SMALLMOUTH BASS ABUNDANCE AND DIETARY HABITS AT THREE MAINSTEM COLUMBIA RIVER DAMS: ARE FOREBAY AND TAILRACE ENVIRONMENTS ‘HOTSPOTS’ OF SALMONID PREDATION?

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INTRODUCTION

Much effort has been devoted to understanding and managing predation by fish and birds on threatened and endangered juvenile salmonids in the Columbia River Basin in recent decades. Northern pikeminnow *Ptychocheilus oregonensis*, which are capable of removing a significant fraction of the outmigrant juvenile salmonid population in the mainstem Columbia River (e.g., John Day Pool, Rieman et al. 1991), have been the focus of a long-term removal fishery (Beamesderfer et al. 1996). Similarly, substantial management measures have been taken to reduce avian predation, including active hazing and the installation of structural deterrents at dams, and the translocation (to presumed lower impact areas) of entire bird colonies in the Columbia River estuary (Roby et al. 2002).

Although studies have documented that smallmouth bass *Micropterus dolomieu* prey on juvenile salmonids in the mainstem Columbia River (Rieman et al. 1991; Ward and Zimmerman 1999; Zimmerman 1999) their potential impact was not viewed as significant, because of their relatively low abundance. Recently, however, concern over the species' impacts has been highlighted (Halton 2008; Sanderson et al. 2009; Carey et al. 2011), due to a number of factors. While smallmouth bass predation has not been identified as an issue in the Willamette and John Day rivers (T. Shrader, ODFW, personal communication), some studies indicate that impacts can be locally severe in the Yakima River (Fritts and Pearsons 2004 and 2006). Additionally, there is growing recognition that the distribution and effects of smallmouth bass in Pacific Northwest river systems are not static, and may vary with a changing climate (Carey et al. 2011). Finally, recent anecdotal accounts of large aggregations of smallmouth bass in areas immediately adjacent to John Day Dam (B. Cordie and J. Randall, USACE, personal communication) suggest that they may have greater impacts at some locations in the mainstem Columbia River than prior surveys conducted beyond these areas have indicated. These observations, combined with the recent call for non-native predator management actions in NMFS's 2008 Biological Opinion on the Operation of the Federal Columbia River Power System, necessitate a more rigorous assessment of current smallmouth bass predation.

The goal of this study is to survey smallmouth bass populations and sample diets within the immediate vicinity of three mainstem Columbia River dams (The Dalles, John Day, and McNary dams) during the main period of juvenile salmonid outmigration (May-August) in order to identify potential 'hotspots' of smallmouth bass predation. By hotspots, we mean areas where smallmouth bass impose a level of predatory impact (a function of consumption and abundance) over that which has typically been observed in other mainstem predation studies (e.g., Zimmerman 1999). Thus, our specific study objectives are (*i*) to describe and compare relative densities of smallmouth bass between forebay sites perceived to be 'hot spots' and other nearby tailrace sites at three dams, using hook-and-line sampling as the primary means for fish capture; and (*ii*) to characterize the diet of dam-angled smallmouth bass, with a specific emphasis on quantifying predation by smallmouth bass on juvenile salmonids at each dam.

METHODS

Study area

We conducted hook-and-line sampling at three mainstem Columbia River dams, The Dalles Dam (TDA), John Day Dam (JDA), and McNary Dam (MCN). Sampling was conducted on both the forebay (i.e., upstream) and tailrace (i.e., downstream) sides of each dam and focused on areas within the Boat Restricted Zone (BRZ) and areas otherwise inaccessible to the public. Specific locations were selected based on a number of considerations, including past observations made by US Army Corps of Engineers (USACE) and Northern Pikeminnow Management Program staff, accessibility, safety, and areas otherwise considered to be suitable bass habitat. Surveyed sites at or near each of the three dams were limited to those areas that, while restricted to public access, were deemed safe to be accessed by project employees, as per USACE issued permit. These sites are here collectively defined as "angling accessible" zones surrounding each dam. Particular emphasis was placed on angling from forebay powerhouse decks to ensure that areas where smallmouth bass were observed foraging during previous summers were included in sampling activities. Our shore- or dam-based angling effort enabled us to sample several different habitat types, including: rip rap shores, bedrock shoals, vertical concrete structures (e.g., forebay walls), spillway footings, floating structures (e.g., docks and debris rafts), vegetated flats, gravel pits, and combinations of the above; sampled areas ranged from 2 to up to 20 m (forebay powerhouse walls) in depth. Given its unique structure and setting, The Dalles Dam had greatest diversity of angling-accessible habitats, whereas John Day and McNary dams sites were structured similarly.

Angling methods

Structure of fishing efforts.—The dam angling team consisted of three experienced bass anglers. A project biologist led the team, selected sample sites, processed fish, and managed data. To maximize angling effort, the project biologist fished when time allowed and up to two other anglers joined the team on occasion, particularly during June. Sampling occurred between the hours of 0530 and 1500, Monday-Friday, from May 9 to August 31, 2011. Due to differing site distances from the duty station or time-related access restrictions, sampling commenced 30 min to one hour later at John Day and McNary dams, than it did at The Dalles Dam.

During the course of the summer, sampling followed a randomized schedule that allocated effort to each dam for two consecutive days (event) within each of 13 six-day temporal sample strata. Within each sample event at a dam, the order in which the two sides would be sampled was also randomized (coin toss). On each sample day, a random number generator was used to determine the sequence in which specific areas were to be sampled, and by which angler(s). Departures from complete randomization were necessitated on occasion due to extraneous factors (e.g., dam maintenance activities and weather).

Tackle and techniques.—Bass dam anglers used a selection of light-weight spinning rods equipped with spinning reels and either 13.6 kg test Power Pro™ braided line or 4.5-6.3 kg test monofilament (Maxima™ or Berkley™). Heavy duty casting rods equipped with level-wind casting reels and braided line (13.6 kg test) were also used, particularly for fishing in extremely deep and/or turbulent water. Our terminal tackle selection consisted of soft-plastic baits (tubes, grubs, worms, lizards, crayfish, and swim baits) in a variety of sizes and colors, crank baits (Rattle Trap™, Bill Dance Fat-Free Shad™, Bomber™, Storm Wiggle Wart™, etc.) and spinner/buzz baits. Soft plastics were fished in a variety of different ways, incorporating jig heads, worm hooks, bait hooks, and sliding egg weights. Jig heads weighed 4-11 g and hooks were typically 2/0 sized; however smaller and larger hooks were occasionally needed to accommodate soft plastics of differing size.

Depending on conditions, tackle was fished using several techniques, including: back bouncing, vertical jigging, drift/swing, cast/retrieve, and still fishing (on the bottom or under a bobber). Back bouncing was a primary technique for angling from the tailrace powerhouse decks. Still fishing and vertical jigging techniques were used on elevated surfaces. Casting and retrieving techniques were used in areas close to water level, whereas drift methods were used in areas with faster moving water. To maintain consistency in methods and knowledge, anglers were supplied with a standard gear selection and were required to stay in communication throughout the day about what tackle/techniques were and were not working. In general, lure selection was made based on angling location, conditions, and recent success, and during times of high catch rates anglers were encouraged to change tackle to determine the extent to which lure selection influenced catch.

Biological sampling.—Each landed smallmouth bass was immediately placed in a bucket, and transported to an aerated live well at a central work-up station. The species, time, location, tackle, and angler details were recorded for each landed fish encounter. Smallmouth bass were further processed according to the following sequence: (*i*) they were scanned for the presence of a passive integrated transponder (PIT) tag, (*ii*) they were measured (fork length, in mm) and weighed (to nearest 5 g on spring scale), and (*iii*) first-time captures were given a PIT tag (injected into abdominal cavity) and a secondary fin clip (anal fin, for PIT-tag loss estimation). Lastly, diet samples were taken from each fish using non-lethal means. Specifically, a modified Seaburg sampler (Seaburg 1957) was used to flush stomach contents from smallmouth bass foreguts into a sieve and ultimately a sample bag. Diet samples were placed on ice in the field and frozen thereafter for later laboratory analysis. Upon recovery, each fish was released back into the area where it was originally caught.

Given that some fish did not fully recover from sample work up (e.g., due to hooking or handling injuries), we opportunistically sampled smallmouth bass stomachs in order to evaluate the effectiveness of our lavage method. Thus, we obtained paired lavage–remaining contents samples for 54 individuals over the course of the summer (see below for further details).

