Predation-based Mortality on Juvenile Salmon in the Strait of Georgia

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Predation is considered to be the mechanism that causes the mortality regulating the abundance of salmon, and was the biological mechanism that Ricker (1954) proposed was responsible for the shape of his recruitment curve. However, Ricker proposed that the density-related impact of predation occurred in fresh water. In the ocean, it is known that the mortality is large and is believed to occur very early after salmon enter the ocean. There are a small number of studies that support this belief, but careful review of these studies also shows that substantial marine mortality occurs after this initial period and that total mortality is variable (Parker 1968).

In this study we attempted to identify the key predators of three species of Pacific salmon in the Strait of Georgia. We identify spiny dogfish (*Squalus acanthias*) and river lamprey (*Lampetra ayresi*) as the major predators of ocean age-0 salmon. We use an ECOPATH mass-balance food web model (Christensen and Pauly 1992) to study the relative important of juvenile salmon in the diets of other potential predators.

Surveys using sunken gill nets were conducted during the spring through winter months of 1998 to 1991 to study spiny dogfish predation. The total number of identifiable juvenile salmon in their guts from all years of the study was 115 chinook, 78 coho, and 7 pink and/or chum. The percentage of dogfish feeding on salmon ranged from 0.8% to 11.9% among years. The abundance of spiny dogfish in the study area ranged from 298,000 in 1990 to 1.4 million in 1988. In 1988, an estimated 7.7 million (or 100% of the release) of chinook and coho salmon were killed by spiny dogfish within 4 weeks. In 1989, 1990, and 1991 the estimated mortality was 0.2 million, 0.1 million and 0.2 million, respectively. The abundance of dogfish and the percent incidence of salmon in dogfish stomachs declined in July.

Surveys for river lamprey were conducted in the Fraser River plume and adjacent waters using a surface trawl (Beamish and Neville 1995). The abundance of river lamprey in the Fraser River plume in 1990 and 1991 was 3.0 and 3.9 million, respectively. In 1990, lamprey fed on herring (19%), chinook (13%), and coho (16%). Using an average of 20% salmon in the diet (Beamish and Neville 1995) and an average of 65 prey killed (Beamish and Williams 1976), we estimated that 20 million chinook, 15 million chum, and 2 million coho were killed in 1990. In 1991, 18 million chinook and 10 million each of chum and coho salmon were killed by river lamprey. This predation amounted to 13% of all coho hatchery production from Strait of Georgia hatcheries in 1990 and 65% of all coho production in 1991.

Trawl sets (616) were conducted throughout the Strait of Georgia in 1998 and 1999 (Table 1). Only two of the potential predators of salmon were found to contain juvenile salmon remains. We also examined the impact of

Table 1. Numbers of potential predators by species and depth caught in mid-water trawl nets during surveys in 1998 and 1999.

	Depth (m)	Pacific hake	Spiny dogfish	Chinook salmon [a]	Coho salmon [a]	Lingcod	Walleye pollock	Wolfeel	Rockfish
1998	0–14	3	251	158	26	3	2	9	0
(372 sets)	15–29	2	108	54	2	0	4	5	0
	30–44	39	759	39	1	0	68	2	0
	45–59	0	141	10	0	0	13	1	0
	60+	10,824	1125	20	2	0	445	0	0
1999	0–14	257	413	54	9	1	207	5	0
(244 sets)	15–29	43	41	25	1	0	15	0	0
	30–44	1504	47	7	0	0	246	0	0
	45–59	39	394	8	0	0	25	0	0
	60+	13,768	42,768	6	0	0	326	0	0

[a] Numbers of coho and chinook are for ocean age-1+ fish only.

potential predators using an ECOPATH mass-balance food web model of the Strait of Georgia. This model indicated that the functional groups were at the expected trophic levels (Fig. 1). In the model, juvenile salmon accounted for 20% of the diet of river lamprey and 11% of the diet of dogfish. The percentage of salmon in the diet of other predators was lower (Table 2). We examined the impact of increasing juvenile salmon consumption percentages in the small pelagics (27 species) and miscellaneous demersal (103 species) groups to 5%. For the small pelagics, the change would require a production of 104,000 t of juvenile salmon or approximately 10.4 billion individuals. For the miscellaneous demersal fish category the increase would require a production of juvenile salmon of 116,000 t or 11.6 billion individuals. Our estimates of coho, chinook and chum production from the Fraser River and other rivers entering the Strait of Georgia in 1990 and 1991 was189 million and 296 million juveniles, respectively (Beamish and Neville 1995). Therefore, the production of 10.4–11.6 billion juveniles required to support an increase of salmon in the diet of small pelagics or miscellaneous demersal fish is impossible because only a fraction of this amount of smolts was actually produced.

Fig. 1. Trophic relationships from the ECOPATH mass-balance food web model of the Strait of Georgia. Solid lines indicate that a prey composes 25% or more of function group's diet. Dotted lines indicate that a prey composes 20-25% of functional group's diet.

