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Quillfish *Ptilichthys goodei*, Filiform Prey for Small Coho and Chinook Salmon

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ABSTRACT: Juvenile quillfish *Ptilichthys goodei* were identified in the stomachs of nine juvenile coho *Oncorhynchus kisutch* and two juvenile Chinook *O. tshawytscha* salmon captured in marine waters of Southeast Alaska in June and July of 1999 and 2000. These extremely elongate prey were nearly as long (maximum 82.3%, mean 65.2%) as their salmon predators, providing the highest prey-predator length ratio reported for juvenile Pacific salmon. Despite this disproportionately high length ratio, however, the mean weight of quillfish consumed per salmon (0.287 g) represented only 35.4% of the total stomach content weight, or 0.5% (range 0.02–1.76%) of the salmon's total body weight. While prey length is clearly an important metric for determining which prey a predator will potentially consume, this study emphasizes that it is not the only determinant.

INTRODUCTION

Coho *Oncorhynchus kisutch* and Chinook *O. tshawytscha* salmon are opportunistic, visual predators (Beacham 1986, Brodeur 1991). In marine environments, diets of both species are dominated by larval and juvenile fishes, with the remainder of the diet typically consisting of crustaceans, such as euphausiids, hyperiid amphipods, and decapod larvae (Brodeur and Pearcy 1990, Landingham et al. 1998, King and Beamish 2000). While Chinook salmon tend to be more piscivorous than coho salmon in marine environments, diet overlap between the two species is typically quite high (Beacham 1986, Brodeur and Pearcy 1990, Landingham et al. 1998).

The quillfish *Ptilichthys goodei* is an extremely elongate demersal species distributed to 360 m depth along the nearshore shelf of the North Pacific, from the Sea of Japan to Oregon, including the Bering Sea (approx. 42°N to 66°N; Richardson and DeHart 1975, Dokolovskaya and Sokolovskiy 1995, Mecklenburg et al. 2002). Adults (up to 390 mm standard length) are thought to spawn in spring because larvae and juveniles are observed during summer. Many larvae and juvenile collections have occurred at night near surface with the use of bright lights, suggesting a pelagic life stage (Chapman and DeLacy 1933, Walker 1953, Clemens and Wilby 1961). By contrast, adults are thought to burrow in soft substrates (Masuda et al. 1984, Dokolovskaya and Sokolovskiy 1995).

Quillfish have been reported from the stomachs of Pacific cod *Gadus macrocephalus* captured in Bering Sea and around the Kamchatka Peninsula. Pacific cod forage in soft bottom sediments for invertebrate prey, where they likely encountered the quillfish (Dokolovskaya and Sokolovskiy 1995). Quillfish were also reported from the stomach of a coho salmon caught off the west coast of Vancouver Island (Clemens and Wilby 1961), and more recently (1997 and 1999) from the stomachs of two maturing Chinook salmon caught in Southeast Alaska (J. Orsi and M. Sturdevant, National Marine Fisheries Service, Juneau, personal communication). However, extensive studies of coho and Chinook salmon diets within the geographic range of quillfish (e.g., Brodeur and Pearcy 1990, Landingham et al. 1998, King and Beamish 2000, Schabetsberger et al. 2003) do not report quillfish as salmon prey, despite their easily recognizable body shape, indicating these predation events are rare.

Here, I describe quillfish identified in the stomachs of juvenile salmon captured in marine waters of Southeast Alaska. These prey were longer, relative to the predator size, than has been previously reported for juvenile Pacific salmon. While biologically interesting in itself, this observation also serves as an important reminder that what determines potential prey is a

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complex set of factors, of which prey length is only one element.

METHODS

Juvenile coho and Chinook salmon were collected monthly from June to September of 1997–2000 in marine waters of the northern region of Southeast Alaska as part of Southeast Alaska Coastal Monitoring (SECM) project (Orsi et al. 2000). Juvenile salmon were sampled during daylight with a rope trawl (18 m deep × 24 m wide) towed at the surface at 1.5 m/sec to collect fish in surface waters. All collected fish were identified, enumerated, and measured to the nearest 1 mm, and a subset of juvenile salmon were euthanized with MS-222, individually tagged, bagged, and immediately frozen.

