0.003**
Relative weight	**-6.24 (2.03)**	10.22 (1.88)	0.42	29.59	**<0.001**
Walleye					
Fulton condition factor	5.20 (4.90)	12.04 (4.26)	0.18	8.00	**0.008**
Relative condition	-0.56 (4.91)	9.18 (4.90)	0.09	3.51	0.069
Relative weight	2.68 (5.67)	5.41 (5.16)	0.03	1.07	0.302
Channel catfish					
Fulton condition factor	3.29 (8.96)	10.14 (6.89)	0.07	2.17	0.152
Relative condition	-0.77 (5.40)	17.14 (5.32)	0.23	10.38	**0.003**
Relative weight	4.65 (9.77)	7.59 (6.29)	0.05	1.46	0.237

TABLE 3.—Results of linear regressions of blood plasma constituents to crude fat (%) content determined through proximate analysis for smallmouth bass, walleye, and channel catfish. Bold text indicates that the intercept or slope of the line differed significantly from zero (P<0.05).

Method	Intercept (b; SE)	Slope (m; SE)	R^2	F	P
Smallmouth bass					
Alkaline phosphates (IU/L)	**3.214 (0.758)**	0.040 (0.023)	0.09	2.98	0.094
Calcium (mg/L)	**3.552 (1.139)**	0.060 (0.076)	0.02	0.61	0.441
Cholesterol (mg/L)	0.669 (0.717)	0.009 (0.002)	0.50	30.31	**<0.001**
Protein (g/L)	-1.890 (2.197)	1.487 (0.514)	0.47	8.36	**0.007**
Triglyceride (mg/L)	**3.180 (0.47)**	0.001 (0.000)	0.26	10.60	**0.003**
Glucose (mg/L)	**5.426 (0.720)**	-0.004 (0.003)	0.08	2.49	0.125
Walleye					
Alkaline phosphates (IU/L)	**10.275 (0.886)**	-0.017 (0.010)	0.09	2.96	0.096
Calcium (mg/L)	1.271 (3.145)	0.659 (0.266)	0.17	6.16	**0.019**
Cholesterol (mg/L)	**12.789 (2.100)**	-0.015 (0.008)	0.10	3.44	0.073
Protein (g/L)	7.763 (4.854)	0.277 (1.089)	0.00	0.06	0.801
Triglyceride (mg/L)	**8.775 (0.870)**	0.000 (0.000)	0.00	0.09	0.762
Glucose (mg/L)	**9.059 (0.874)**	-0.000 (0.004)	0.00	0.00	0.926
Channel catfish					
Alkaline phosphates (IU/L)	**10.513 (4.295)**	0.199 (0.168)	0.06	1.41	0.248
Calcium (mg/L)	**12.168 (5.286)**	0.322 (0.509)	0.02	0.40	0.533
Cholesterol (mg/L)	**10.863 (2.259)**	0.010 (0.004)	0.20	5.19	**0.033**

Protein (g/L)	**23.468 (6.596)**	-2.770 (2.241)	0.07	1.53	0.230
Triglyceride (mg/L)	**11.716 (1.796)**	0.002 (0.001)	0.23	6.32	**0.020**
Glucose (mg/L)	**14.713 (3.798)**	0.003 (0.128)	0.00	0.04	0.844

TABLE 4.—Results of linear regressions water (%) to crude fat (%) content and energy meter readings to water (%) and crude fat (%) for smallmouth bass, walleye, and channel catfish. Proximate constituents were determined through proximate analysis and bold text indicates that the intercept or slope of the line differed significantly from zero (P<0.05).

Method (x)	Component (y; %)	Intercept (b; SE)	Slope (m; SE)	R^2	F	P
Smallmouth bass						
Water (%)	Crude Fat	**88.77 (8.02)**	-1.19 (0.11)	0.72	110.06	**<0.001**
Energy meter reading	Water	**73.20 (0.87)**	-0.11 (0.04)	0.17	8.31	**0.006**
Energy meter reading	Crude Fat	**3.34 (1.32)**	0.06 (0.06)	0.02	1.07	0.306
Walleye						
Water (%)	Crude Fat	**80.71 (4.74)**	-1.05 (0.07)	0.86	232.15	**<0.001**
Energy meter reading	Water	**73.88 (2.12)**	-0.02 (0.09)	0.16	6.63	**0.014**
Energy meter reading	Crude Fat	2.26 (2.38)	0.27 (0.09)	0.17	7.33	**0.010**
Channel Catfish						
Water (%)	Crude Fat	**88.86 (3.44)**	-1.12 (0.05)	0.94	445.81	**<0.001**
Energy meter reading	Water	**86.22 (1.84)**	-0.44 (0.04)	0.83	144.43	**<0.001**
Energy meter reading	Crude Fat	**-8.73 (2.17)**	0.51 (0.04)	0.83	139.54	**<0.001**

FIGURE 1.—Image of fish indicating the locations and order at which readings were taken with the energy meter. Four readings were taken on both the left and right side of the fish.

