Snake River Fall Chinook Salmon Life History Investigations

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Introduction

Predation by nonnative fishes is one factor that has been implicated in the decline of juvenile salmonids in the Pacific Northwest. Impoundment of much of the Snake and Columbia rivers has altered food webs and created habitat favorable for species such as Smallmouth Bass *Micropterus dolomieu*. Smallmouth Bass are common throughout the Columbia River basin and have become the most abundant predator in lower Snake River reservoirs (Zimmerman and Parker 1995). This is a concern for Snake River Fall Chinook Salmon *Oncorhynchus tshawytscha* (hereafter, subyearlings) that may be particularly vulnerable due to their relatively small size and because their main-stem rearing habitats often overlap or are in close proximity to habitats used by Smallmouth Bass (Curet 1993; Tabor et al. 1993).

Concern over juvenile salmon predation spawned a number of large-scale studies to quantify its effect in the late 1980s, 1990s, and early 2000s (Poe et al. 1991; Rieman et al. 1991; Vigg et al. 1991; Fritts and Pearsons 2004; Naughton et al. 2004). Smallmouth Bass predation represented 9% of total salmon consumption by predatory fishes in John Day Reservoir, Columbia River, from 1983 through 1986 (Rieman et al. 1991). In transitional habitat between the Hanford Reach of the Columbia River and McNary Reservoir, juvenile salmon (presumably subyearlings) were found in 65% of Smallmouth Bass (>200 mm) stomachs and comprised 59% of the diet by weight (Tabor et al. 1993). Within Lower Granite Reservoir on the Snake River, Naughton et al. (2004) showed that monthly consumption (based on weight) ranged from 5% in the upper reaches of the reservoir to 11% in the forebay. However, studies in the Snake River were conducted soon after Endangered Species Act (ESA) listing of Snake River Fall Chinook Salmon (NMFS 1992). During this time, Fall Chinook Salmon abundance was at an historic low, which may explain why consumption rates were relatively low compared to those from studies conducted in the Columbia and Yakima rivers where abundance was higher (e.g., Tabor et al. 1993; Fritts and Pearsons 2004).

We speculate that predation on subyearlings by Smallmouth Bass in the Snake River may have increased in recent years for several reasons. Since their ESA listing, recovery measures implemented for Snake River Fall Chinook salmon have resulted in a large increase in the juvenile population (Connor et al. 2013). Considering that subyearlings probably now make up a larger portion of the forage fish population, it is plausible they should make up a large portion of Smallmouth Bass diets. Second, migrating subyearlings delay downstream movement in the transition zones of the Clearwater River and Snake River for varying lengths of time (Tiffan et al. 2010), which increases their exposure and vulnerability to predators. Spatial overlap in locations of Smallmouth Bass and subyearlings that died during migration provides support for this (Tiffan et al. 2010). Finally, the later outmigration of subyearlings from the Clearwater River results in their presence in Lower Granite Reservoir during the warmest summer months when predation rates of Smallmouth Bass should be highest.

In 2016, we focused our efforts on Smallmouth Bass predation in Lower Granite Reservoir downstream of the transition zones and the confluence area where we worked during 2012–2015. Similar to past years, our first objective was to quantify Smallmouth Bass consumption rates of subyearlings, determine relative bass abundance, and describe bass diets. In addition, Tiffan et al. (2016a) posited that predation risk to subyearlings may be higher in shoreline habitats that are more suitable for Smallmouth Bass and lower in shoreline habitats that are more suitable for subyearlings. To test this hypothesis, our second objective examines the relationship between Smallmouth Bass predation of subyearlings and habitat suitability.

Methods

Study Area

We conducted our study in Lower Granite Reservoir, which is the first impoundment encountered by juvenile salmonids emigrating from the Snake and Clearwater Rivers. From 2012 to 2015, our predation research focused on the upper end of the reservoir where the river transitions from a free-flowing to impounded state. During 2016, our study area encompassed the lower 42 km of the reservoir from Lower Granite Dam (river kilometer [rkm] 173) to the Port of Wilma (rkm 215; Figure 1). We divided the reservoir into three equal reaches: lower (rkm 173–187), middle (rkm 187–201), and upper (rkm 201–215). This was done because Smallmouth Bass abundance and consumption can vary spatially (Beamesderfer and Rieman 1991; Petersen 1994), and the amount of subyearling habitat decreases with increasing proximity to the dam (Tiffan et al. 2016a).

Sampling methods

We used a stratified random design to plan our sampling of Smallmouth Bass in three different habitats types based on their suitability to subyearlings as identified by Tiffan et al. (2016a). We refer to the first habitat type as “suitable”, which comprised naturally occurring shorelines where the probability of subyearling presence was ≥0.5 based on the logistic regression model developed by Tiffan et al. (2016a). We used this probability cut-off point to define suitable rearing habitat for subyearlings. We refer to the second habitat type as “natural”, which also comprised naturally occurring shorelines. This habitat generally had steep lateral bed slopes and large talus substrate that made it unsuitable as subyearling rearing habitat because it’s associated probability was <0.5. The remainder of shorelines in our study area was comprised of “riprap”, which was also categorized as unsuitable for subyearling rearing based on the findings of Garland et al. (2002). Next, we used a GIS (ArcGIS, Redlands, California) to identify and measure the shoreline distance of each habitat patch and type in our study area. Transects were established within each habitat patch that varied from 100 m to 200 m in length. No transects