In the laboratory, thawed fish were measured (fork length [FL, mm] and weight [g]), and up to 10 fish from each station and date were randomly selected for stomach content analysis. The stomachs of fish were extracted, fixed in 10% buffered formalin, and then later transferred to 70% ethanol. Prey items in the stomachs were identified to a general taxonomic category or to species and weighed to the nearest 0.001 g to provide prey biomass estimates. The total lengths (TL) of intact prey were measured for comparison to predator length (i.e., juvenile coho and Chinook salmon). Prey length was also expressed as the proportion of predator length. No attempt was made to correct for preservation shrinkage of prey items.

RESULTS

Juvenile quillfish were identified from the stomachs of nine coho and two Chinook salmon juveniles captured in June and July of 1999 and 2000 in marine waters of Southeast Alaska (Table 1). The mean size of the coho salmon (170.1 mm FL, 63.4 g) was slightly smaller than that of Chinook salmon (196.0 mm FL, 107.7 g). Each juvenile salmon had an average of 2.8 quillfish in its stomach. Juvenile coho and Chinook salmon with quillfish in their stomachs represent 17.0% and 18.2% of the 53 coho and 11 Chinook caught in 7 tows for which stomach content analysis was performed. This is 1.7% and 1.0%, respectively, of the 519 coho and 206 Chinook from 225 tows over four years (1997–2000) and 20 stations that were analyzed for stomach content analysis as part of a larger study (Weitkamp 2004).

A total of 14 whole quillfish were identified in the juvenile salmon stomachs, in addition to pieces that were not possible to assign to an individual quillfish. The mean size of these whole fish was 111.0 mm TL (range 80.2–122.6 mm) and 0.151 g (range 0.043–0.279 g; Table 1). The maximum diameter of quillfish averaged 1.8 mm (range 1.6–2.1 mm). The

Table 1. Information on the capture date, location, and size of coho and Chinook salmon and their quillfish prey. Coho numbers 1–3 were caught together in the same haul, as were coho 5–6, and 7–8; the latter two groups were caught in consecutive hauls. Quillfish lengths and prey-predator length ratios were only calculated for whole quillfish.

					Quillfish					
Fish No.	Capture Date	Capture location[a]	Salmon length (mm)	Salmon wt. (g)	No. of Quillfish	Mean length (mm) (*St. dev.*)	Max. length (mm)	Total wt. (g)	Quillfish as % salmon wt.	Quillfish as % stomach wt.
Chinook salmon										
1	24 July 1999	Taku R.	171	57.1	2[b]	–	–	0.106	0.19	41.7
2	20 July 2000	Icy Strait B	221	158.2	3[c]	119 (*5.2*)	123	0.372	0.24	24.0
Coho salmon										
1	26 June 1999	Taku R.	136	28.3	1[b]	–	–	0.148	0.52	64.1
2	26 June 1999	Taku R.	149	38.4	1	110	110	0.120	0.31	18.6
3	26 June 1999	Taku R.	146	36.4	4[c]	116 (*0.1*)	120	0.642	1.76	97.4
4	26 June 1999	False Pt. Retreat	139	29.2	1[b]	–	–	0.072	0.25	13.5
5	27 July 1999	Icy Strait C	187	71.1	5[c]	120 (*0.2*)	122	0.563	0.79	38.5
6	27 July 1999	Icy Strait C	194	90.8	6[d]	120 (*1.3*)	122	0.841	0.93	43.9
7	27 July 1999	Icy Strait D	221	113.5	3[b]	–	–	0.043	0.04	10.4
8	27 July 1999	Icy Strait D	213	123.6	1[b]	–	–	0.025	0.02	2.9
9	30 June 2000	U Chat. Strait D	146	39.2	4[d]	98 (*17.5*)	118	0.220	0.56	34.4

[a] Station locations are: Taku River mouth: 58° 11.19′ N, 134° 11.71′ W; False Point Retreat: 58° 22.00′ N, 135° 00.00′ W; Icy Strait B: 58° 14.22′ N, 135° 29.26′ W; Icy Strait C: 58° 15.28′ N, 135° 26.65′ W; Icy Strait D: 58° 16.38′ N, 135° 23.98′ W; Upper Chatham Strait D: 58° 9.63′ N, 135° 2.05′ W.