Chapter 2

Autumn Diets of Smallmouth Bass, Walleye, and Channel Catfish in the Middle Columbia River, USA

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Abstract

In the Columbia River basin (CRB), predation on endangered juvenile salmonids by nonnative piscivores has been the focus of much attention. Recently, managers have raised concerns that the expanding population of American shad *Alosa sapidissima* in the CRB—a high energy food resource available in the fall—may be contributing to the increased growth and fitness of nonnative piscivores and indirectly influencing predation on salmonids. For this reason, we quantified the autumn diets of smallmouth bass *Micropterus dolomieu*, walleyes *Sander vitreus*, and channel catfish *Ictalurus punctatus* in reservoirs of the lower and middle Columbia River. Although crayfish were the dominant prey item in the diet of smallmouth bass—comprising 50% by weight and 39% by number—juvenile American shad made up 12% by weight and 11% by number and were the most common prey fish consumed by them. The importance of shad in the diet of smallmouth bass also varied temporally, with the amount (% by weight) decreasing from 26% during September to 0% in November. Walleye ate fish exclusively, with peamouth *Mylocheilus caurinas* (44% by weight) and American shad (42% by weight) being the most common prey fish consumed by them. In contrast, channel catfish ate mostly crayfish (37% by weight) and insects (13%) and had no evidence of American shad in their diet. Our results indicate that juvenile American shad are an important component of the diets of smallmouth bass and walleye in the fall, but the relative contribution of this diet item to the condition and fitness of these predators awaits discovery. Our results should facilitate future management decisions regarding populations of American shad in the CRB.

Introduction

The introduction of nonindigenous species poses one of the greatest threats to native fauna and is a contributing factor to the decline of nearly half of the species protected under the Endangered Species Act (ESA; Czech and Krausman 1997; Wilcove et al. 1998). Predation by nonindigenous species on native fauna is one of the major impacts. The introduction of nonindigenous piscivores (NIP), such as smallmouth bass *Micropterus dolomieu*, walleye *Sander vitreus*, and channel catfish *Ictalurus punctatus*, into the Columbia River Basin (CRB) to enhance sport-fish opportunities began in the late 1800's. With the construction of hydropower facilities and resulting reservoirs in the CRB, these fishes have flourished and are considered to be significant predators, sometimes on ESA-listed salmonids (Poe et al. 1991).

Another introduced species, the American shad *Alosa sapidissima*, colonized the CRB soon after being introduced into the Sacramento River, California, in 1871 (Petersen et al. 2003). From 1938 to 1957, few American shad crossed Bonneville Dam but after the construction of The Dalles Dam in 1957, their population increased, averaging almost 300,000 adult fish passing Bonneville Dam from 1958 to 1974. This expanding population of American shad raised concerns that congregations of these fish near fish ladders could impact passage of salmonids (Monk et al. 1989) and resulted in the ladders at John Day Dam and Bonneville Dam being modified to improve the passage of adult American shad. Since these passage modifications, the number of adult American shad passing Bonneville Dam has increased six-fold, averaging nearly two million fish per year. The majority of American shad spawning occurs upstream of Bonneville Dam to McNary Dam (i.e., the Middle Columbia River; MCR) and juvenile American shad are present in reservoirs of the MCR during the late summer through fall (Gadomski and Barfoot 1998; Petersen et al. 2003; Haskell et al. 2006).

Juvenile American shad represent a potential high energy food resource for NIP that historically did not exist in high numbers (Petersen et al. 2003). Many have hypothesized that large numbers of juvenile American shad in the fall may bolster the growth and survival of NIP prior to the onset of winter. However, little is known about the diet of NIP in the fall because almost all sampling from previous food habit studies was timed to correspond to the outmigration of juvenile salmonids and usually ended in August (e.g., Poe et al. 1991; Zimmerman 1999; Naughton et al. 2004). In fact, only northern pikeminnow *Ptychocheilus oregonensis* were found to consume significant quantities of juvenile American shad in the late summer (Poe et al. 1991; Petersen et al. 1994). This does not mean, however, that the NIP do not eat juvenile American shad, but instead probably reflects the consequences of sample timing and location. Juvenile American shad in the MCR move downstream as summer progresses into fall (Haskell et al. 2006) and previous sampling for smallmouth bass, walleye, and channel catfish probably occurred at times and in locations where the spatial overlap between them and juvenile American shad was minimal. That juvenile American shad use mainstem shorelines as well as sloughs and backwater habitats during rearing (Limburg 2001; Gadomski and Barfoot 1998; Peterson et al. 2003) suggest that spatial and temporal overlap of juvenile American shad and NIP occurs in the MCR.

For this work, we documented the general food habits of smallmouth bass (SMB), walleye (WAL), and channel catfish (CHC) from the MCR during late-September through mid-November. To our knowledge, this is the first time diet samples have been collected in the autumn for these species. Our intent was to document the magnitude of juvenile American shad in the diets of these NIP. Ultimately, we will use this information to determine if the consumption of juvenile American shad by NIP in the fall improves their growth and fitness,

which could increase their overwinter survival, and impact ESA listed salmonids. Managers could then use this information to guide decisions regarding the potential management of American shad in the CRB.

Methods

Study area—The MCR comprises three reservoirs (Bonneville (BON), Celilo (TDA), and Umatilla (JDA) formed by three large hydroelectric projects, Bonneville Dam (rkm), The Dalles Dam (rkm 308), and John Day Dam (rkm 345; Figure 1). The three reservoirs are 77, 39, and 123-km-long and range in mean elevation from 23-81 m. Within these three reservoirs, there are about 683 km of shoreline and 24,702 hectares of water surface area. Temperatures in the reservoirs range from about 4 to 27°C and partial stratification occurs during summer (Poe et al. 1991). The reservoirs are likely mesotrophic and polymictic (Hjort et al. 1981, Poe et al. 1991).

