BODY SIZE AND LEARNED AVOIDANCE AS FACTORS AFFECTING PREDATION ON COHO SALMON, *ONCORHYNCHUS KISUTCH*, FRY BY TORRENT SCULPIN, *COTTUS RHOTHEUS*

Wild coho salmon juveniles, *Oncorhynchus kisutch,* in Washington streams range in fork length (FL) from about 30 mm at the time of emergence from the gravel to 120 mm on migration to the sea. Predation by sculpins, *Cottus* spp., is limited to the smaller salmon; few salmon >45 mm FL have been recovered from the stomachs of sculpins (Patten 1962, 1971a, 1972). Yet, sculpins are capable of eating hatchery reared fall chinook salmon, *O. tshawytscha,* of 60 mm FL (Patten 1971a). Apparently, the reason sculpins do not normally prey on wild coho salmon >45 mm FL is not entirely dependent on the relative sizes of prey and predator.

The present study is on the ability of torrent sculpin, *C. rhotheus,* to prey on coho salmon >45 mm FL, as well as the predator avoidance behavior of coho salmon to torrent sculpins in stream aquaria adjacent to the Cedar River near Ravensdale, Wash., during 1965 and 1966. One experiment indicates the absolute size of coho salmon that can be caught, subdued, and swallowed by a torrent sculpin of a given length. The other suggests that coho salmon previously exposed to torrent sculpins become less susceptible to these predators in future interactions.

Facilities and Procedures

Two related studies—one on predator-prey size relations and the other on the learned predator avoidance ability of coho salmon prey—were conducted in stream and holding aquaria that received water from the Cedar River. The two stream aquaria were 2.4 m long, 0.6 m wide, and 0.6 m high; water depth ranged from 2 to 18 cm. The eight holding aquaria were 34 cm wide, 41 cm long, and 36 cm high; water depth was 18 cm (a more complete description of the experimental facilities is given by Patten 1971b).

Water was gravity fed from a low level dam on the Cedar River to a head box through a flume and then to the aquaria. Each aquarium received a continuous supply of clear water; temperatures in the morning during the study ranged from 4.4° to 12°C.

Torrent sculpins were collected by electrofishing in Soos Creek, King County, Wash., and coho salmon were seined in upper Rock Creek of the Cedar River drainage. It was assumed that the state of hunger of all torrent sculpins was similar, that the coho salmon had little experience with fish predators, and that this experience was similar for all subjects. The assumption for the coho salmon was probably valid because the only other common species of fish at the seining site was the shorthead sculpin, *C. confusus*—a relatively nonpredaceous species of fish (unpubl. studies of author). Furthermore, the few individuals of the shorthead sculpin observed were small.

The effect of predator-prey length relations on predation was determined from 23 tests where six coho salmon of a given length group were available to four torrent sculpins of a given length group (Table 1) for 4 days. The test procedure was to collect torrent sculpins the first day and place them in a holding aquarium without food; on the second day, coho salmon were collected and six individuals within 5 mm of a given length were placed in a holding aquarium; on the third day, four torrent sculpins within 5 mm of a given length were introduced into the holding aquarium containing the coho salmon; 4 days later, the number of coho salmon eaten was recorded and the experimental fish were discarded. The largest available size group of torrent sculpins used was 120 mm total length (TL).

TABLE 1.—Results of 23 tests where six coho salmon of a length group were subjected to predation by four torrent sculpins of a length group. Predation on one or more coho salmon is denoted by P and no predation by N.

Total length of sculpin (mm)	Fork length of salmon (mm)						
	40	50	60	70	80	90	100
60	–	P	N	–	–	–	–
80	P	P	P	N	–	–	–
80	–	P	N	–	–	–	–
100	–	–	P	P	N	–	–
100	–	–	P	N	–	–	–
100	–	–	–	N	–	–	–
120	–	–	P	P	P	N	N
120	–	–	–	–	N	N	N
120	–	–	–	–	P	–	–

The ability of coho salmon to learn to evade predation was tested by comparing the relative survival of naive coho salmon (those which had not been exposed to torrent sculpin predators) with coho salmon conditioned to predation by the torrent sculpin. Coho salmon were conditioned by placing 20 individuals into a stream aquarium with eight torrent sculpins. Some of those that had survived a 48-h association with torrent sculpins

were maintained in holding aquaria without torrent sculpins for 24 h before being subjected to predation in test conditions. Two types of test groups, each consisting of 20 coho salmon (per stream aquarium), were used. In the naive group, all coho salmon were naive; in the naive and conditioned group, 10 naive and 10 conditioned fish were tested together.

The procedure for testing naive coho salmon was to collect torrent sculpins and place them in holding aquaria without food; on the second day, coho salmon were collected and 20 individuals, 37 to 42 mm FL, were placed in each stream aquarium; on the third day, 10 torrent sculpins, 83 to 127 mm TL, where lengths averaged about 100 mm per test group, were transferred from the holding aquarium to each stream aquarium. Forty-eight hours later, the surviving coho salmon were counted and experimental fish were discarded.

The procedure for testing the naive and conditioned group of coho salmon was similar to the foregoing test procedure except that on the second day, 10 naive coho salmon were collected and placed in each stream aquarium with 10 conditioned coho salmon. The tip of a ventral fin of the conditioned coho salmon was clipped at the time they were introduced into the stream aquarium to allow them to be recognized at the end of the test. Thus, if there was an adverse effect from clipping, it would be on the group with the greater expected survival. Eight replicate tests were made on each of the two conditions.