[b] No identified quillfish were whole, so total lengths were not measured.

[c] Only two fish were whole and could be measured.

[d] Only three fish were whole and could be measured.

total weight of quillfish in the stomachs of coho and Chinook averaged 0.297 g and 0.239 g, respectively, equivalent to 0.58% and 0.21% of the salmon's body total weight or 36.0% and 32.9% of the total stomach content weight, respectively (Table 1).

The ratio between prey (quillfish) and predator (juvenile salmon) lengths averaged 0.652, with a maximum value of 0.823 (Fig. 1). This ratio was significantly higher than the ratio for other larval and juvenile fishes (e.g., Pacific sand lance *Ammodytes hexapterus*, capelin *Mallotus villosus*, Pacific herring *Clupea harengus*, Walleye pollock *Theragra chalcogramma*, flatfishes *Pleuronectidae*) identified in the stomachs of juvenile coho and Chinook salmon for the broader study (mean = 0.186, Mann-Whitney statistic, $U = 3522$, $p < 0.05$, d.f. = 398; Weitkamp 2004).

Juvenile coho and Chinook salmon consume a variety of "elongate" piscine prey, including Pacific sand lance, capelin, Northern anchovy Engraulis mordax, and Pacific herring (Beacham 1986, Brodeur and Pearcy 1990, Landingham et al. 1998). To explore how filiform quillfish are relative to these other elongate prey, the length-weight relationships for quillfish were compared to those for Pacific sand lance. In the larger study of juvenile salmon diets (Weitkamp 2004), this species had the second highest prey-predator length ratio after quillfish (mean 0.261, maximum 0.479, n = 52), and were also the second longest prey species after quillfish (mean 58 mm, maximum 103 mm; L. Weitkamp, unpublished data). Eight quillfish found in juvenile salmon stomachs averaged 120 mm long (range 115.3–122.6 mm) and weighed an average of 0.182 g (range 0.109–0.278 g). By comparison, using Robards et al.'s (2002) Pacific sand lance length-weight ratios, a 120 mm Pacific sand lance would weigh between 5.0 and 6.9 g, or 28 to 38 times more than a quillfish of comparable length. Clearly, quillfish are exceptionally thin and elongate prey.

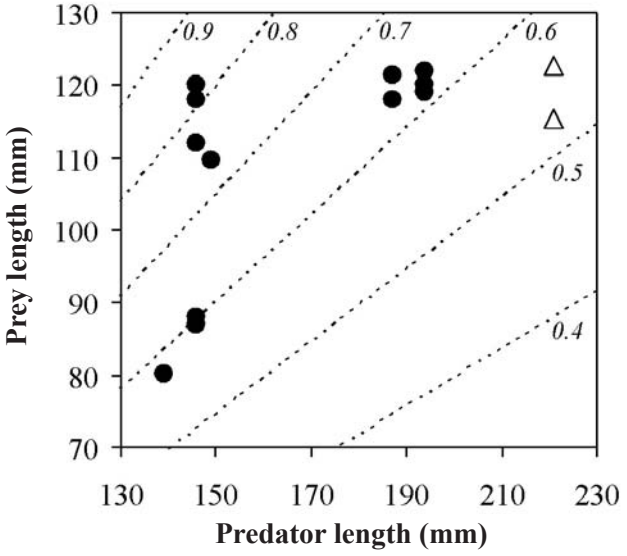

Figure 1. Length of juvenile coho (solid circles) and Chinook (open triangles) salmon predators and their quillfish prey. Isopleths of prey–predator length ratios are indicated.