Predators were collected at fixed sites within the BON, TDA, and JDA by electrofishing, netting, and angling from 28 October to 9 November 2010. Sites included near-dam areas (forebay and tailrace zones) and mid-reservoir areas away from dams and were similar to those being used by the northern pikeminnow monitoring program (see Rieman and Beamesderfer 1990). For electrofishing, each site was subdivided into several nearshore transects that were about 500 m long. The number of transects depended on the length of the site and a standardized effort for each transect was 15 min of continuous output at 4–5 A. We randomly chose sites for electrofishing in each reservoir. We also deployed sinking experimental gill nets (60 m long × 1.8 m deep with panels of 13-, 19-, 25-, 32-, and 38-mm-bar mesh) generally set perpendicular to shore for 1–2 h. Unlike electrofishing, our netting and angling efforts were not randomized because our goal was to collect as many NIP predators as possible in the short time allotted. On several occasions, we set hoop-nets, trammel nets, and fyke nets to see if these gear types were

effective at capturing NIP and suitable for fishing in the MCR. The reservoir to be sampled was determined randomly and most areas were visited once during November. In most reservoirs, we sampled for one day in each the forebay, tailrace, and mid-reservoir sites of the Bonneville, The Dalles, and John Day Reservoirs, for a total of eight days of sampling.

Upon capture, all predators were anesthetized (using either 200 mg/L MS-222 for sacrificed fish or one tablet of Alka-Seltzer Gold© in 2.5 L of water for released fish), measured (fork length in mm), and weighed (g). Stomach contents of smallmouth bass and walleyes 150 mm and larger were removed by gastric lavage with a modified Seaburg sampler (Seaburg 1957). Forguts were removed from channel catfish. Individual samples were placed in labeled Whirl-Pak bags, stored on ice, and later frozen. For this pilot effort, we also included diet information from fish collected for our work described in Chapter 1.

At our laboratory, stomach samples were thawed and prey items identified under a dissecting microscope. Level of taxonomic resolution varied by prey type: Mollusks and annelids were identified to class, insects to order, crayfish, prawns, and shrimps to genus, and fish to species (except for suckers *Catostomus* spp. and sculpins Cottidae). Rare food items were distributed into different categories, such as: vegetation, rocks, wood, and unidentified items. Individuals within each category were enumerated, placed on a paper towel for 30 s, and weighed to the nearest 0.001 g. Partially digested prey fish were identified using their diagnostic bones (Hansel et al. 1988) and we apportioned mass of unidentified fish parts among identified fish species in a diet sample. For each predator, we tallied common prey items and calculated the mean percentage by number and weight of each prey category and plotted the data by time and reservoir.

Results

Catch data—For electrofishing, we sampled 61 transects. A total of 77 SMB with a mean ± SD fork length (FL) of 181 ± 98 mm (range 42–431 mm) were collected—all from JDA (64%) and TDA (36%). Most of these fish (70%) were collected from mid-reservoir areas (Figure 2). In general, catch rates were low (i.e., 70% of transects resulted in no catch of predators) and four transects accounted for 70% of our total catch. We also collected eight largemouth bass *M. salmoides* (FL range = 104–481 mm) from the tailrace areas of JDA (*N*=6) and BON (*N*=2); seven of these fish had no food in their stomachs and one ate some smallmouth bass. No walleye or channel catfish were collected.

For netting, we conducted 2 overnight fyke net sets, 4 overnight hoop net sets, 8 gillnet sets, and 6 trammel net sets. In total, 75 fish were collected comprising 13 taxa, with fyke nets (65%) and trammel nets (28%) accounting for the majority of the catch. Suckers *Catastomus* spp., bullhead *Ameiurus* spp., and white sturgeon *Acipenser transmontanus* were the most common species collected. Only one SMB (gillnet) and one CHC (trammel net) were collected. The diet information below also includes fish captured for our work described in Chapter 1. These included 47 SMB (310 ± 77 mm; range = 151–503 mm); 30 WAL (405 ± 64 mm; range = 233–580 mm); and 31 CHC (301 ± 103mm; range = 179–580 mm).

Smallmouth bass diet—Of the 125 fish collected, 50 had food in their stomachs. The most common prey items, by % weight, were crayfish (50%), American shad (12%), amphipods (8%), sculpins (8%), and northern pikeminnow (6%; Table 1). These prey items also made up 39, 11, 8, 4, and 3% of the diet by % number. American shad, northern pikeminnow, and sculpins were the most common prey fish consumed by SMB. The diet of SMB varied from September to November, with crayfish always being the most common prey item, American shad decreasing in abundance, and other prey increasing in abundance over time (Figure 3). The

diet of SMB also varied spatially, with most crayfish being eaten in BON and JDA and most American shad being consumed in TDA (Figure 4).