Laboratory Methods

Smallmouth bass diet samples were processed using the methods developed for the biological evaluation of the Northern Pikeminnow Management Program (e.g., Porter 2010). In the laboratory, thawed diet samples were sorted into coarse prey categories (fish, crayfish, other invertebrates, and misc. items [unidentified organic matter, lures, etc.]) in trays and weighed (wet weight) to the nearest 0.01 g by prey type. Diet samples containing fish were then subject to a soft-tissue digestion procedure so that diagnostic bones could be isolated, making finer taxonomic identification possible. Chemical digestion consisted of a two-stage process: (i) samples were immersed in a pancreatin (2% wet weight), sodium sulfide nonahydrate (1% wet weight), and tap water solution and held at 48°C for 24 h, (ii) a sodium hydroxide (3% wet weight) solution was added to each sample to dissolve remaining fats. Remaining bones were rinsed in a sieve (425 µm), transferred to a Petri dish, and examined under a dissecting microscope for identification. We used a combination of bone keys (Hansel et al. 1988, Frost 2000, and Parrish et al. 2006) to identify prey fish to the lowest practical taxonomic level (typically genus). Additionally, we determined the number of individual fish in samples based on the counts of paired bones in the digested product.

Analysis Methods

To determine whether or not there are localized areas of intense predation by smallmouth bass on salmonids (i.e., "hotspots"), we conducted a three-part analysis to characterize patterns in abundance, consumption of salmonids, and predatory impact (a function of abundance and consumption) across sites.

Abundance evaluation.—First, we tested for differences in the relative abundance of smallmouth bass across sites. To do this, we first indexed abundance, based on the catch per unit of effort (CPUE = Σ landed bass /Σ angler hours; bass·angler h^{-1}) enumerated for each sampling occasion. We then used an analysis approach that considered the time-series nature (i.e., non-independent, serially correlated errors) of the data in our comparison of values across dams (TDA, JDA, MCN) and sides of dams (forebay, tailrace). Using the R Package 'gls', we fit a linear model that included dam, side, and dam×side interaction effects, with the serial correlation in residual error modeled using a first-order autoregressive function (AR-1; note, alternative correlation structures were assessed using AIC and AR-1 proved most useful). If a main or interaction effect was deemed significant ($\alpha = 0.05$), we made post-hoc pair-wise comparisons using the R package 'contrast'.

In addition to CPUE, we estimated the absolute abundance of smallmouth bass at each sample site. We did this for two reasons: first to determine whether CPUE patterns reflect true abundance differences, as CPUE is not only a function of abundance, but also catchability, which may differ between habitats; and second to provide a context for our overall predation impact assessment (see below). To do this, we evaluated a suite of open (Jolly 1965; Seber 1965) and closed (Otis et al. 1978) capture–recapture models that require capture information tabulated at the individual level (i.e., capture histories for PIT-tagged individuals), including the closed multi-census model (M_t) by Otis et al. 1978, that is equivalent to the Schnabel estimator. Although recaptures comprised nearly 30% of our catch towards the end of the study period, initial analyses indicated that the low recapture rate during the first 2/3 of our study prevented meaningful abundance estimation using the capture–recapture modeling approach. Thus, here we report estimates produced using the Schnabel estimator only. It is important to acknowledge the limitations of this approach relative to our data: (*i*) given our gear, our realm of inference extends only to the 'population' within the hook-and-line accessible region surrounding each forebay or tailrace study site, (*ii*) one or more assumptions required for unbiased estimation of abundance using the Schnabel estimator (i.e., population closure, perfect mark retention and identification, equal capture probability, no effect of handling on recapture probability) is likely violated.

Diet evaluation.—We quantified the diet patterns of smallmouth bass based on three measures. First, we estimated the composition of diets based on the percent of wet mass of coarse prey categories as a proxy for the importance of fish (all species) to the energy budget of smallmouth bass. We then estimated the frequency of occurrence (i.e., no. guts with prey$_i$ / total sample size), with a particular emphasis placed on salmonids. Towards quantifying predation on salmonids, we estimated the rate at which smallmouth bass consumed salmonids based on the relationship between Ward and Zimmerman's (1999) consumption index (CI) and measured consumption rates. We first computed CI as

$$CI = 0.0407 \bullet e^{0.15T} \bullet W^{0.23} \bullet (S \bullet GW^{-0.29}), \quad (1)$$

where T is mean water temperature (^{o}C) for the period and location (forebay or tailrace, at each dam) of interest, W is mean predator weight (g), S is the mean number of salmonids per predator, and GW is the mean gut weight (g) per predator, and constants are smallmouth bass-specific allometry parameters. Consumption rate (CR, salmonids$\cdot d^{-1}$) was then approximated based on the empirical relationship between CI and CR (Ward and Zimmerman 1999),

$$CR = -0.003 + 1.969\ CI. \quad (2)$$

We estimated all diet-related parameters on a sample-day basis and compared values between sites (dam and side of dam) using the same statistical methods described above for CPUE.

Predatory impact assessment.—To understand the significance of any documented predation in a salmonid conservation context, an answer to the question 'how many salmonids might smallmouth bass have eaten during the 2011 outmigration?' is needed. We developed a means for approximating an answer to this question using the abundance and consumption data described above. Specifically, we estimated the total consumption of juvenile salmonids in forebay and tailrace habitats at each dam as the product of estimated (*i*) smallmouth bass abundance (season-wide estimate of population size) and (*ii*) daily per capita consumption rates (CR, salmonids·d^{-1}) for each area *i*, summed over the *j* days in the study period (i.e., Total $\text{Consumption}_i = \Sigma\, N_i \cdot \text{CR}_j$ for dam-side combination *i*). Given uncertainty in abundance estimates, we computed total consumption at the point estimate of abundance, as well as the upper and lower 95% confidence bounds, for each site, and discuss consumption totals in only coarse measures (i.e., 1,000s of fish consumed).

In addition to the above analyses, we provide a number of related data summaries relevant to our biological evaluation. We characterize temporal patterns in a suite of environmental conditions that can influence predator behavior or success (flow, spill, and temperature), as well as the relative timing of the 2011 juvenile salmonid outmigration. The former is based observations logged at The Dalles Dam (U.S. Geological Survey reporting site: 14105700) and USACE environmental monitoring summaries for each dam (spill volumes), whereas the latter is based the Fish Passage Center's passage index (www.fpc.org) and is reported for John Day and McNary dams only (a passage index is not currently estimable for The Dalles Dam). For context, 2011 flow and temperature conditions were compared to historical values. We used the period extending from 1973 to date for a flow baseline, as this period best approximates the modern flow regime of the Columbia River (i.e., the last major storage dam was closed in that year); for temperature, we used the available 14-year record (1997-date) for USGS site 14105700. Finally, given the influence of smallmouth size on their predatory impact on salmonids, we compared fork length distributions among dams using ANOVA, and relate these distributions to the range of smallmouth bass sizes shown to have a greater impact on salmonids in other systems (e.g., Yakima River, 150-300 mm FL; Fritts and Pearsons 2006).

RESULTS

Environmental conditions and passage timing

Dam angling began on 9 May and ran through 30 August, 2011. Extreme river conditions were encountered at all dams during much of this sampling season. River flow was near average for the first half of May, then increased sharply in June to reach one of the highest levels observed in the past 30+ years, and remained well above average until the end of the sampling season (Figure 1). These high flows translated into high spill levels, averaging 5,500 to nearly 8,000 $m^3 \cdot s^{-1}$, and associated turbulence in the tailrace sampling environment, during much of June and part of July. Turbidity was elevated for much of June and July, especially at John Day Dam where the influence of the nearby John Day River confluence was apparent. 2011 water temperatures were also

outside of the range observed in recent years (1997 onward), with daily average temperatures remaining *ca*. 2 °C below average until the sampling season was nearly finished (Figure 1).
Based on available passage data, our sampling captured nearly all of the sub-yearling Chinook outmigration window at McNary and John Day dams (Figure 1). Our sampling missed a portion of the juvenile steelhead and yearling Chinook outmigration, as some of these fish began emigrating before the start of May. Although passage index data were not available for The Dalles Dam, we suspect that the juvenile outmigration window was similarly captured there given its proximity (*ca*. 40 km downstream).