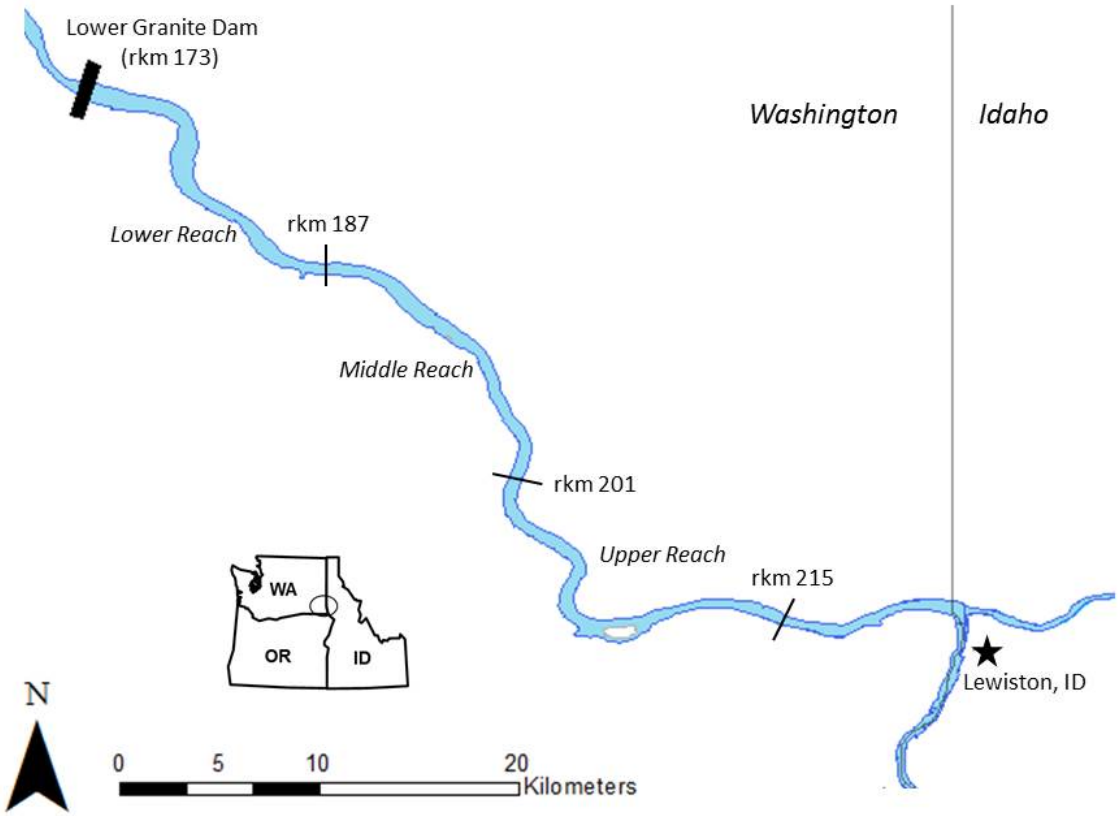

Figure 1. Lower Granite Reservoir on the Snake River and the three reaches that were sampled to evaluate Smallmouth Bass predation on subyearling fall Chinook Salmon in 2016.

were established in habitat patches that were <100 m. Finally, we randomly selected 16 transects in each reservoir reach during each sampling week (described below), without replacement, from the entire pool of 100–200-m transects. Transects were selected in proportion to the availability of shoreline habitat types in each reservoir reach (Table 1).

We collected Smallmouth Bass using nighttime electrofishing biweekly from April 25 to June 15, 2016. We used two electrofishing boats, each with one person as a dip netter. Electrofishing output was 400 V DC with 60 pulses per second at 2–4 amps. Sampling was typically conducted over three consecutive nights with one night being spent in each reach. Along each transect, all stunned Smallmouth Bass ≥150 mm TL were netted and placed in an aerated live well. We also estimated the number of subyearlings and Sand Rollers *Percopsis transmontana*—two of the most common prey of Smallmouth Bass (Erhardt et al. 2014). After completing each transect, we collected stomach contents from Smallmouth Bass using nonlethal lavage modified from Seaburg (1957) that removed 99.8% of diet items (Erhardt et al. 2014). The lavage instrument consisted of a ¼-in (0.635-cm) diameter tube connected to a common garden spray nozzle that supplied filtered river water via a wash-down pump installed on the boat. Stomach contents were collected in a 425-µm sieve and preserved in 90% ethanol.

Fish abundance

We tabulated the numbers of Smallmouth Bass collected and the numbers of subyearlings and Sand Rollers seen during electrofishing by sampling week, habitat, and reach. We expressed all CPUEs as the mean±SD number of fish collected or seen per 100 m of shoreline.

Dietary analysis

Smallmouth Bass diet items were identified to the lowest practical taxon, counted, blotted for 30 s, and weighed wet (±0.001 g). Ingested fish were usually identified to species using diagnostic bones (i.e., dentary, cleithrum, opercle; Parrish 2006). Bones were measured with an ocular micrometer mounted in a dissecting scope and used to back-calculate FL or SL at ingestion using species-specific bone-length regressions from the literature (Hansel et al. 1988) or from regressions we derived (Erhardt et al. 2014). We used additional regressions to calculate FL from standard, nape to tail, or dorsal standard lengths when necessary (Vigg et al. 1991; Parrish et al. 2006). Fish remains that did not contain diagnostic bones were classified as "unidentified" and were weighed. When a sample only contained unidentifiable fish parts along with a diagnostic bone, we associated all weight to the species identified. In the few instances when consumed salmonids could not be identified, they were assigned to the species of similar-sized salmonid species consumed during the same sampling interval.

We summarized the predominant diet items (percent by weight) of Smallmouth Bass by week, habitat, and reach. We also examined the length-frequency distribution of Chinook Salmon that were consumed by bass and identified subyearlings as being <120 mm FL based on our previous work with subyearlings.

Table 1. Sampling effort expended to collect Smallmouth Bass in different shoreline habitats in Lower Granite Reservoir during 2016. Sampling occurred during the weeks of April 25, May 9, May 31, and June 13.

Reach	Habitat	Total habitat length (m)	Percent of available habitat sampled	# 100–200-m transects sampled			
				Apr 25	May 9	May 31	Jun 13
Upper	Suitable	18,675	35.9	18	9	9	9
	Natural	5,053	38.1	7	2	2	2
	Riprap	13,796	37.8	2	5	5	3
Middle	Suitable	8,224	30.5	5	4	4	4
	Natural	8,806	36.6	5	5	5	5
	Riprap	13,415	40.4	8	7	7	7
Lower	Suitable	7,164	35.0	4	4	4	4
	Natural	12,291	30.4	7	6	6	5
	Riprap	12,492	36.2	6	6	6	6

Consumption rate

We calculated the consumption rate *C* (number of Chinook Salmon/Smallmouth Bass/day) in a series of steps similar to Fritts and Pearsons (2004). First, we calculated the original weight of each prey fish at ingestion for each bass by using length-weight regressions (Vigg et al. 1991; Parrish et al. 2006) with the back-calculated length at ingestion described above. These were summed with other diet items (if present) to derive a meal weight (*MW*) for each individual bass (Vigg et al. 1991). We accounted for a 21.3% weight loss (Shields and Carlson 1996) associated with preservation in ethanol for all diet items used in the calculation. Next, we input *MW* into an evacuation rate model of Smallmouth Bass digestion of salmonids developed by Rogers and Burley (1991) and modified by Fritts and Pearsons (2004) that predicts time (in hours) to 90% evacuation (E_{90}):

$$ET_{90} = (24.542)(MW^{0.29}e^{-0.15T}W^{-0.23})(24),$$

where *W* is bass weight (g; measured or estimated), and *T* is temperature. We used the mean daily temperature that was collected from data loggers from each bank near the center of each

reach. Finally, we calculated C for each individual bass using the equation presented by Ward et al. (1995):

$$C = n(24/ET_{90}),$$

where n is the number of Chinook Salmon found in the bass gut. C was averaged for each transect for all bass examined, including bass with empty stomachs (e.g., $C = 0.000$).