Length Relation

The experimental procedure placed the coho salmon in close proximity to torrent sculpins for a prolonged period to enhance the possibility of predation. Torrent sculpins responded to this opportunity by preying on larger coho salmon than has been observed in nature (Table 1). The maximum size of coho salmon a torrent sculpin is capable of preying upon is probably limited by the physical size of a coho salmon that a torrent sculpin can catch, subdue, and swallow. While the swimming ability is probably greater for larger coho salmon, this may not be too important because predation by torrent sculpins is accomplished by ambush rather than by pursuit. Torrent sculpins under natural conditions rarely eat coho salmon 40 to 80 mm FL, indicating that some factor of coho salmon behavior must decrease their susceptibility to predation.

The average survival of the naive group consisting only of naive fish was 45.5%; within the naive and conditioned group, consisting of conditioned and naive coho salmon tested together, the naive fish had a 71% survival, and the conditioned coho salmon had a 75% survival. Cumulative chi-square tests of homogeneity showed no significant differences within the naive test group or within the naive and conditioned group (Table 2). The Z test showed no significant difference between the conditioned and naive coho salmon that were tested together ($Z_{P0.05} = +0.53 < 1.645$). There was, however, a significant difference between the group consisting of naive coho salmon only and the group consisting of naive plus conditioned coho salmon ($Z_{P0.05} = +5.29 > 1.645$).

Mortalities of coho salmon were significantly reduced by conditioning; also, naive fish tested with conditioned fish behaved as conditioned fish. The results of these tests are probably due to rapid conditioning of the coho salmon and a transferable predator avoidance reaction. Rapid conditioning was evident because conditioning of fish to a stimulus other than predators is usually accomplished only after many trials. Conditioning coho salmon to evade predation by exposing them to torrent sculpins probably reinforces a strong innate avoidance behavior. In another case, rapid conditioning of sockeye salmon, *O. nerka,* to evade predation by rainbow trout, *Salmo gairdneri,* has been demonstrated by Ginetz and Larkin (1976). Experiments by Russians have shown that certain fishes, including the chum salmon, *O. keta,* increased their ability to evade predation after a 2- to 4-day training period with predators (Kanid'yev et al. 1970).

TABLE 2.—Comparative survival of two groups of coho salmon that were exposed to predation by the torrent sculpin. One group consisted of naive fish only and the other consisted of naive and conditioned coho salmon combined. The initial number of coho salmon per group per stream aquarium was 20.

Naive group		Naive and conditioned group			
		Naive		Conditioned	
No. of fish	Survivors	No. of fish	Survivors	No. of fish	Survivors
20	6	10	7	10	9
20	12	10	9	10	10
20	12	10	6	10	6
20	7	10	7	10	9
20	8	10	5	10	8
20	10	10	7	10	6
20	12	10	9	10	7
20	6	10	7	10	5

A transferable predator avoidance reaction may account for the conditioned and naive coho salmon acting as a homogeneous group in the present study. Conditioned coho salmon had learned to avoid torrent sculpins through some unknown mechanism. Apparently the naive fish behaved as conditioned individuals through visual clues resulting in mimicry. O'Connell (1960) noted mimicry in sardines in a conditioned response experiment where unconditioned replacement fish performed in unison with the school of conditioned fish from the first trial. Kanid'yev et al. (1970) indicated that the consensus of Russian workers was that sight played the main role in developing the predator avoidance reaction and that reinforcement is maximal for fish that are observers.

Sculpins commonly cohabit streams with and prey on young salmon. Growth of salmon to a size too large for sculpins to successfully prey on effectively removes them from this predator predation. The maximum size of coho salmon that a torrent sculpin can catch and eat in laboratory conditions is much larger than those that are normally preyed upon in nature. This indicates that although growth is effective in limiting torrent sculpin predation on coho salmon, other factors are equally important. Among salmon, the coho has a well-developed innate predator avoidance response (Patten 1975). The response apparently can be reinforced by experience with fish predators and this conditioning probably increases their early survival in streams.

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DESCRIPTION OF MEGALOPA OF SNOW CRAB, *CHIONOECETES BAIRDI* (MAJIDAE, SUBFAMILY OREGONIINAE)

Chionoecetes bairdi Rathbun, a brachyuran crab, occurs on the continental shelf from Puget Sound in Washington State, northward into the Bering Sea, and westward along the Aleutian Islands. The species has been taken as deep as 474 m (Garth 1958), but adults commonly occur at depths less than 190 m. *Chionoecetes bairdi* may be quite abundant in inshore areas throughout its range and has become an important subsistence and commercial species because of its large size and accessibility. It supports an extensive fishery in the Bering Sea and Gulf of Alaska for three nations—the United States, the Soviet Union, and Japan.

The range of *C. bairdi* overlaps that of three other species of *Chionoecetes: C. tanneri* Rathbun, *C. angulatus* Rathbun, and *C. opilio* (O. Fabricius). *Chionoecetes tanneri* ranges from Mexico north to the State of Washington, and commonly occurs between 370 and 1,630 m on the outer slopes of the continental shelf (Garth 1958). *Chionoecetes angulatus* occurs throughout the range of *C. bairdi,* but *C. angulatus* occurs on the lower slopes of the shelf edge between 730 and 2,980 m (Garth 1958). *Chionoecetes opilio* occurs only in the Bering Sea, and its distribution is often sympatric with *C. bairdi.* Two other species of *Chionoecetes* occur in the western Pacific Ocean,