Effort and catch

Angling effort.—We fished for an average of 20.5 angler hours (lines in water) at each project on each sample day, totaling 1,639.8 hours across sites for the season (Table 1). We generally logged more angler hours at The Dalles (601.0 h total) and McNary dams (567.0 h) than John Day Dam (471.8 h), due to the greater distance to the latter project from our daily base than the other two (The Dalles, OR for John Day and The Dalles dams; Hermiston, OR for McNary Dam). With the exception of June, when an extra bass angler participated in the fishery, effort was distributed evenly across the sample season (Figure 2). After accounting for incomplete May sampling, we averaged 74 hours per side (i.e., forebay or tailrace) per dam, which was somewhat short of our pre-season 100 h per area per month effort goal. It should be noted, however, that this target was set based on a power analysis anticipating CPUE values considerably lower than any measured during the season (see below).

Catch patterns.—In total, the dam angling team landed 1,439 smallmouth bass over the course of the season. Over half of these came from John Day Dam, and the remaining catch (46% of total) was split approximately evenly between The Dalles and McNary dams (Table 2). On an aggregate basis, 197 (14%) of the landed smallmouth bass were previously caught individuals (i.e., tagged recaptures), whereas daily recapture rates averaged 30-40% towards the end of the season. Observed hooking-related mortality (5.0%) and PIT-tag loss (inferred from secondary marks, 3.6%) were relatively low. Hook-and-line encounters of non-target fish were also modest, and totaled 81 individual fish for the season. The majority of non-target encounters was composed of a mix of walleye *Sander vitreum* (22), northern pikeminnow (25), and sculpin *Cottus* sp. (20) catch (Table 3), and no mortality of non-target catch was observed.

Smallmouth bass catches varied through time and across the three dams (Figure 2). At the low end, we caught relatively few fish during May and early June at The Dalles and McNary dams; daily catches averaged 5-10 landed smallmouth bass in both forebay and tailrace sites. At the extreme high end, our maximum daily catch—71 landed smallmouth bass—occurred in the John Day tailrace during early June. McNary and The Dalles catches increased consistently, albeit at a modest level, for the remainder of the season. At John Day Dam, our tailrace catch dropped off considerably in late July, whereas the opposite occurred in the John Day forebay environment; the increase in John

Day forebay catches were particularly evident at powerhouse sample areas. With the exception of John Day, temporal and season-wide differences in forebay vs. tailrace catches were minimal (see below for statistical comparison of CPUE).

We maintained records of smallmouth bass catch by tackle and technique, and despite consistently trying different gear, soft plastic lures were by far the most productive style of lure. 1,284 of the 1,439 (89.2%) smallmouth bass landings were due to soft plastics. Smoke-colored tubes with copper glitter were the single most effective style of soft plastic, yielding a total of 193 smallmouth bass; a combination of several other smoke-colored variants (tubes and grubs, glitter combinations) yielded an additional 482 of the smallmouth bass, totaling nearly a third of our catch. Soft plastics featuring white accounted for another fifth of our catch, whereas soft plastics with black as the dominant color were associated with 12.0% of our catch. Approximately 11% of all landed smallmouth caught were caught on lures, with 7.5% due to Rattle Traps™ and the remaining 47 fish due to a combination of other lures (e.g. Storm Wiggle Wart™, Rooster Tail™, Bomber™, Bill Dance Fat Free Shad™, other diving crank baits, spinner baits, buzz baits).

CPUE and Abundance Estimates.—Given the relative consistency in sampling effort across the season, smallmouth bass CPUE varied in a manner consistent with the seasonal and project-to-project catch patterns described above. CPUE was low but similar at both The Dalles and McNary sites, averaging one fish per 2-3 angler hours for the season and exhibiting an increasing trend across the sample season (Table 4; Figure 2). At John Day Dam, smallmouth bass CPUE was nearly 5-fold higher than at the other projects, and exhibited a reversal in tailrace vs. forebay catch dominance as the summer progressed. In terms of a statistical test of the hotspots hypothesis, our analysis revealed a significant effect of dam only on CPUE ($F_{2,74}$=3.72, $P = 0.03$; Table 5, Figure 3); neither the 'side of dam' (i.e., forebay, tailrace) nor the side-dam interaction effect was significant ($P > 0.70$ in both cases). In terms of specific dam-to-dam differences CPUE at John Day was found to be significantly higher than at both McNary and The Dalles dams ($P < 0.05$ for both). McNary and The Dalles CPUE values were not significantly different ($t = 0.11$, df = 74, $P = 0.91$). Further, the existence of a significant dam effect in models was consistent across a range of alternative 'gls' model parameterizations, e.g., alternative autocorrelation structures, inclusion of fixed date effects, etc. In sum, relative abundance, as indexed by dam angling CPUE, differed between the three projects but not systematically between forebay and tailrace environments.

Based on release–recapture patterns for smallmouth bass during the sample season, we estimated the total size of populations within the angling-accessible forebay or tailrace zone at each dam (Table 6, Figure 3). Site-to-site differences in population estimates generally mirrored those observed for CPUE, with the strength of association between these two parameters estimated at $R = 0.83$ (Pearson correlation coefficient, $t = 2.99$, df=4, P=0.040). Population estimates for The Dalles forebay and tailrace and McNary tailrace ranged 100-500, whereas those for the John Day forebay and tailrace and McNary forebay ranged from approximately 1,000 to 2,500. Additionally, estimates suggest a trend towards larger 'angling-accessible' populations in tailrace compared to forebay areas at The Dalles and John Day dams (i.e., based on confidence intervals), but no difference at McNary Dam.

Smallmouth bass fork length analysis.—We caught smallmouth bass that ranged 118-525 mm and averaged 280 mm in fork length, over all sites and sample days. ANOVA results indicated that dam ($F_{2,1218}$=59.0, P<0.001), side-of-dam ($F_{1,1218}$=47.7, P<0.001), and the dam*side interaction effects ($F_{2,1218}$=15.8, P<0.001) each accounted for a significant component of overall FL variation. More specifically, smallmouth bass in The Dalles Dam forebay (mean = 311 mm, standard error = 9) and tailrace (mean = 302 mm, standard error = 6) sites, and the McNary tailrace site (mean = 324 mm, standard error = 6), were similarly sized on average, and were the largest fish encountered across the study areas (Figure 4). Smallmouth bass caught at John Day Dam (forebay [mean = 249 mm, standard error = 3] and tailrace [mean = 275 mm, standard error = 2]) and in the McNary forebay (mean = 268 mm, standard error = 8) tended to be smaller on average, with John Day forebay fish averaging the smallest of any site. With the exception of the John Day tailrace vs. McNary forebay contrast and the The Dalles forebay vs. tailrace contrast, pair-wise comparisons illustrated that inter-site differences were statistically meaningful (P<0.05, post hoc pair-wise *t*-test with Holm's correction). It is also worth noting that length-frequency distributions tended towards unimodal for the six study areas on an aggregate and site-specific level (Appendix A). Lastly, a sizeable proportion of populations encountered at all dams was within the size class of 150-300 mm, including 77 and 79% of all smallmouth bass caught in the John Day tailrace and forebay, 41% and 66% of smallmouth bass caught in McNary tailrace and forebay areas, and 57% and 48% of smallmouth bass in The Dalles tailrace and forebay.

Diet and predatory impact evaluation

Our examination of guts from 54 of the smallmouth bass that died as a result of hooking injuries revealed that gastric lavage conducted on live animals was very effective (measured by % removal efficiency = lavaged mass / [lavaged mass + mass extracted via dissection]). Thirteen of these individuals contained fish, and 100% of that mass was flushed during lavage. Non-crayfish invertebrate mass was evacuated at a 96% rate (n = 29 guts contained this prey). Crayfish (n = 29 guts contained this prey) were flushed at the lowest rate (88%), but still quite effectively using lavage methods. Only one of the samples considered empty following lavage in the field (n = 11) contained biomass, 0.1 g of vegetation.

Based on an examination of more than 1,400 samples, we observed that the average smallmouth bass diet consisted of an approximately 40:60 mix of fish and invertebrate (crayfish + non-crayfish) biomass on a season-total level across the three dams. The proportion of biomass due to fish prey was 2-3 times higher at John Day (39% forebay, 50% tailrace) and McNary dams (47% forebay, 55% tailrace) than The Dalles Dam (14% forebay, 26% tailrace). Diets were seasonally variable, but a few temporal trends were evident (Appendix B): the fraction of fish biomass in diets rose consistently with the passage of subyearling Chinook at the McNary forebay site and to a lesser extent at John

Day Dam (forebay and tailrace); also, the diet fraction consisting of non-crayfish invertebrates—the amphipod *Corophium* primarily—increased noticeably in the John Day forebay during the month of August.