Results

Fish abundance

Smallmouth Bass CPUEs were highest in the lower reach and lowest in the upper reach of the reservoir during all sampling weeks (Figure 2). This generally held true across habitat types. CPUEs in shoreline habitats generally increased seasonally. In the lower reach, the catches of bass were generally higher in suitable habitat followed by natural habitat (with the exception of the week of May 9) and riprap habitat (Figure 2). In the middle reach, the catch of bass was highest during late May. In both middle and upper reaches, the catches of bass were generally lower in suitable habitat with the exception of during mid-June when they were highest in that habitat (Figure 2).

The mean sizes of Smallmouth Bass were similar between reaches within the same habitat type (Figure 3). Bass were generally larger in suitable habitat and smaller in riprap habitat (Figure 3).

Subyearling Chinook Salmon were present in 44% of suitable habitat, 35% of natural habitat, and 42% of riprap transects sampled throughout the study (Table 2). The catch of subyearlings in suitable habitat (means, 25–27 fish/100m) was about four to five times higher than the catch in natural (means, 5–7 fish/100 m) and riprap habitat (means, 5–6 fish/100 m) in the upper and middle reaches (Figure 4; Table 2). In the lower reach, subyearling catch in suitable habitat (mean, 15 fish/100 m) was about three to five times higher than the catch in the other habitats (means, 3–5 fish/100 m). The maximum numbers of subyearlings observed in suitable habitat were 160 fish/100 m in the upper reach, 86 fish/100 m in the middle reach, and 40 fish/100 m in the lower reach (Table 2). The maximum number of subyearlings observed in natural and riprap habitats never exceeded 25 fish/100 m in all reaches.

Sand Rollers were present in 86% of suitable habitat, 77% of natural habitat, and 82% of riprap transects sampled throughout the study (Table 2). The mean catch of Sand Rollers in the upper reach was nearly 800 fish/100 m in natural habitat (Figure 4; Table 2). Sand Roller catch was substantially lower in suitable habitat and declined from a mean of 253 fish/100 m in the upper reach to 62 fish/100 m in the lower reach (Figure 4; Table 2). Few Sand Rollers were observed in riprap habitat in all reaches and in natural habitat in the middle and lower reaches. The maximum numbers of Sand Rollers observed ranged from 10 to 5,701 fish/100 m in all habitats and reaches (Table 2).

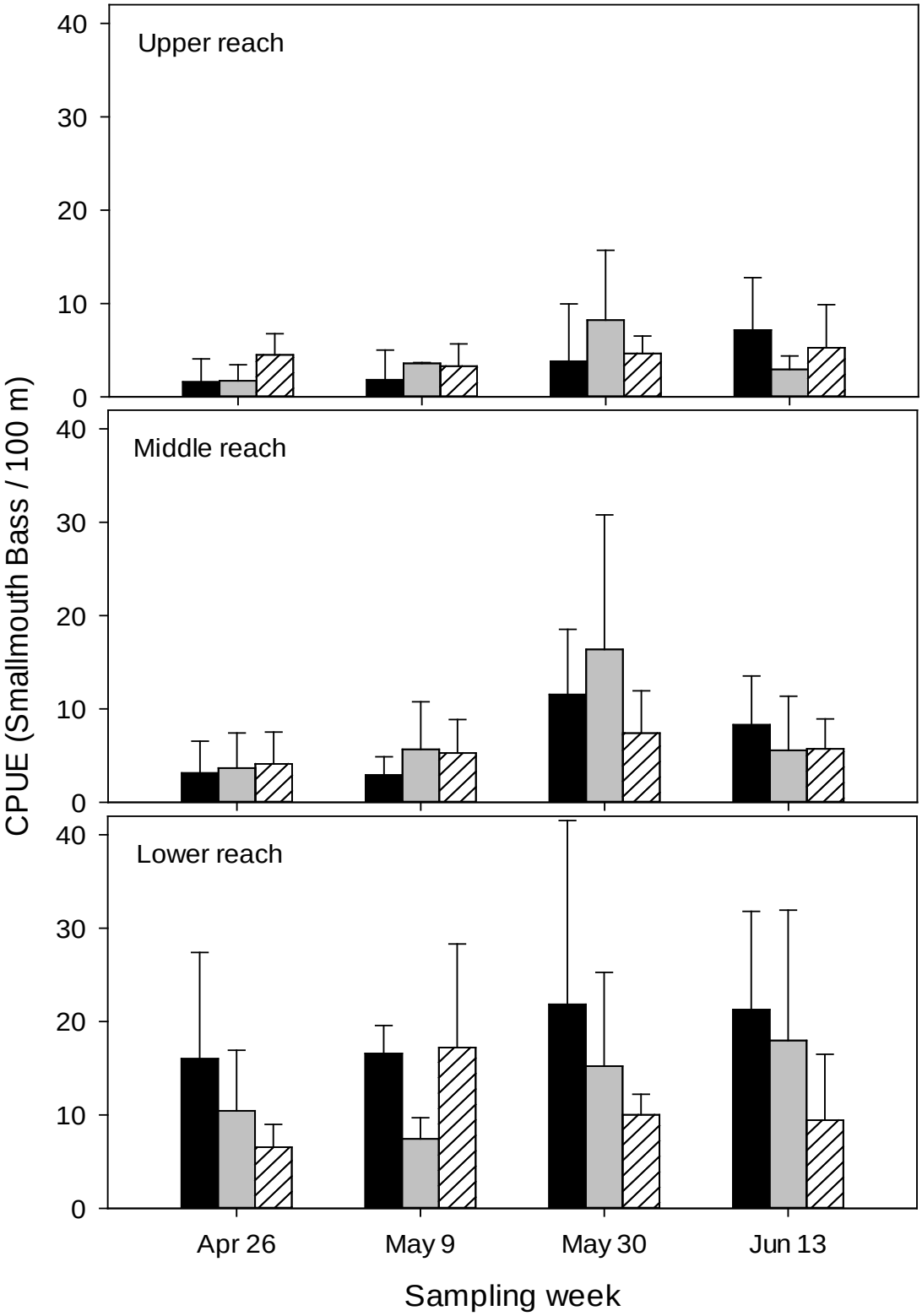
Upper reach
Middle reach
Lower reach
CPUE (Smallmouth Bass / 100 m)
0
10
20
30
40
Apr 26
May 9
May 30
Jun 13
Sampling week

Figure 2. Mean±SD electrofishing CPUE (Smallmouth Bass/100 m) by sampling week, habitat, and reach in Lower Granite Reservoir, 2016. Black bars represent "suitable" habitat, gray bars represent "natural" habitat, and hatched bars represent "riprap" habitat.