Walleye—Of the 30 WAL collected, only 10 had food in their stomachs. For the eight fish we collected near Camas, WA, the most common prey items, by % weight, were peamouth *Mylocheilus caurinas* (44%), American shad (42%), and northern pikeminnow (14%; Table 1). These prey items made up 50, 42, and 8% of the diet by number. American shad, peamouth, and northern pikeminnow were the most common prey fish consumed. The diets of two WAL collected from the JDA consisted only of American shad.

Channel catfish—Diet samples were collected from 17 CHC. All fish were collected from the JDA and 65% were from the forebay. The most common prey items were crayfish (37%), caddisflies (13%), vegetation (12%), and sculpins (8%; Table 1). By % number, these prey items made up 28, 15, 8, and 3% of the diet. Clams, amphipods, and invasive mysid shrimp were the most common prey items consumed by CHC. The diet of CHC showed some spatial variation, with crayfish dominating the diet in mid-reservoir areas and other prey items being common in the forebay (Figure 5).

Discussion

The purpose of our research was to describe the general diets of SMB, WAL, and CHC during the fall. We were particularly interested in the contribution of juvenile American shad to their diets because of the role this high calorie prey item may play in the health, condition, and overwinter survival of these NIP. We found that only SMB and WAL ate juvenile American shad and the importance of this prey item varied between the two predators—accounting for, on average, about 12% of the diet (by weight) for SMB and 71% for WAL. Further, SMB showed some temporal and spatial variation in their consumption of juvenile American shad. To our

knowledge, our results are the first reported for these species in the fall and suggest that juvenile American shad may be a significant contributor to the diet of SMB and WAL during this time.

Overall, our sampling efforts were limited to a short period, from late September to early November. As such, our diet information needs to be tempered by this limited, pilot effort. During this period, catch rates of our target fish were generally low despite capturing relatively high numbers of other fishes. Suski and Ridgway (2009) and Potter et al. (2009) noted that SMB and WAL move into deeper water during the fall. Although we are unaware of any information regarding the seasonal depth distribution of these fish in MCR, it seems likely that they moved to deeper water as water temperatures cooled and were not vulnerable to electrofishing. Our use of several types of traps and nets was meant to target fish in deeper water. However, our limited sampling with these gears makes it difficult to judge their efficacy and we plan to sample shallow near-shore and deep offshore areas with a variety of gear types in the future.

Although SMB and WAL ate significant amounts of juvenile American shad, their diets also contained other important items, including crayfish (for SMB) and other fish (for both species). To understand the importance of American shad to the physiological condition of these predators will require a complete understanding of their entire diet. For instance, although juvenile American shad represent a high calorie food source (when compared to other prey items) that could enhance the growth and fitness of fish that eat them (Sauter et al. 2004), we do not know whether the contribution of American shad to the physiological condition of these predators is any greater than other important prey items. However, in a series of bioenergetics analyses, Sauter et al. (2004) altered the caloric value of the diet of SMB and WAL and predicted that the growth of these predators would increase when the proportion of juvenile American shad in the diet increased from zero to 15%–20% during the fall. They speculated that

this increased growth could result in increased consumption of ESA-listed salmonids in the Columbia River. In future years, we will use more extensive diet information, condition information (as described in Chapter 1), and bioenergetics models to further evaluate the influence of juvenile American shad—and other diet items—on the physiological condition (i.e., fat content) of SMB, WAL, and perhaps CHC.

Some of our results were similar to those from other diet studies in the MCR that occurred earlier in the spring and summer. For example, other studies have also found that crayfish were the dominate prey item by mass for SMB—at least in impounded reaches of the Columbia River (Poe et al. 1991; Zimmerman 1999). They, like us, also reported substantial temporal and spatial variation in the diet of SMB, which probably reflects changes in available prey and behavioral differences (e.g., offshore movements) of SMB that occur seasonally. For walleye, others have reported that fish were the dominate prey item for several months in the spring and summer (Maule and Horton 1984; Poe et al. 1991; Zimmerman 1999). It is noteworthy that SMB and WAL consumed relatively high numbers of northern pikeminnow, which suggests that the interactions of piscivores in the MCR warrants further study.

In summary, we documented the diets of SMB, WAL, and CHC in the MCR during the fall. Of these predators, only SMB and WAL consumed juvenile American shad. Crayfish and other fishes were also important diet items of these predators. In 2011, we plan on more extensive sampling of the MCR from August through November to more completely describe the diet of our target predators. By doing this, we hope to document the relative contribution of juvenile American shad to the physiological condition of SMB, WAL, and CHC. These results should be useful for future management decisions regarding populations of American shad in the Columbia River.

Disclaimer

Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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TABLE 1.—Diet composition of smallmouth bass, walleye and channel catfish collected in the Middle Columbia River from 27 September 2010 to 9 November 2010

	Smallmouth Bass						Walleye				Channel Catfish	
	Bonneville (*N*=20)		The Dalles (*N*=4)		John Day (*N*=26)		Lower Columbia (N=8)		John Day (N=2)		John Day (N=17)	
	% *N*	% Mass	% *N*	% Mass	% *N*	% Mass	% *N*	% Mass	% *N*	% Mass	% *N*	% Mass
Crustaceans												
Amphipods	0	0	21	23	11	12	0	0	0	0	18	7
Cladocerans	0	0	24	2	3	2	0	0	0	0	0	0
Crayfish	47	46	6	23	37	57	0	0	0	0	28	37
Mysid shrimp	0	0	4	2	6	6	0	0	0	0	10	4
Siberian prawns	0	0	0	0	4	4	0	0	0	0	0	0
Fish												
American shad	19	19	31	47	0	0	30	32	100	100	0	0