In terms of population-level occurrence patterns, fish were found in approximately one third of all smallmouth bass diet samples (Table 7). Bone identification revealed that salmonids (*Oncorhynchus* sp., primarily subyearling fall Chinook based on their size and timing of appearance in diets [below]) and sculpin (Cottidae) were the fish taxa that occurred most frequently in diets, averaging 10% overall and ranging from 0-23% (min at The Dalles tailrace, max at McNary forebay) and 3-25% (min at John Day forebay, max at McNary tailrace) for the two taxa, respectively. Cyprinids and lamprey (Petromyzontidae) were the next most prevalent fish taxa in diets, but each occurred at only a 1% frequency overall.

Indices of salmonid consumption by smallmouth bass (CI), and corresponding consumption rates, varied markedly across the sample sites and the study period. Daily CI estimates averaged 0.2 (corresponding CR = 0.4 salmonids · day^{-1}) overall, and within-site season averages ranged from zero in The Dalles forebay (i.e., due to no observations of salmonids in diets) to 0.5 (CR = 1.0 salmonids · day^{-1}) in the McNary forebay. Our statistical evaluation of CI patterns demonstrated a significant effect of dam only (i.e., side-of-dam and interaction effects were non-significant; Table 5). More specifically, CIs were significantly higher at McNary than the other two dams (post hoc pair-wise contrasts, $P < 0.05$). Seasonally, CIs remained flat through early July, at which time they increased at all sites except The Dalles tailrace (Figure 5). These mid-summer CI increases were most striking at McNary Dam where they rose to a peaks of 1.1 and 1.8 (CR = 2.1 and 3.5 salmonids · day^{-1}), in forebay and tailrace sites, respectively. A seasonal CI increase was also evident at the John Day Dam forebay, where it reached 0.6 (CR = 1.1 salmonids · day^{-1}) at its highest point. CIs remained high at each of these three sites through mid to late August. Tailrace CIs for The Dalles (max = 0.2) and John Day (max = 0.3) displayed a similar seasonal trend, but of peaks were of considerably lower magnitude.

After converting CIs to equivalent CRs and interpolating values for days that were not sampled, we estimated daily and season-total salmonid consumption for the entire population of smallmouth bass accessible from each sampling area. Based on this, we estimated that approximately 200,000 (130,000-340,000) salmonids (presumably subyearling Chinook, given the seasonality of impacts reported above) were consumed within forebay and tailrace areas at the three dams in total during the sample season. 66% of this consumption total (~133,000 fish) was due to just two sites, the John Day and McNary forebays (Figure 6); smallmouth bass at The Dalles Dam were responsible for about 4% of this total, and the balance (~60,000 fish) was evenly split between the John Day and McNary tailrace smallmouth bass populations.

DISCUSSION

This inaugural effort at conducting a dam angling fishery for smallmouth bass provided new insight on the magnitude and spatial distribution of their predation on juvenile salmonids at three mainstem Columbia River dams. Our preliminary work demonstrates that predation has the potential to be locally intense near these dams, specifically at McNary Dam (both sides) and in the John Day forebay, throughout the duration of the juvenile fall Chinook outmigration period. Further, it warrants further study to provide a numerical context for gauging the conservation significance of such non-native species impacts.

Observed consumption levels, first measured in terms of the Ward and Zimmerman (1999) consumption index (CI), were generally greater than those estimated from smallmouth bass diet samples for forebay and tailrace habitats over the past 20 years by the Northern Pikeminnow Management Program (NPMP, e.g., Weaver et al. 2009). It is worth noting, however, that the NPMP's sampling operations are boat electrofishing-based and do not occur as close to dams as angling (due to safety and security, per USACE order); these comparisons, though informative, are thus somewhat confounded. At McNary dam, for instance, CIs in excess of 1.0 were commonly observed in the present study, whereas the highest value estimated from past NPMP predator indexing activities was 0.6 (in the John Day forebay, 1991; Weaver et al. 2009). NPMP smallmouth bass CI estimates more typically averaged 0.1 or less across sites and years. As we discuss later, hook-and-line sampling likely selects for actively feeding fish and may select for piscivorous individuals, thus inflating the CIs.

Smallmouth bass consumption patterns can also be compared to those for systems beyond the Columbia River, if assessed in terms of consumption rates (CR). Values estimated from dam-angled samples, derived from an empirical relationship between CI and CR, appear to be at the high end of what has been estimated elsewhere. During the height of juvenile fall Chinook outmigration, dam-angled smallmouth bass were estimated to have consumed on the order of 2-4 fish per day, on par with the upper end of the range estimated elsewhere in the Pacific Northwest, and in excess of anything previously reported for the mainstem Snake and Columbia rivers (reviewed in Carey et al. 2011).

Given the above considerations and site-level patterns in smallmouth bass abundance, some of our sample sites—namely the John Day and McNary forebays—can be reasonably considered predation hotspots in a relative sense (i.e., compared to other portions of the mainstem Columbia, and tributary areas). These hotspots likely exist due to the juxtaposition of areas of suitable bass habitat (e.g., rocky rip rap shorelines flanking dams; reviewed in Brown et al. 2009) and areas of delayed salmonid migration (Venditti et al. 2000). This conclusion is supported by our finding of no predation within The Dalles forebay, where outmigrating salmonids experience little forebay delay compared to other mainstem Columbia projects (Johnson et al. 2007). While our data suggest that elevated levels of predation by smallmouth bass can occur in the forebay of some Columbia River impoundments, the question remains as to whether or not such areas are hotspots in an absolute sense (i.e., worthy of future management efforts to reduce the potential for piscivorous predation).

We estimate that between one tenth and one half of a million salmonids were consumed within the areas immediately adjacent to The Dalles, John Day, and McNary dams during the 2011 outmigration period. Although dam-specific outmigrant population estimates are not available, one can gain perspective on the significance of consumption of this magnitude by considering estimates relative to an approximation of total smolt production for all areas upstream of McNary Dam. Assuming that subyearling Chinook was the primary prey species, available information suggests that 20 million individuals were released from hatcheries above McNary in 2011 (www.fpc.org), and wild production for the same area, although not known, may be on the order of 50+ million (i.e., across Hanford, Snake/Clearwater, Yakima production areas). After accounting for outmigrants collected by the smolt transportation program and those lost due to in-river mortality, the total population of subyearling Chinook reaching the McNary Dam forebay was likely in excess of 50 million during 2011. This places the total loss of subyearling Chinook to smallmouth bass predation across The Dalles, John Day, and McNary dams at somewhere on the order of 0.4 to nearly 1% of the total outmigrant population. While it is possible that certain stocks may have contributed disproportionately to this loss (e.g., due to differences in timing, body size, etc.), mortality of this magnitude is modest relative to the range of variation caused by inter-annual patterns of in-river environmental conditions (e.g., Tuomikoski et al. 2011).

Study limitations

Despite providing new insight into the potential magnitude of smallmouth bass predation at Columbia River dams, our findings are not without their limitations. First, 2011 presented a set of environmental conditions that were anomalous. In particular, water temperatures were cold and flows and turbidity levels were high for much of the outmigration period. Such conditions likely resulted in a lesser consumption rate and overall predation level by smallmouth bass relative to a more ‘average’ year (Naughton et al. 2004). Conversely, elevated flow conditions in the John Day River may have contributed to “channeling” smolts to the John Day Dam bypass, whereby the locally increased smolt densities may have caused an increase in their vulnerability to predation by smallmouth bass. Thus, 2011 may not be representative of typical hydraulic and ecological river conditions. This reality underscores the need for sampling over multiple years.

Second, our survey approach may have introduced some bias into estimates of consumption and/or abundance, and therefore total predation. For instance, although we were interested in characterizing the ‘average’ smallmouth bass diet, it is understood that fish do not enter hook-and-line samples at random (i.e., they do so by actively ingesting lures). While it is unknown whether or not this affects the picture of smallmouth bass diets that one obtains, observed gravimetric fractions of coarse prey categories (i.e., fish, invertebrate biomass) were consistent with those estimated for smallmouth bass using other capture methods (e.g., electrofishing, Zimmerman 1999). Furthermore, angling is virtually the only means by which smallmouth bass could have been safely collected at our study sites.