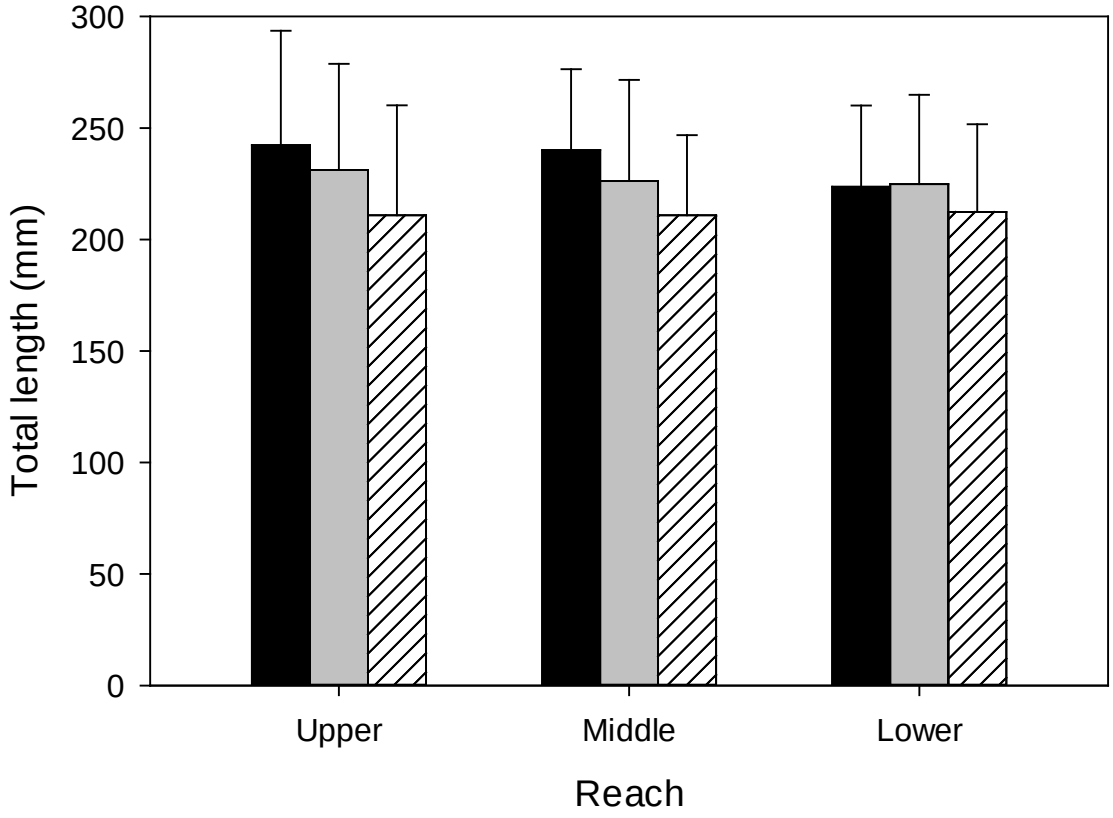

Figure 3. Mean±SD total lengths of Smallmouth Bass collected in "suitable" (black bars), "natural" (gray bars), and "riprap" (hatched bars) habitats for all weeks combined in Lower Granite Reservoir, 2016.

Table 2. Summary of catch of subyearling fall Chinook Salmon and Sand Rollers by reach and habitat type in Lower Granite Reservoir, 2016.

		Subyearlings				Sand Rollers			
Reach	Habitat	Number of transects with 0 catch	Number of transects with >0 catch	Catch (mean±SD, fish/100 m)	Catch (range, fish/100 m)	Number of transects with 0 catch	Number of transects with >0 catch	Catch (mean±SD, fish/100 m)	Catch (range, fish/100 m)
Upper	Suitable	23	22	27±38	1–160	5	40	253±480	2–2599
	Natural	8	5	7±5	1–15	2	11	796±1708	4–5701
	Riprap	6	9	5±6	1–10	1	14	24±36	1–157
Middle	Suitable	10	7	25±30	1–86	0	17	198±356	1–1335
	Natural	12	8	5±6	1–19	0	20	44±53	3–187
	Riprap	17	12	6±7	1–23	1	28	31±40	1–164
Lower	Suitable	11	5	15±15	5–40	6	10	62±99	6–288
	Natural	17	7	5±4	1–12	11	13	8±11	1–34
	Riprap	19	5	3±1	1–5	10	14	5±2	1–10