Northern pikeminnow	8	16	0	0	0	0	10	16	0	0	0	0
Peamouth	8	8	0	0	0	0	60	52	0	0	0	0
Sculpin	3	6	0	0	7	11	0	0	0	0	3	8
Insects												
Dipterans	3	0	0	0	4	4	0	0	0	0	1	0
Ephemeroptera	0	0	0	0	2	1	0	0	0	0	0	0
Trichoptera	0	0	0	0	2	0	0	0	0	0	15	13
Mollusks												
Clams	1	0	0	0	0	0	0	0	0	0	8	7
Snails	3	1	0	0	1	0	0	0	0	0	0	0
Other												
Nematodes	0	0	3	1	0	0	0	0	0	0	0	0
Rock	1	2	3	1	4	3	0	0	0	0	0	0
Sponges	0	0	0	0	10	0	0	0	0	0	0	0
Vegetation	8	0	9	1	7	0	0	0	0	0	8	12
Unknown	0	0	0	0	1	1	0	0	0	0	7	11

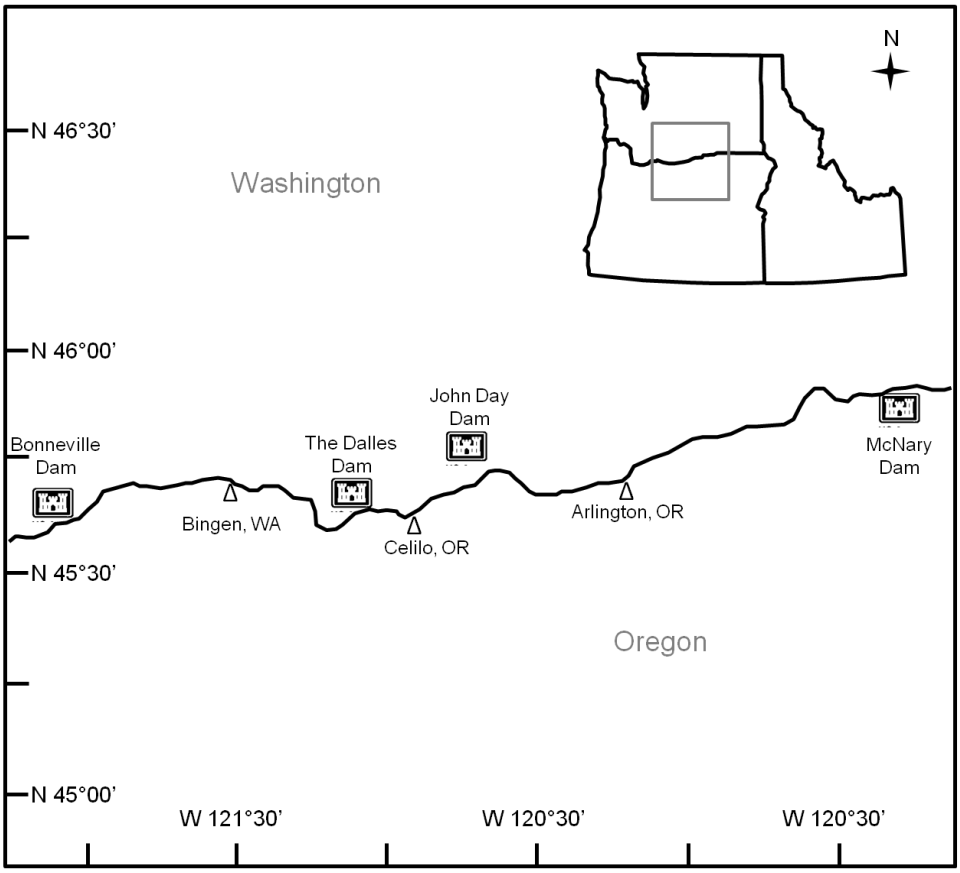

FIGURE 1.— Map of study site and sampling areas of the Middle Columbia River. Forebay areas were upstream of Bonneville Dam, The Dalles Dam, and John Day Dam, mid-reservoir areas are represented by Δ and designated by a nearby town for reference, and tailrace sampling areas were downstream of The Dalles Dam, John Day Dam, and McNary Dam.