Regarding abundance, it is clear that our data violate at least the closure assumption of the Schnabel population estimator (i.e., fish can move freely in or out of the 'angling-accessible' forebay/tailrace area), and also perhaps that of equal capture/recapture probability (e.g., differences in likelihood of recapture due to previous hooking, size-related differences, etc.). If smallmouth bass move freely in or out of study areas, bias can only arise if marked or unmarked fish do so at different rates, which is unlikely. As for equal capture/recapture probability, we noted that smallmouth bass were amenable to repeated capture by hook-and-line, with many individuals being caught more than once (e.g., 25% of the smallmouth bass tagged in The Dalles forebay were caught 3+ times, and one fish was caught 5 times). Nonetheless, the potential for fish being 'hook shy' and delayed hooking-related mortality indicates that our estimates may be subject to a modest positive bias.

Lastly, although we covered large areas, we were unable to sample in all dam-accessible locations where smallmouth bass might be found. Although this occurred entirely because of safety issues, gaining a complete and unbiased picture of total predation near the three projects will require consideration of measures (e.g., harnesses) facilitating safe access to areas not sampled during 2011.

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Table 1. Monthly and side-specific angling effort totals at The Dalles, John Day, and McNary dams.

		Total fishing effort (angler hours)				
Dam	**Side**	**May**	**June**	**July**	**August**	**Total**
The Dalles	Forebay	72.8	98.0	55.0	77.5	303.3
	Tailrace	65.3	93.0	59.5	80.0	297.8
	Total	138.0	191.0	114.5	157.5	601.0
John Day	Forebay	57.3	74.0	64.0	59.0	254.3
	Tailrace	32.0	63.3	71.5	50.8	217.5
	Total	89.3	137.3	135.5	109.8	471.8
McNary	Forebay	49.0	107.0	57.5	80.0	293.5
	Tailrace	23.3	108.3	63.0	79.0	273.5
	Total	72.3	215.3	120.5	159.0	567.0
	All sites	299.5	543.5	370.5	426.3	1,639.8

Table 2. Smallmouth bass catch, by disposition, for forebay and tailrace sites at each dam.

		First time captures				Recaptures		
Dam	**Side**	**Tagged and released**	**Hooking mortality**	**Released untagged**	**Removed**	**ID'd and released alive**	**Hooking mortality**	**Missing tag, tagged and released**
The Dalles	Forebay	93	2	2	0	33	0	1
	Tailrace	159	6	0	5	34	1	1
	Total	252	8	2	5	67	1	2
John Day	Forebay	305	23	2	0	45	2	0
	Tailrace	347	26	0	0	25	2	1
	Total	652	49	2	0	70	4	1
McNary	Forebay	107	7	0	1	7	0	0
	Tailrace	153	3	1	0	40	1	4
	Total	260	10	1	1	47	1	4
	All sites	1,164	67	5	6	184	6	7

Table 3. Non-target fish encountered during the May-August 2011 bass dam angling study.

	The Dalles		John Day		McNary		Grand
Species	**FB**	**TR**	**FB**	**TR**	**FB**	**TR**	**Total**
American shad	0	0	0	1	0	0	1
Bluegill	0	0	0	0	0	1	1
Channel catfish	0	0	0	0	0	1	1
Chinook jack	0	1	0	0	0	0	1
Chinook juvenile	1	0	0	1	1	0	3
Largemouth bass	0	0	0	0	1	4	5
Mountain whitefish	0	1	0	0	0	0	1
Northern pikeminnow	0	6	0	17	0	2	25
Sculpin	2	5	2	1	4	6	20
Steelhead	0	0	0	0	1	0	1
Walleye	0	3	0	2	0	17	22
All species	3	16	2	22	7	31	81

Table 4. Mean monthly catch per unit of effort (CPUE) of smallmouth bass by dam and side of dam.

		Catch per unit of effort (fish / angler h)				
Dam	**Side**	**May**	**June**	**July**	**August**	**Total**
The Dalles	Forebay	0.04	0.40	0.67	0.67	0.43
	Tailrace	0.09	0.70	0.86	1.05	0.69
	Total	0.07	0.54	0.77	0.86	0.56
John Day	Forebay	0.12	0.32	2.02	3.68	1.48
	Tailrace	1.72	2.36	1.86	1.26	1.84
	Total	0.69	1.26	1.93	2.56	1.65
McNary	Forebay	0.00	0.15	0.52	0.95	0.42
	Tailrace	0.09	0.46	1.13	1.00	0.74
	Total	0.03	0.31	0.84	0.97	0.57
	All sites	0.24	0.63	1.22	1.34	0.88

Table 5. Time-series ANOVA results for comparison of smallmouth bass catch per unit of effort (CPUE) and consumption indices across dams and sides of dams. Numerator degrees of freedom are 74 and 68 for CPUE and Consumption Index analyses, respectively.

Response	Effect	df	F	*P*-value
CPUE	Dam	2	3.7	0.029
	Side	1	0.1	0.717
	Dam*Side	2	0.0	0.963
Consumption Index	Dam	2	3.9	0.024
	Side	1	0.0	0.827
	Dam*Side	2	0.3	0.773

Table 6. Abundance estimates for smallmouth bass within the angling-accessible zone of The Dalles, John Day, and McNary dams, 2011 (LCB = lower 95% confidence bound, UCB = upper 95% confidence bound, CV = coefficient of variation).

Dam	Side	Population	LCB	UCB	CV
The Dalles	Forebay	192	153	260	14%
	Tailrace	511	389	700	15%
John Day	Forebay	1,056	832	1,377	13%
	Tailrace	2,601	1,799	3,850	20%
McNary	Forebay	927	467	1,979	39%
	Tailrace	361	290	470	12%

Table 7. Frequency of occurrence (i.e., no. samples with taxon / total no. samples) of fish taxa in smallmouth bass diets.

	JDA		**MCN**		**TDA**	
Category	**FB**	**TR**	**FB**	**TR**	**FB**	**TR**
Total sample	374	392	117	202	121	204
Empty	9	40	7	20	14	19
	(2.4%)	(10.2%)	(6.0%)	(9.9%)	(11.6%)	(9.3%)
Containing fish	87	113	37	94	16	54
	(23.3%)	(28.8%)	(31.6%)	(46.5%)	(13.2%)	(26.5%)
Catostomidae (suckers)	0	0	0	0	0	1
	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(0.5%)
Centrarchidae (sunfish)	0	0	1	1	0	1
	(0.0%)	(0.0%)	(0.9%)	(0.5%)	(0.0%)	(0.5%)
Clupeidae (shad)	0	0	0	0	0	0
	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(0.0%)
Cottidae (sculpin)	10	51	3	51	6	20
	(2.7%)	(13.0%)	(2.6%)	(25.2%)	(5.0%)	(9.8%)
Cyprinidae (minnows)	0	0	3	2	1	2
	(0.0%)	(0.0%)	(2.6%)	(1.0%)	(0.8%)	(1.0%)
Gasterosteidae (stickleback)	2	0	1	2	0	0
	(0.5%)	(0.0%)	(0.9%)	(1.0%)	(0.0%)	(0.0%)
Ictaluridae (catfish)	1	0	0	1	0	0
	(0.3%)	(0.0%)	(0.0%)	(0.5%)	(0.0%)	(0.0%)
Petromyzontidae (lamprey)	2	3	1	3	0	0
	(0.5%)	(0.8%)	(0.9%)	(1.5%)	(0.0%)	(0.0%)
Salmonidae (trout, salmon)	55	14	27	33	0	11
	(14.7%)	(3.6%)	(23.1%)	(16.3%)	(0.0%)	(5.4%)
Unidentified	9	24	3	13	0	12
	(2.4%)	(6.1%)	(2.6%)	(6.4%)	(0.0%)	(5.9%)
Other	0	1	1	0	0	0
	(0.0%)	(0.3%)	(0.9%)	(0.0%)	(0.0%)	(0.0%)