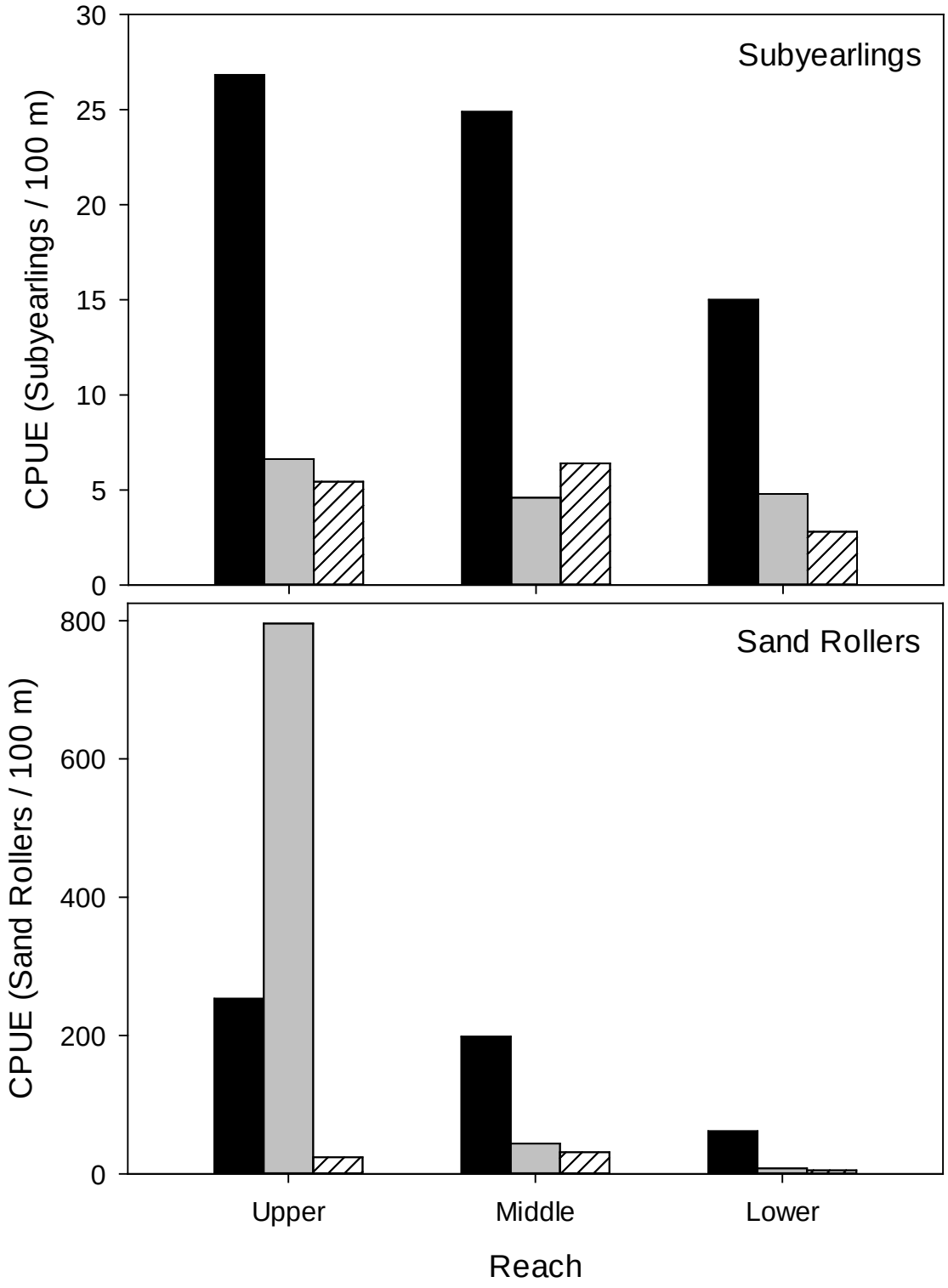

Figure 4. Mean CPUEs of subyearling Chinook Salmon (top panel) and Sand Rollers (bottom panel) in electrofishing transects that contained fish in different reaches in Lower Granite Reservoir, 2016. Black bars represent "suitable" habitat, gray bars represent "natural" habitat, and hatched bars represent "riprap" habitat.

Diet

Smallmouth Bass ate mainly fish and crustaceans, and the percentages in their diets varied by reach, habitat type, and sampling week (Figure 5). Length-frequency data suggested that most Chinook Salmon consumed were subyearlings (Figure 6). The percentages of subyearlings in bass diets were low during late April and early May but increased in late May and June in all reaches and habitats (Figure 5). The highest percentages of subyearlings in bass diets were 50% in riprap habitat in the upper reach in mid-June, 42% in natural habitat in the middle reach in late May, and 40% in suitable habitat in the lower reach in mid-June.

Sand Rollers were most prominent in the diets of Smallmouth Bass in the upper reach in late April and early May as well as in suitable habitat in the middle reach during the same time (Figure 5). Generally, Sand Rollers were not prevalent in the diets of bass in the middle and lower reaches with the exception of bass sampled in natural habitat in the lower reach during mid-June. Other predominant prey fish consumed by bass were Bluegill *Lepomis macrochirus*, Pumpkinseed *Lepomis gibbosus*, Black Crappie *Pomoxis nigromaculatus*, and juvenile Smallmouth Bass; but bass also ate catfish spp, Chiselmouth *Acrocheilus alutaceus*, Coho Salmon *O. kisutch*, sculpin spp., juvenile Largemouth Bass *Micropterus salmoides*, Northern Pikeminnow *Ptychocheilus oregonensis*, Peamouth *Mylocheilus caurinus*, and sucker spp. These fishes comprised the greatest percentages of bass diets during late April and early May in all reaches and habitats (Figure 5). After that, bass ate mainly subyearlings and Sand Rollers. Crayfish was the main crustacean consumed by bass of all sizes; however, the opossum shrimp *Neomysis mercedis* was prominent in the diets of smaller bass. Crayfish were eaten in all reaches and habitats, and at times they comprised the largest portion of bass diets (Figure 5).

Consumption

Smallmouth Bass consumption of subyearlings increased from 0–0.06 fish/bass/d during late April and early May to about 0.1–0.4 fish/bass/d during late May and mid-June (Figure 7). During late May, consumption of subyearlings was similar between habitats in the upper and middle reaches but highest in suitable habitat in the lower reach. During mid-June, bass in natural habitat in all reaches consumed subyearlings at the highest rates (Figure 7). The highest consumption rate was 0.43 fish/bass/d in natural habitat in the upper reach during mid-June. Some of the highest consumption of subyearlings in suitable habitat (0.16–0.21 fish/bass/d) occurred in the lower reach in late May and mid-June.

Smallmouth Bass consumption of Sand Rollers was highest in upper reach during all weeks and habitats, and ranged from about 0.1 to 0.2 fish/bass/d (Figure 8). Bass consumption of Sand Rollers decreased from the upper to lower reservoir, and generally increased seasonally within each reach. An exception to this occurred in suitable habitat in the middle reach during