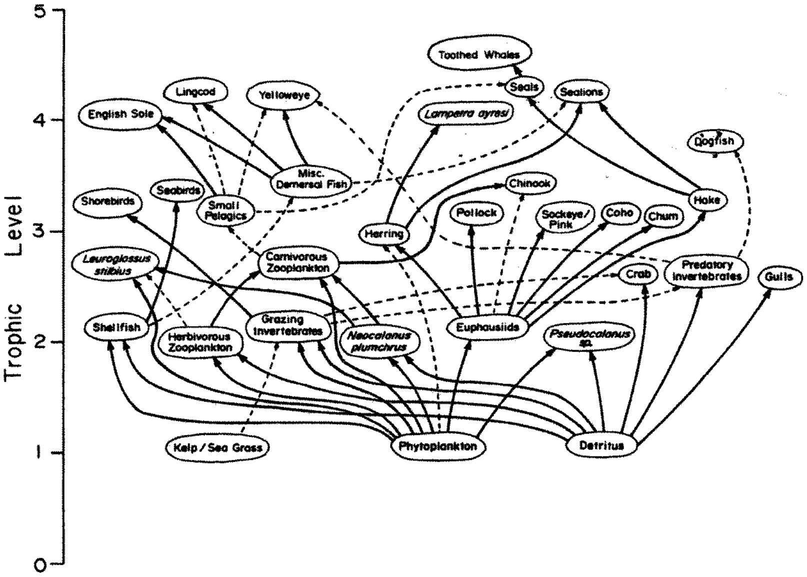

Table 2. Estimated tonnes consumed and percent incidence of salmon in the diet of predators in the Strait of Georgia ECOPATH mass-balance food web model. Percent incidence less than 0.1% is highlighted with an asterisk. In these cases there may be predation below 0.1%. However, this cannot be tested in our current model and using a predation rate of 0.1% resulted in more salmon being consumed than could be supported.

Predators	Chum (t)	%Chum	Coho (t)	%Coho	Chinook (t)	%Chinook	Sockeye/ Pink (t)	%Sockeye/ Pink
Shorebirds	62	2.0					62	2.0
Small pelagics		< 0.1*		< 0.1*		< 0.1*		< 0.1*
River lamprey	59	5.3	56	5.1	56	5.1	50	4.5
Seabirds	11	0.1	34	0.3	34	0.3	11	0.1
Gulls	26	1.0	3	0.1	3	0.1	3	0.1
Misc. demersal		< 0.1*		< 0.1*		< 0.1*		< 0.1*
Pink/sockeye								
Coho	552	1.0	110	0.2	55	0.1	55	0.1
Chinook	690	1.0	138	0.2	138	0.2	345	0.5
Toothed whales [a]								
Hake	265	0.1		< 0.1*	265	0.1	0	0.0
Dogfish	145	0.5	1449	5.0	1449	5.0	145	0.5
Lingcod	97	2.0	97	2.0	5	0.1	5	0.1
Sealions[a]								
Seals[a]								
Total consumed	1,907		1,887		2,005		676	

[a] These predators feed primarily on adult salmon.

These studies identified river lamprey and spiny dogfish as the major fish predators of juvenile salmon in the early marine period. However, both these predators reduce their feeding on salmon by late summer. Our surveys show that there are relatively few other potential predators. The variability in predation mortality, the incidental nature of salmon as prey, the decline in salmon in diets by mid-summer, the low amount of salmon in the total annual consumption of potential predators, and the scarcity of potential predators in our catch indicates that early marine mortality is probably not the only mechanism that regulates the numbers that return. This conclusion is consistent with some of the first studies of marine mortality that showed that 2–4% mortality occurred daily in the first 40 days, but 0.4–0.8% occurred daily after this period (approximately 410 days) (Parker 1968). We interpret the results of our study to indicate that the predation-based concept for the natural regulation of adult salmon abundance is more complex than previously thought. Therefore, we propose that there are two distinct mortalities. We call these mortalities an early marine mortality and a carrying capacity mortality. These mortalities combine to produce the total natural mortality; Early marine mortality (EM_m) + Carrying capacity mortality (CC_m) = Total mortality (T_m).

Both EM_m and CC_m could operate at the same time but the impact of one could diminish as the other predominates. Predation-based mortality may be the dominant early marine mortality while growth may be more associated with carrying capacity mortality. The carrying capacity mortality is the linkage to climate change. Partitioning the impact of mortalities facilitates the understanding of the natural regulatory process and provides a theory to assess the impact of climate. Holling (1965) improved our understanding of the predation process by separating the numerical responses (more predators arrive to feed) from the functional response (one predator eats more prey). The hypothesis of two distinct mortalities is an idea that needs to be tested, but it is an idea that we think is a timely contribution to the developing concern of managing salmon in a changing climate.

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