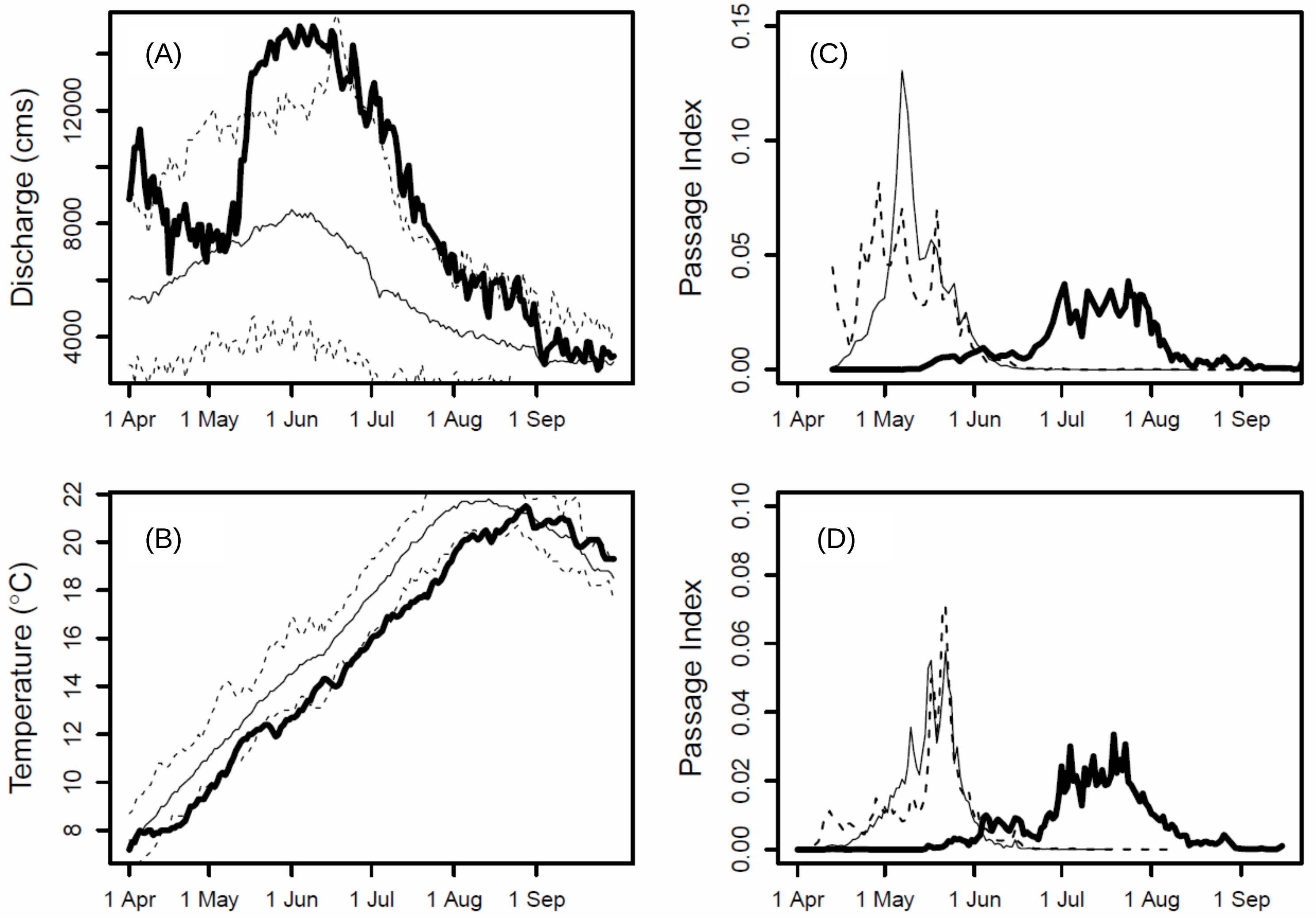


Figure 1. (A) Daily discharge (cubic meters per second) at The Dalles Dam (USGS station 14105700) during 2011 (thick solid line), and mean (+/- 95% quantiles, thin solid and dashed lines) values for the period extending from the end of major storage reservoir construction (Columbia Basin wide) to 2010. (B) Daily temperature at The Dalles Dam USGS station relative to the mean and range (thin solid and dashed lines) for its historical record (1997-2010). Passage index values (scaled to species-dam totals) for steelhead (thin dashed line), age-1 Chinook (thin solid line), and age-0 Chinook (thick solid line) for McNary (C) and John Day (D) dams.

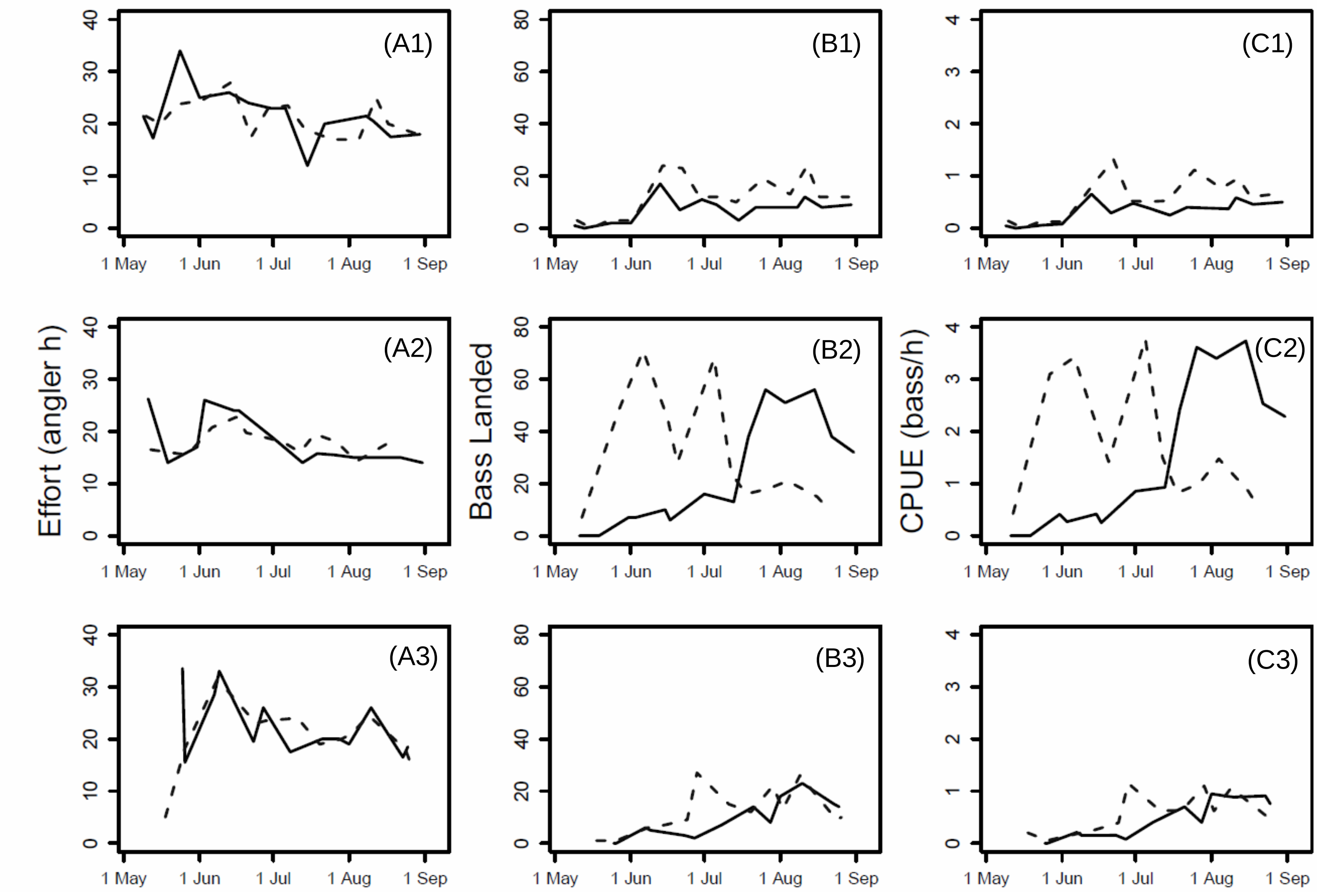


Figure 2. Effort (angler hours), catch, and CPUE (SMB / angler hour) by study site and sample day. Figures for each parameter are ordered column-wise (A = effort, B = catch, and C = CPUE) whereas dams are arranged by row (1 = The Dalles, 2 = John Day, and 3 = McNary; i.e., A1 = effort for The Dalles, A2 = effort for John Day, etc.). Tailrace values appear as dashed lines, whereas forebay values appear as solid lines.