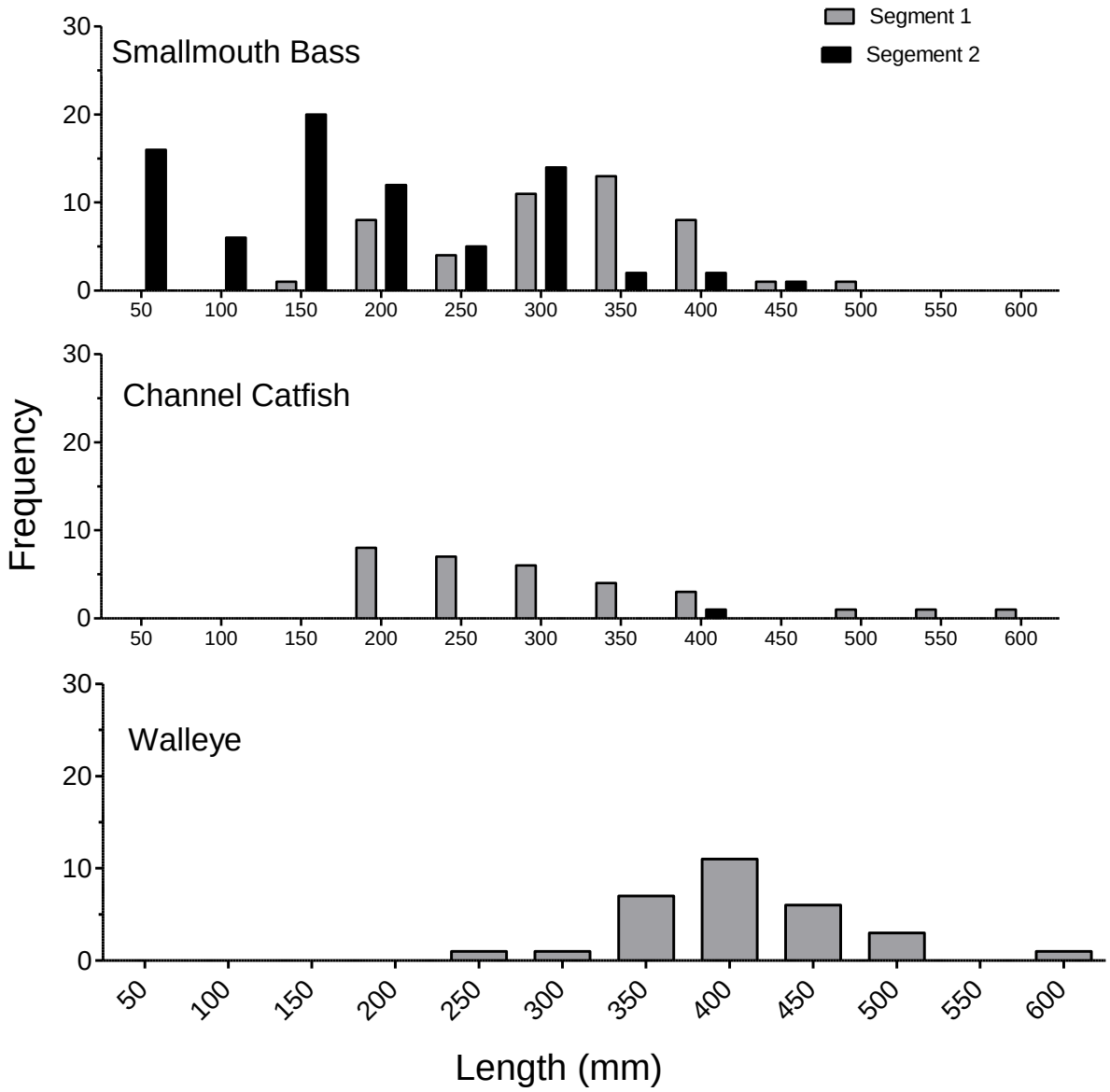

FIGURE 2.—Length frequencies of smallmouth bass, channel catfish, and walleye collected from the Columbia River during 2010. Segment one refers to fish collected from 27 September 2010 to 21 October 2010 (see chapter one). Segment two refers to fish collected from 28 October 2010 to 9 November 2010 (this chapter).