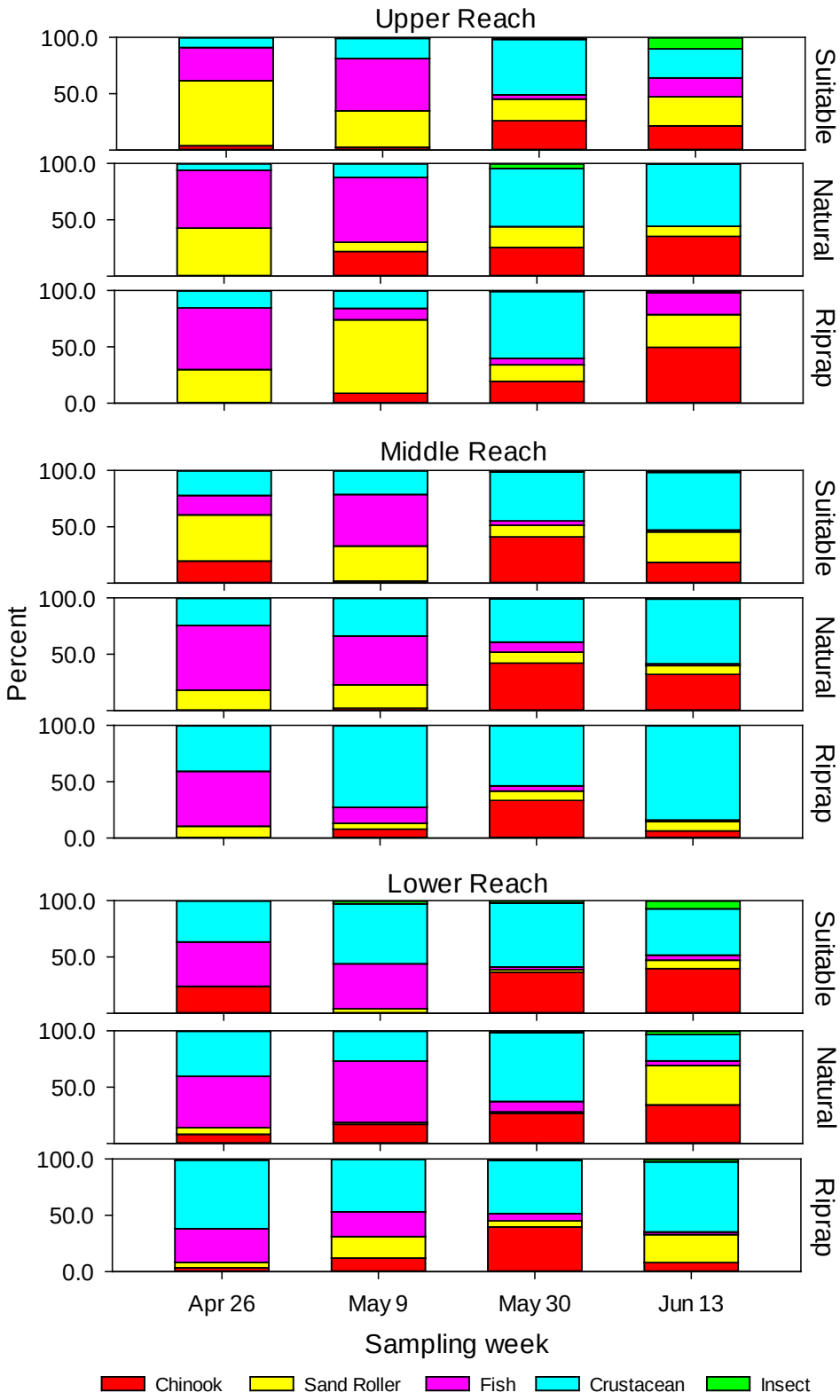

Figure 5. Percentage (by weight) of specific prey consumed by Smallmouth Bass in different reaches and habitats (shown at the right of each panel) in Lower Granite Reservoir during 2016.

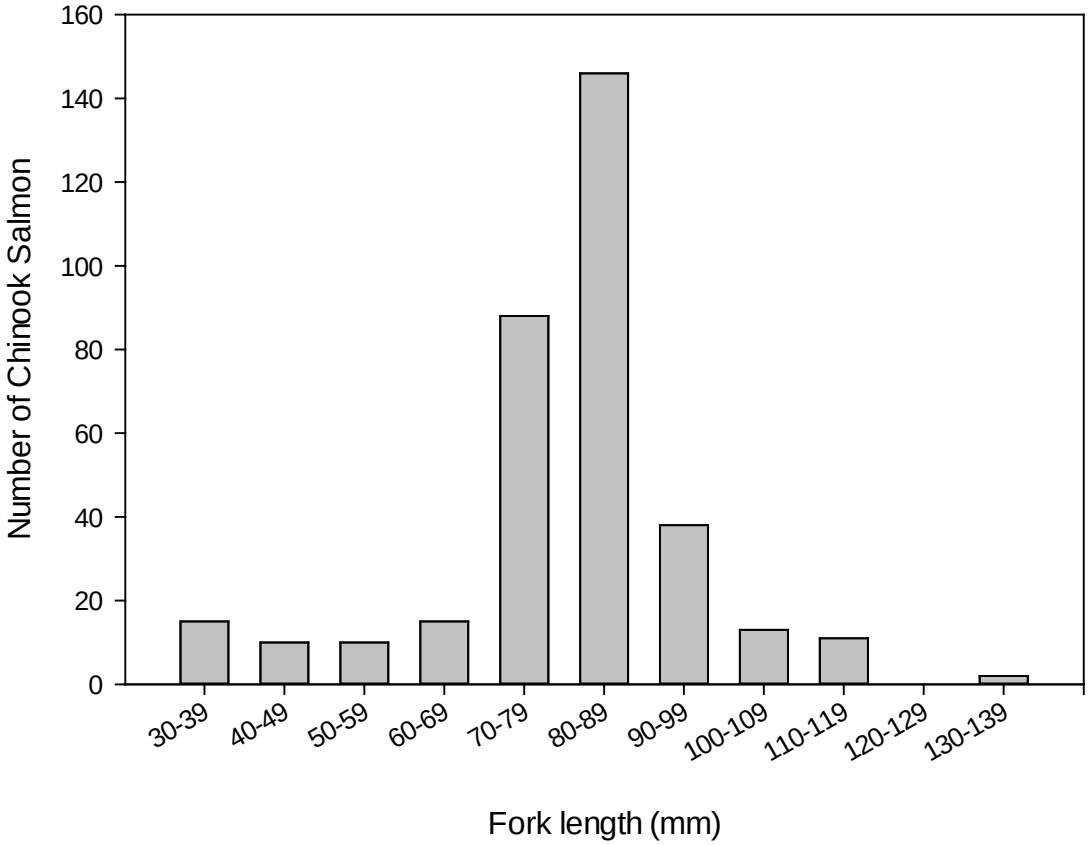

Figure 6. Length-frequency distribution of Chinook Salmon consumed by Smallmouth Bass in Lower Granite Reservoir during 2016.