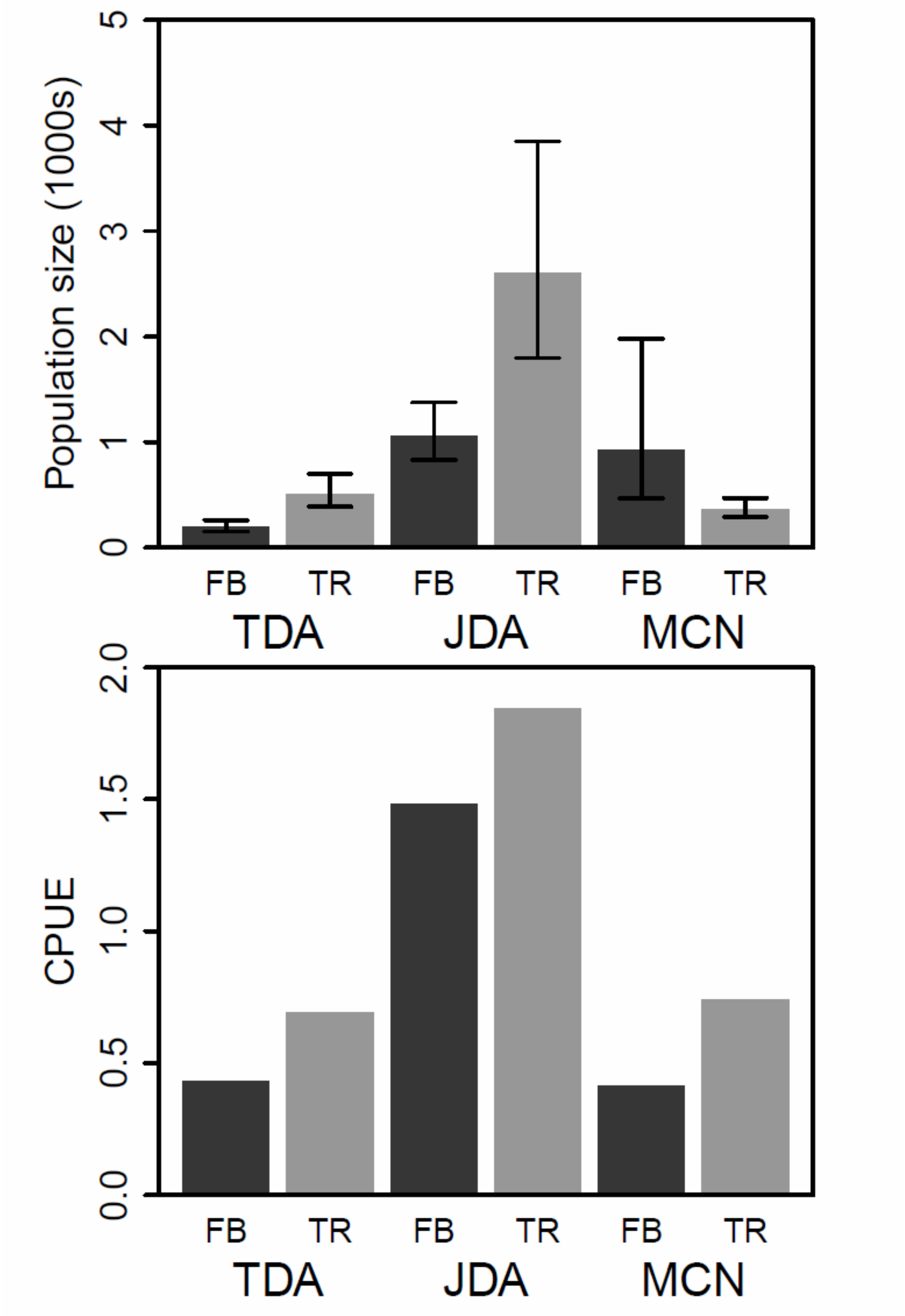


Figure 3. Bar chart of CPUE and population estimates by dam and side of dam. Displayed CPUE values are mean season-wide estimates; error bars around population estimates correspond to 95% upper and lower confidence bounds.

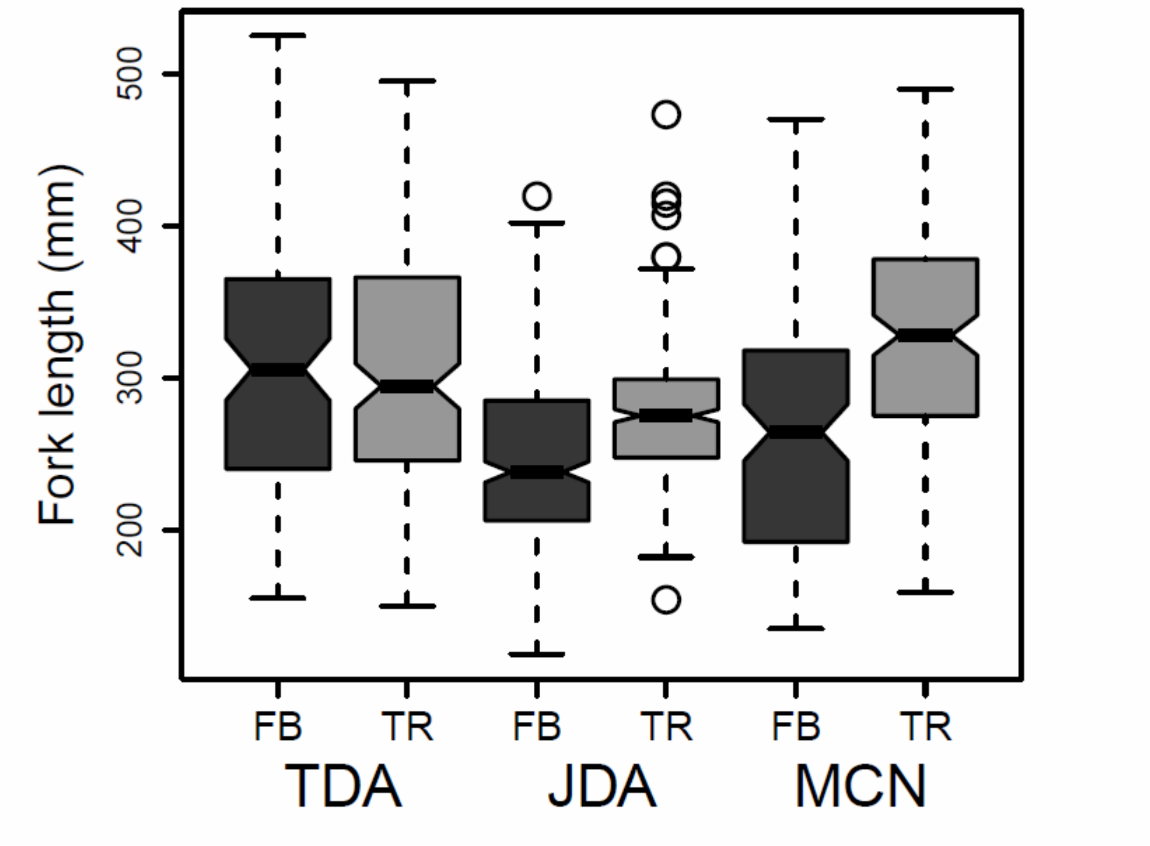


Figure 4. Box-and-whisker plots of fork length distributions for each site. Upper and lower box bound correspond to the first and third quartiles of the distributions, the center line corresponds to the median, the lower and upper whiskers are the 5^{th} and 95^{th} percentiles, and the circles are outliers. Note, the notch width (+/- 1.58 times inter-quartile range / $n^{0.5}$) approximates a 95% CI around the median; a lack of notch overlap between boxes approximates a statistically significant difference in distributions.

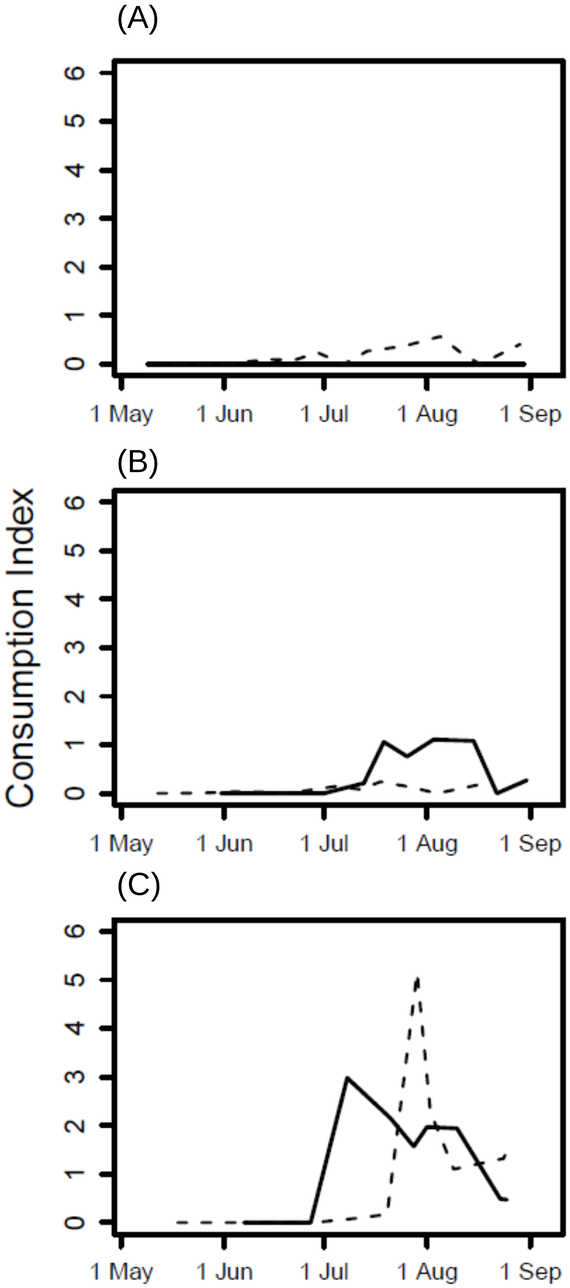


Figure 5. Consumption index values by study site and sample day for (A) The Dalles Dam, (B) John Day Dam, and (C) McNary Dam. Tailrace values appear as dashed lines, whereas forebay values appear as solid lines.