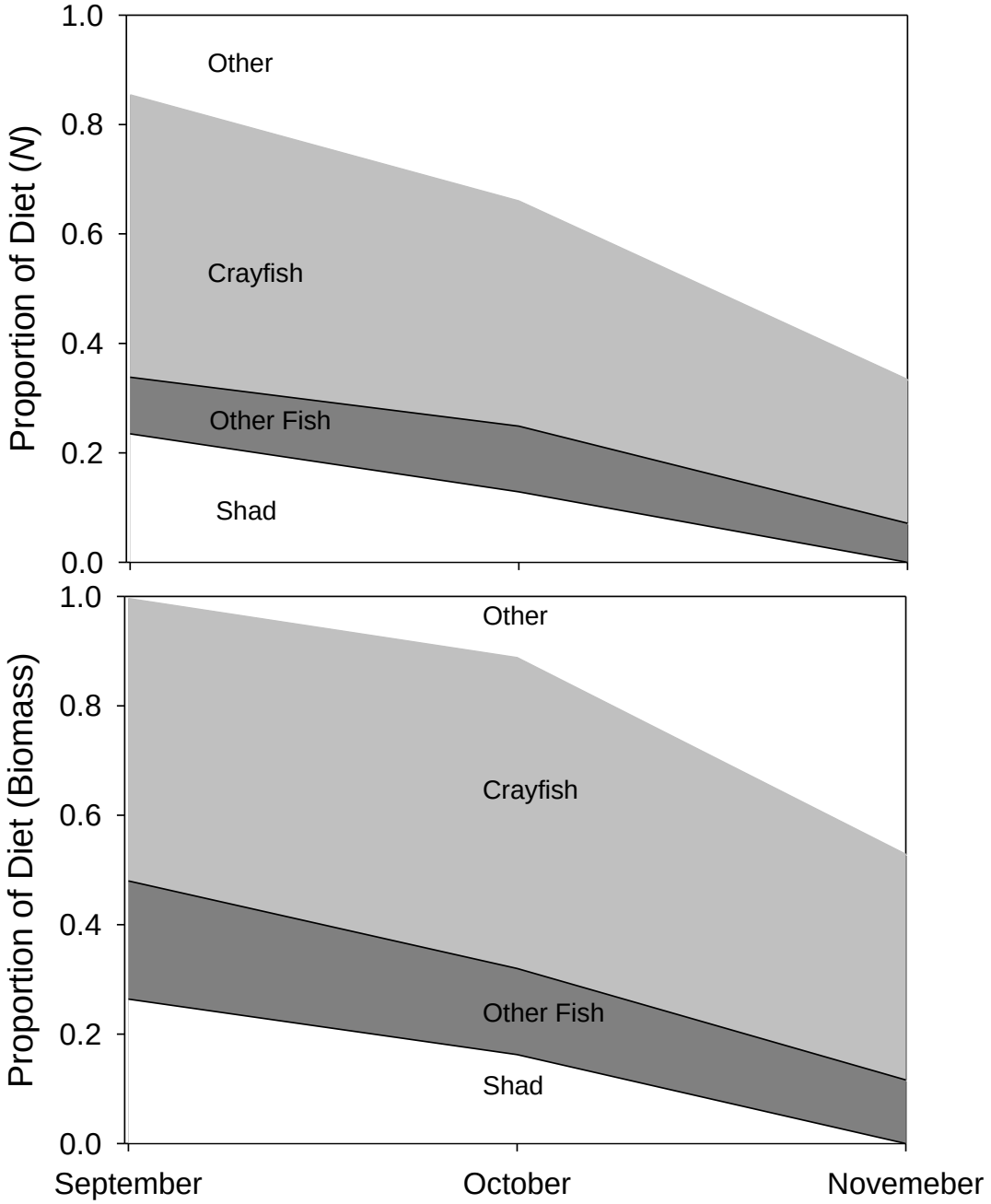

FIGURE 3.—Temporal variation in the diets of smallmouth bass from September through November 2010. Top graph illustrates changes in their diet as the number of prey items consumed and the bottom graph illustrates changes in their diet as the mass of prey items consumed.