DISCUSSION

A variety of factors influence fish predatory behavior, including prey availability (e.g., visibility, size, location, abundance, escape response), past predator experience, predation risk, and nutritional status of both predators and prey (Hyatt 1979, Higgs et al. 1995). A number of studies have examined the maximum size of piscine prey that salmonids, including Chinook and coho salmon, consume (e.g., Parker 1971; Hargreaves and LeBrasseur 1985, 1986; Damsgård 1995). The results of these studies suggest that under ideal (captive) conditions, salmonids will consume prey that are 40% to 51% of their body length. However, the size of prey consumed in the wild is typically much smaller than this maximum, from 15% to 37% of their body length (Damsgård 1995, Pearsons and Fritts 1999, Keeley and Grant 2001). Although these findings are salmonid-specific, other piscivorous fishes display a similar pattern of consuming smaller fish than they are capable of, and ingesting prey that are 20% to 30% of their length (Popova 1978, Juanes 1994, Mittlebach and Persson 1998).

The quillfish reported here were an average of 65.2% (maximum 82.3%) of the body length of the juvenile coho and Chinook salmon that consumed them. By comparison, the most extensive analysis to date of juvenile Chinook and coho salmon diets ($n > 1{,}000$ for each species) in marine waters off Washington and Oregon, Brodeur (1991) provided maximum prey sizes of 55% and 44% of predator lengths for coho and Chinook salmon, respectively, with mean values typically between 14% and 23% (depending on prey species and predator size). Hargreaves and LeBrasseur (1986) stated that yearling coho salmon were capable of consuming salmon fry that were 75% of their length, although whether this assertion was based on actual observation or estimation is unclear. Pearsons and Fritts (1999) observed that captive juvenile coho salmon would attack lures up to 64% of their length, although the prey they consumed were considerably smaller. Obviously, quillfish are exceptionally long prey for juvenile salmon, even under ideal conditions.

Salmon, like other piscivorous fishes, are gape-limited predators (Mittelbach and Persson 1998). Using length–gape relationships for relatively small-mouthed salmonid, Arctic Charr *Salvelinus alpinus* (Damsgård 1995), the smallest juvenile salmon reported here (136 mm) would have a gape of 5.1 mm, over twice as wide as the maximum quillfish width measured (2.1 mm). This suggests even the smallest salmon could fit several quillfish into its mouth at once.

Similarly, prey volume does not appear to be a limiting factor, despite the challenges of fitting such elongate prey into relatively short salmon stomachs. For example, quillfish only provided an average of one third of coho and Chinook stomach contents by weight, and one individual (coho 3) was able to consume nearly 1.8% of its body weight in quillfish (Table 1). Furthermore, maximum stomach fullness (expressed as percent body weight) observed in the larger study was 9.1% and 6.6% for juvenile coho and Chinook salmon, respectively (Weitkamp 2004), indicating these juvenile salmon are capable of greatly expanding their stomachs when necessary.

The fact that juvenile Chinook and coho salmon consumed these extremely long prey suggests that other factors, such as prey behavior or escape response, had greater influence on their predation success than prey length, gape limitations, or stomach capacity. The behavior of prey in response to predator attacks is a significant determinant of whether the prey is successfully eaten or not (Ivlev 1961, Pitcher and Wyche 1983, Savitz and Bardygula-Nonn 1997). With its extremely elongate and narrow body, it is unlikely that quillfish are capable of either fast escape speeds or abrupt changes in direction that would facilitate their escape from attacking salmon. In addition, they may be more fragile when physically attacked than fish species typically consumed by juvenile salmon. These factors apparently make quillfish vulnerable to predation despite their unusually long relative length. Accordingly, while prey length is clearly an important metric for determining the size of prey that a predator may consume, using prey length to predict vulnerability includes assumptions about prey body shape and ignores the multitude of factors, in addition to prey length, that determine successful predation events.

With regards to the quillfish, they appear to be relatively common in Southeast Alaska, compared to other parts of their range (e.g., off the Oregon coast, Richardson and DeHart 1975). For example, quillfish have been reported in Fredrick Sound (56°50′N, 134°25′W), approximately 120 km south of the SECM study area (Quast and Hall 1972). Quillfish have also been recovered in the SECM study three times in addition to those found in juvenile salmon stomachs: a quillfish was caught in the trawl in 1997 (Orsi et al. 2000), and quillfish were identified in the stomachs of two maturing Chinook salmon caught in the study, mentioned earlier. The reoccurrence of quillfish in Southeast Alaska suggests the area may prove valuable for directed research on this little-studied species.

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