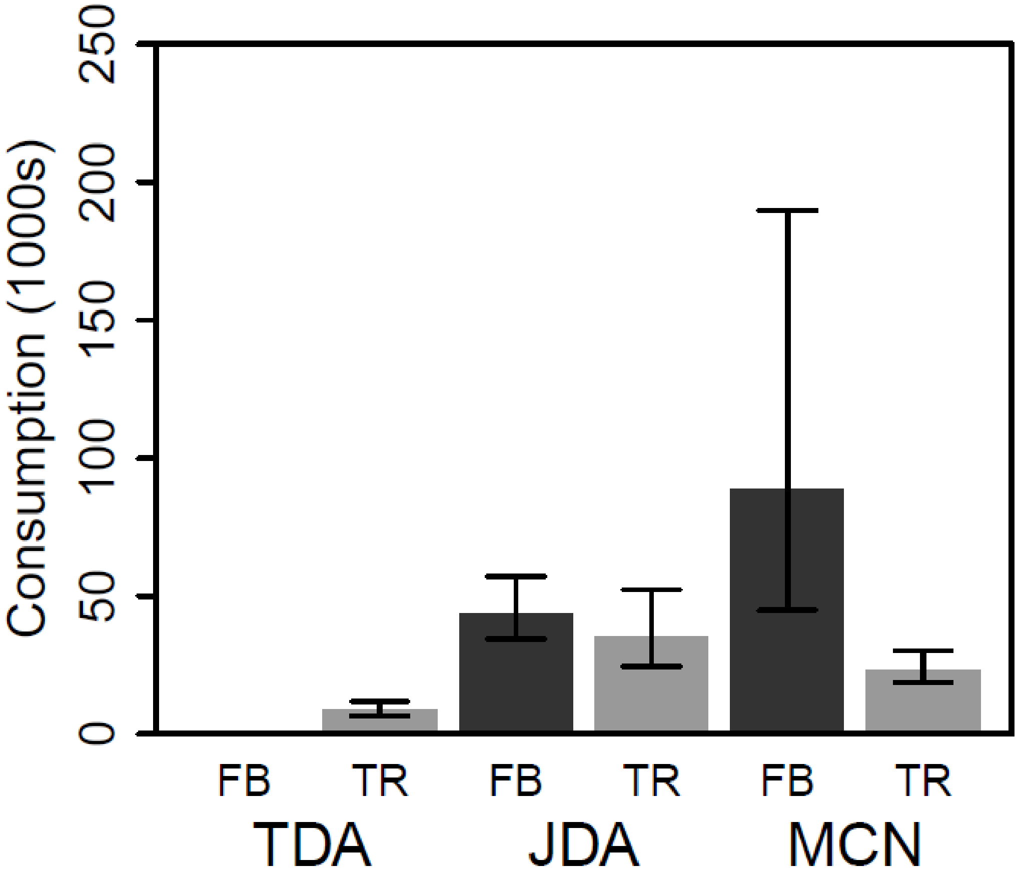
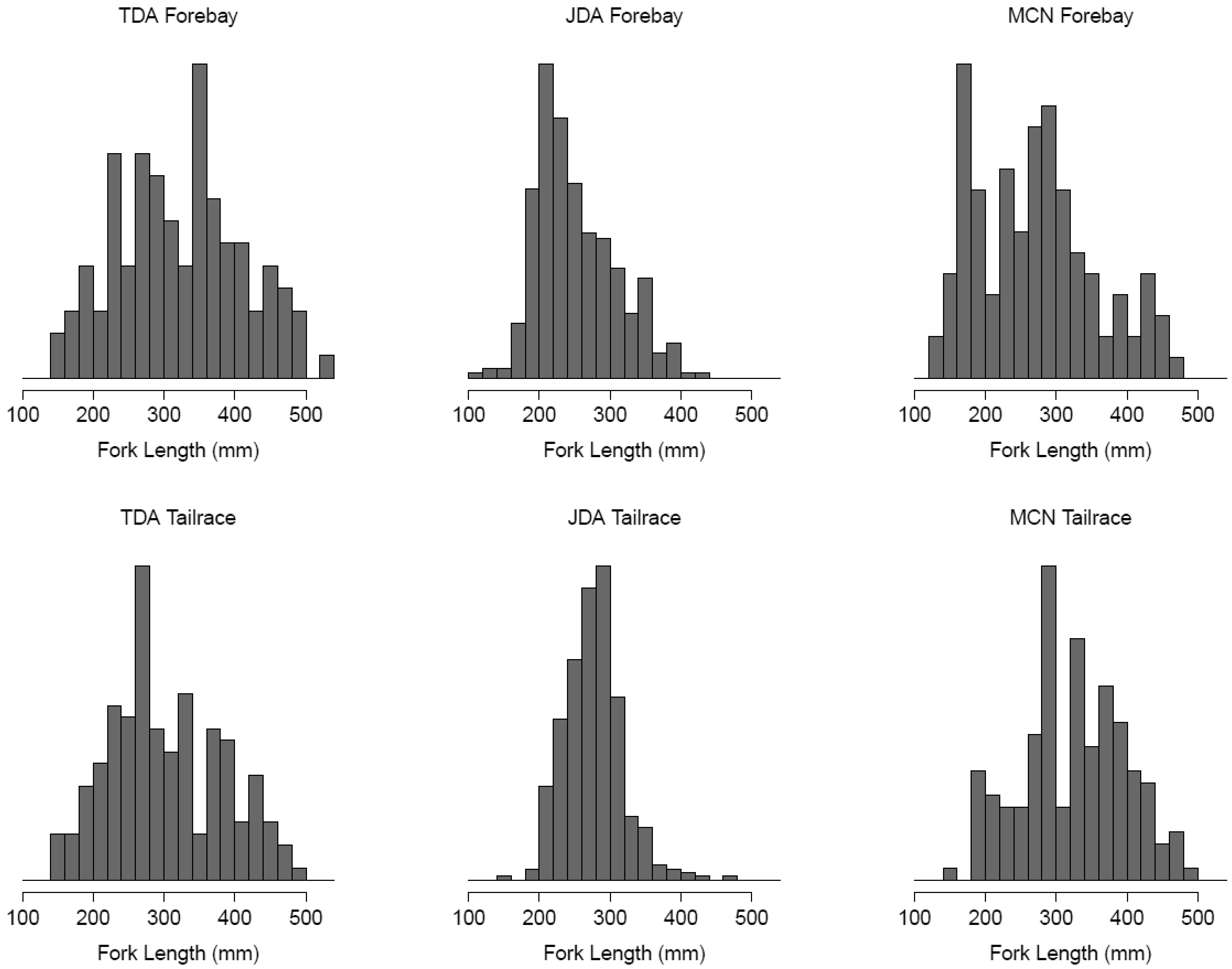


Figure 6. Estimated total consumption of salmonid juveniles by the population of bass within the angling-accessible area of The Dalles, John Day. and McNary dam forebay and tailrace areas. Note, error bars around totals correspond to consumption calculated at the 95% upper and lower confidence bounds of population estimates.

Appendix A. Length-frequency histograms for smallmouth bass caught at The Dalles (TDA), John Day (JDA), and McNary (MCN) dams, May-August 2011.



Appendix B. Composition (% wet mass) of smallmouth diets at The Dalles (A1 = forebay, A2 = tailrace), John Day (B1 = forebay, B2 = tailrace), and McNary (C1 = forebay, C2 = tailrace) dams during the 2011 sampling season.