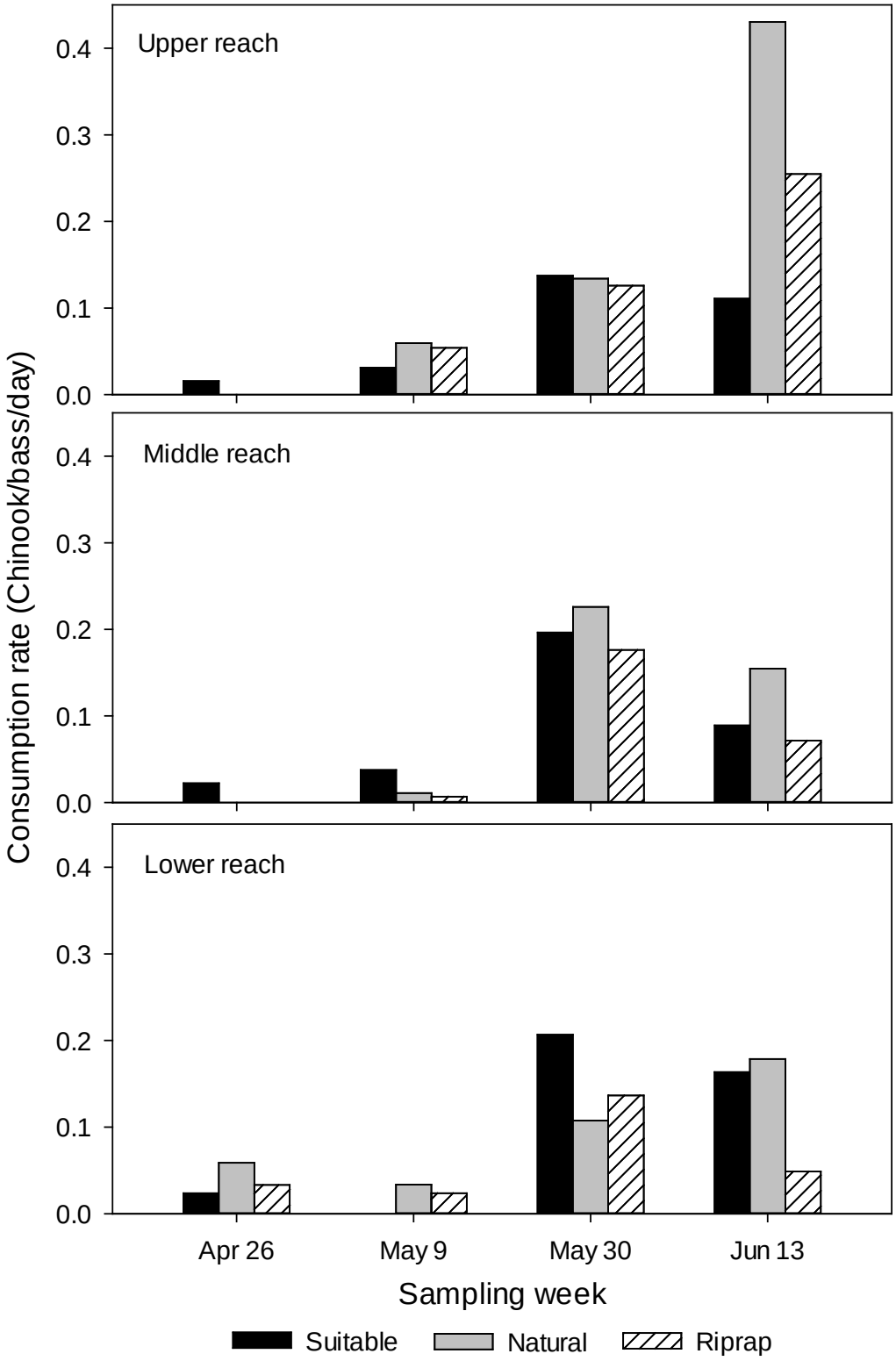

Figure 7. Consumption rate of Chinook Salmon by Smallmouth Bass in different reaches and habitats in Lower Granite Reservoir during 2016.