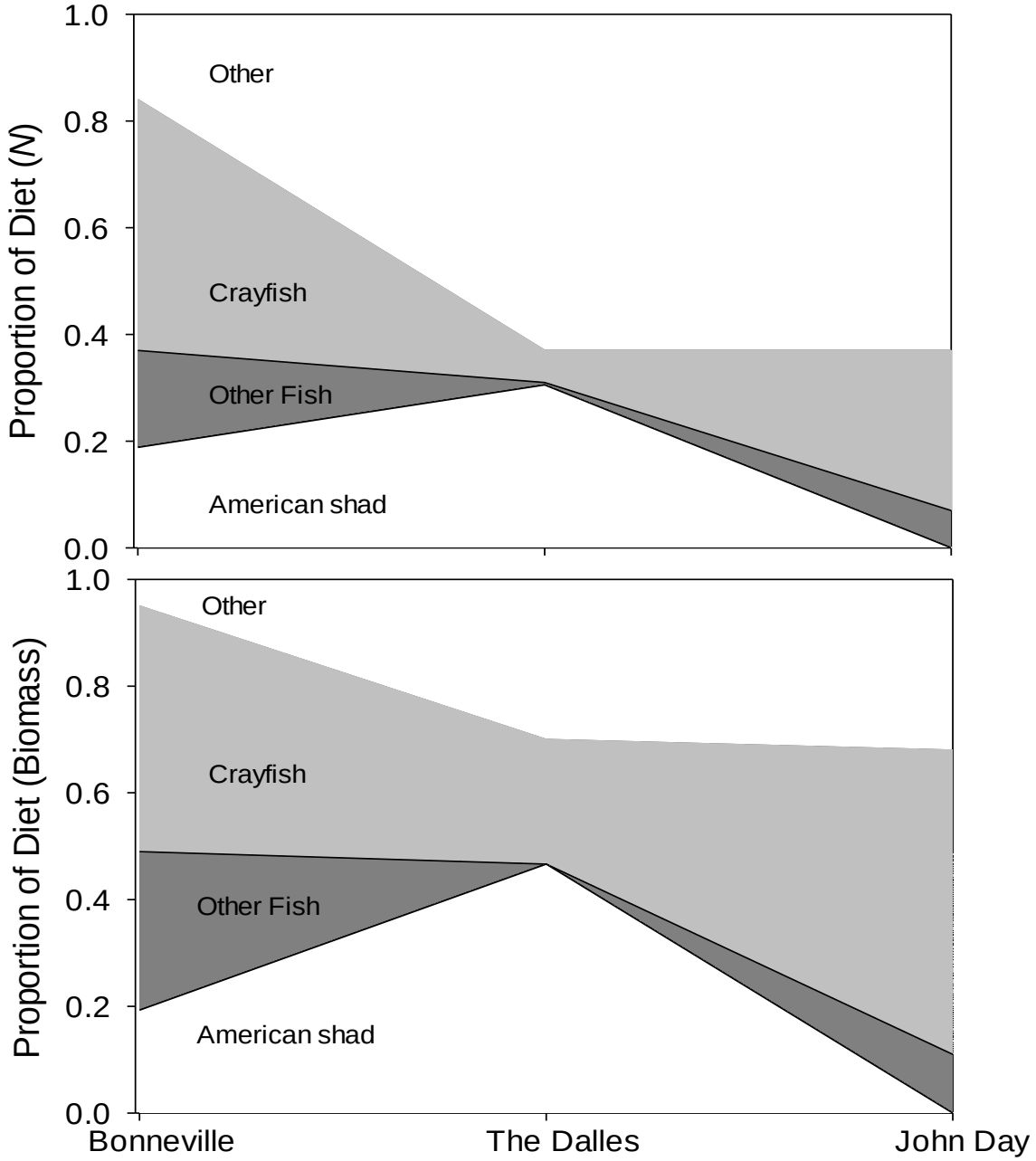

FIGURE 4.—Spatial variation in the diets of smallmouth bass between Bonneville, the Dalles and the John Day Reservoirs of the Columbia River. Top graph illustrates spatial changes in diets as the number of prey items consumed and the bottom graph illustrates changes in diets as the mass of prey items consumed.

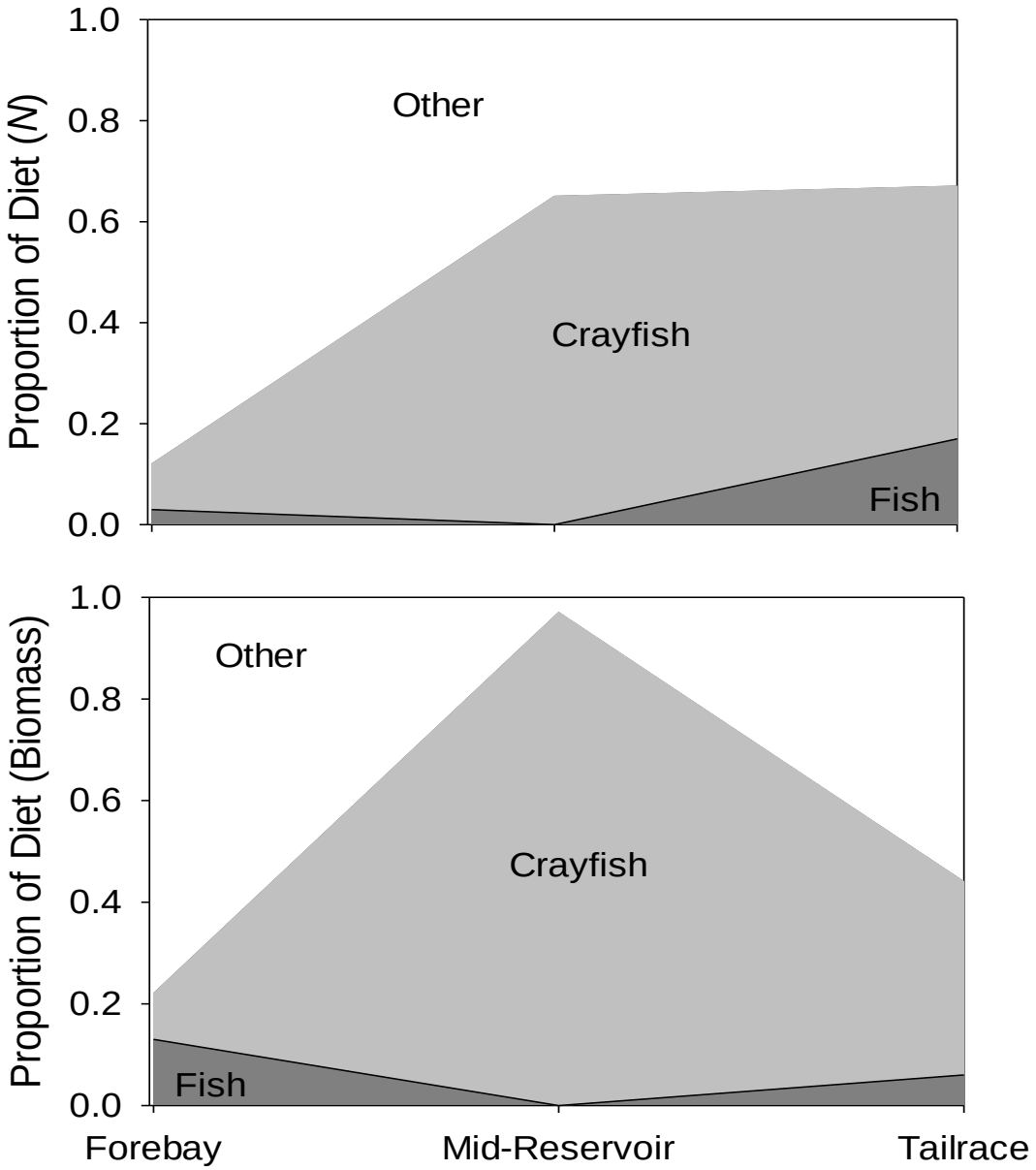

FIGURE 5.—Spatial variation in the diets of channel catfish between forebay, mid-reservoir, and tailrace areas of the John Day Reservoir (Columbia River). Top graph illustrates spatial changes in diets as the number of prey items consumed and the bottom graph illustrates changes in diets as the mass of prey items consumed.