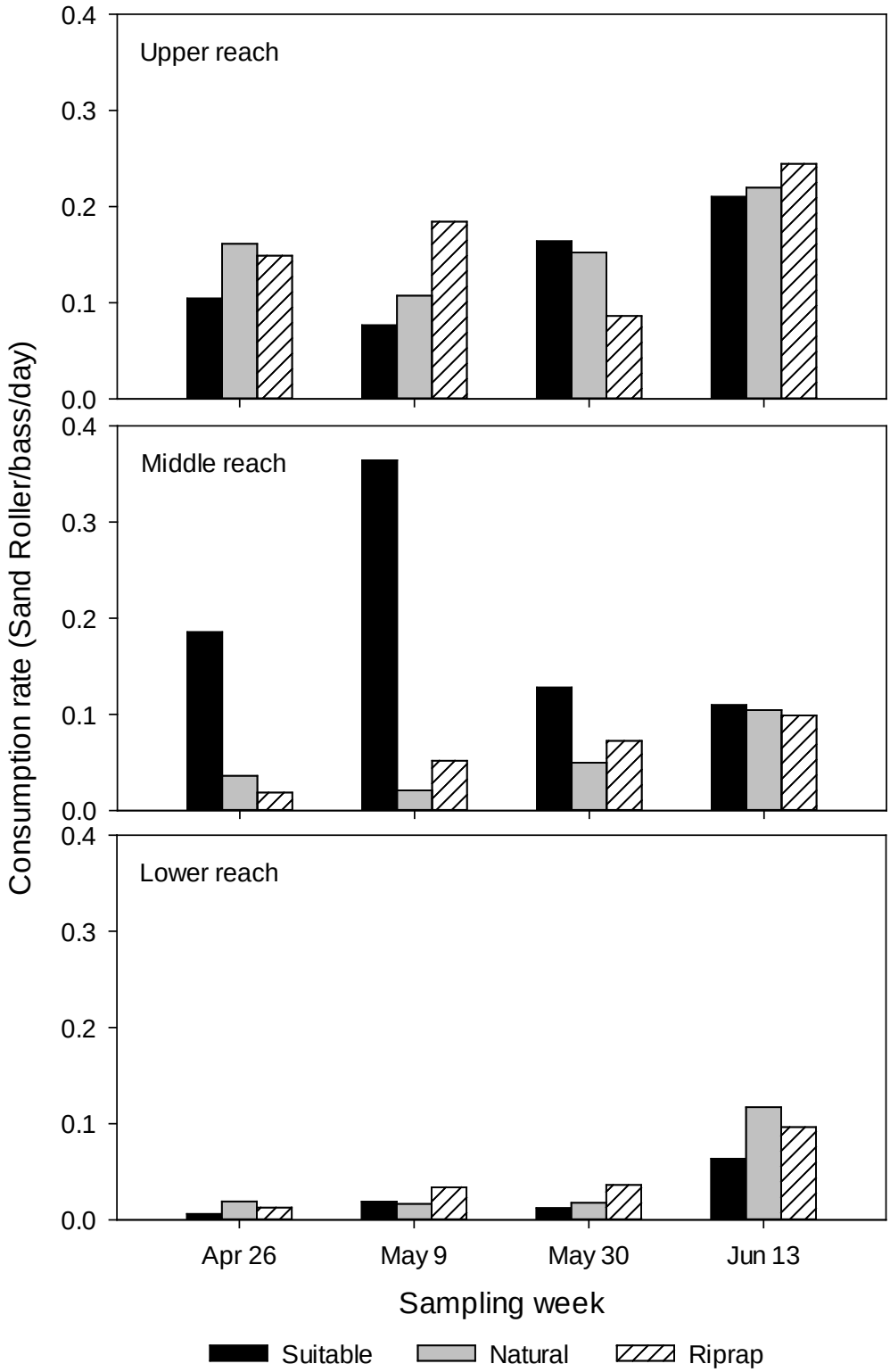

Figure 8. Consumption rate of Sand Rollers by Smallmouth Bass in different reaches and habitats in Lower Granite Reservoir during 2016.

late April and early May where consumption of Sand Rollers was some of the highest observed (means, 0.19–0.36 fish/bass/d; Figure 8). Consumption of Sand Rollers was comparatively low in the lower reach in all habitats and weeks particularly from late April through late May when consumption rates were <0.04 fish/bass/d.

Discussion

We found the highest Smallmouth Bass CPUEs in the lower reach of Lower Granite Reservoir which contrasts with the findings of Anglea (1997) and Naughton et al. (2004). These researchers found fewer bass in the lower portion of the reservoir than in the middle and upper portions. However, the overall bass abundances we observed in our study area were lower than bass abundances in transitional habitats in the Snake and Clearwater arms of the reservoir, which is consistent with the findings of Naughton et al. (2004). Tiffan et al. (2016b) reported shoreline catches of 25 to 48 bass/100 m in transitional habitats in the upper reservoir. By comparison, our catches were typically less than 20 bass/100 m in the lower reach and less than 10 bass/100 m in the middle and upper reaches.

The spatial differences in Smallmouth Bass abundance that we observed in the reservoir may be related to the nature and availability of habitat preferred by bass. The lower reach of the reservoir contained more riprap and natural habitat, which was characterized by steeper lateral bed slopes and larger substrates (Tiffan et al. 2016a). Smallmouth bass prefer larger substrates (Munther 1970; Todd and Rabeni 1989), which may explain their greater abundance in that part of the reservoir. In contrast, the upper reach contains the most shallow-water habitat and fine substrates in the reservoir and may explain the lower bass abundance there (Tiffan et al. 2016a).

Habitat differences within the reservoir may also explain some of the patterns we observed in Smallmouth Bass consumption of subyearlings. Habitat suitable for subyearling rearing is much reduced in the middle and lower reaches compared to the upper reservoir (Tiffan et al. 2016a). This is because these reaches lack the shallow-water habitat with low lateral bed slopes that subyearlings prefer (Tiffan et al. 2006). However, Smallmouth Bass also use this type of habitat for spawning. The general lack of suitable habitat that bass use for spawning coupled with greater bass abundance in the middle and lower reservoir may explain the higher consumptions rates of subyearlings in those parts of the reservoir where both prey and predators were concentrated. Conversely, subyearlings may have suffered less predation in suitable habitat in the upper reach because there was more habitat area to use and fewer bass.

The risk of Smallmouth Bass predation on subyearlings associated with different habitats in Lower Granite Reservoir is difficult to discern. We expected bass consumption of subyearlings to be relatively low in suitable habitat compared to natural and riprap habitat, but that was not always the case. As discussed above, this may relate to the availability of Smallmouth Bass spawning habitat. Bass may be more abundant during spawning in suitable

habitat which is why consumption may have been high that habitat. Bass spawning is probably limited in natural and riprap habitat, which may result in different habitat-related predation opportunities. The catch of subyearlings in natural and riprap habitat was always lower than in suitable habitat, but consumption rates were often high in those habitats, which suggests that predation risk may be higher in those habitats. However, in instances where bass consumption of subyearlings was low in less preferred habitat (e.g.., riprap, lower reach, mid-June), it is possible that subyearling abundance was so low as to never result in a very high bass consumption rate. However, higher bass abundance in such habitat may offset a lower consumption rate and thereby increase predation risk. Finally, although we collected bass from specific habitats, we do not know if they fed in those habitats. We assume that subyearlings were consumed by bass in the habitats from which they were collected, but this assumption was not tested.

The proportions of hatchery- and natural-origin subyearlings consumed by Smallmouth Bass probably varied throughout our study. The sampling we did in late April and early May occurred before the release of production subyearlings from upriver hatchery release points. Thus, the subyearlings consumed during those sampling weeks were likely of natural origin. By late May, over 2 million hatchery subyearlings had been released above our study area and many of the consumed fish were probably of hatchery origin, although natural-origin fish were likely consumed as well. Future research may allow us to partition consumed subyearlings into hatchery and natural origin with greater certainty.

Sand Rollers were less prominent in Smallmouth Bass diets in our study area than they were in transitional habitats located in the upper end of the reservoir (Tiffan et al. 2016b). Except in a few instances, Sand Rollers typically composed <25% of Smallmouth Bass diets in our study. By comparison, Sand Rollers often composed >50% of Smallmouth Bass diets in reaches above and below the Snake and Clearwater River confluence where some percentages exceeded 90% (Tiffan et al. 2016b). The greater bass consumption of Sand Rollers in the upper reach of the reservoir may be related to their greater abundance there as they used shallow habitats for spawning. We also found a greater diversity and higher percentages of other prey fish in Smallmouth Bass diets in our study area than in upriver transitional habitats. Many of these fish were centrarchids. As hypothesized by Tiffan et al. (2016b), non-salmonid prey fish may be helping to relieve predation pressure on subyearlings fall Chinook salmon in the reservoir.

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