proportionately in the diet. In the 400- to 562-mm fish from lakes, aquatic insects and crustaceans were equal in abundance while the 400- to 562-mm fish from streams fed exclusively on fish and fish eggs. This change in diet may have reflected the size of the food item that fish were able to ingest rather than the type of food item preferred.

Composition of Diet

Aquatic insects and crustaceans were the most frequent food items and the most abundant by volume. These findings concur with those of Wallis (1948) in Oregon; DeLacy (1941), Roos (1959), Nelson (1959), and Armstrong (1965b) in Alaska; Savvaitova and Reshetnikov (1961) and Kazarnovski (1962) in Siberia; and Nishio (1934) in Japan who found that invertebrates occurred more frequently and in greater volume than any other food type in the freshwater diet of Dolly Varden. Aquatic insects were the most common food item, with either caddis or dipteran flies the most abundant insects.

Aquatic insects were the most frequent item in the diet of Dolly Varden on Amchitka, with dipterans the most common insects. The midge in its three life forms was by far the most common dipteran.

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Ecology of Threespine Stickleback *Gasterosteus aculeatus* Linnaeus on Amchitka Island, Alaska

Richard A. Valdez and William T. Helm

Introduction

Threespine stickleback *(Gasterosteus aculeatus)* appear to be the most numerous and widely distributed freshwater fish on Amchitka, although Dolly Varden *(Salvelinus malma)* probably contribute the greatest biomass. These fish often occupy the same waters. Limited numbers of Aleutian sculpin *(Cottus aleuticus)* and pink, sockeye, and coho salmon *(Oncorhynchus)* are also found (as also reported by McCann).[1]

Our work emphasizes food habits of the threespine stickleback on Amchitka as a way to determine their role in the bioenergetics of the Island's freshwater ecosystem.

Several investigators including Markley (1940), Hartley (1948), Hynes (1950), Carl (1953), and Greenbank and Nelson (1959) have reported that the threespine stickleback feeds mainly on small insects (chironomids and ephemerids), small crustaceans (isopods and amphipods), and zooplankton (cladocerans, ostracods, and copepods). Diets are supplemented by small clams, fish eggs and fry, and sometimes algae.

The Study Area

Four watersheds in the southeastern third of the Island were selected as study areas (Fig. 1). These included seven lakes and four streams.

The lakes ranged from 2.5 to 27.9 ha surface area and from 0.9 to 1.8 m depth. All were exposed to frequent wind and were apparently in overturn

This paper is based on work performed under AEC Contract AT(26-1)-171 for Battelle Memorial Institute, Columbus Laboratories.

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[1] John A. McCann. 1962. A summer of biological field work done on Amchitka during the summer of 1962. U.S. Fish and Wildlife Serv. Rep., 1962.

most of the time so that no thermocline was detected in any lake studied. Surface-water temperatures ranged from 7.5 to 12.5 C in the summer. The thin ice cover that formed in the winter often alternated with layers of slush.

The average flows of the four streams, accessible to anadromous fishes, ranged from 0.03 to 0.10 m^3/sec. Dense growths of rushes, sedges, and broad-leaved plants created canopies over large sections of all the streams and limited light penetration. Dissolved oxygen concentrations were at or near saturation.

Common aquatic plants on Amchitka included the genera *Myriophyllum, Sparganium, Hippuris, Callitriche, Equisetum, Potamogeton, Isoetes, Ranunculus, Fontinalis,* and *Caltha.*

Collections and Analysis

Threespine stickleback were collected and examined in June, July, August, and December 1968. Fish were collected from lakes with a 6.1- by 1.2-m nylon bag seine with a 0.6-cm square mesh. A 110-volt, 400-cycle AC backpack shocker was used to collect stream fish although recovering shocked stickleback from the aquatic vegetation was sometimes difficult.

Captured fish were placed in plastic bags along with identification tags with information on date of capture and sampling station. Fish were preserved as soon as possible in buffered 10% formalin. No captured fish were observed to regurgitate.

Total length and body weight were recorded for each fish. Stomachs were removed and analyzed individually by examining only food items in the anterior portion of the digestive tract between the buccal cavity and the pyloric sphincter. Food items were studied in a petri dish under binocular microscopes and identified to genus if possible. It was possible to identify some fragmentary food items on the basis of head characteristics. Data collected during food availability surveys indicated what food items would be encountered in stomach analyses. Food items were tallied numerically and volumetrically.

Two size groups of stickleback were selected from a sample of 138 fish collected in July to compare diets between young-of-the-year and those in their second or third summer of life.

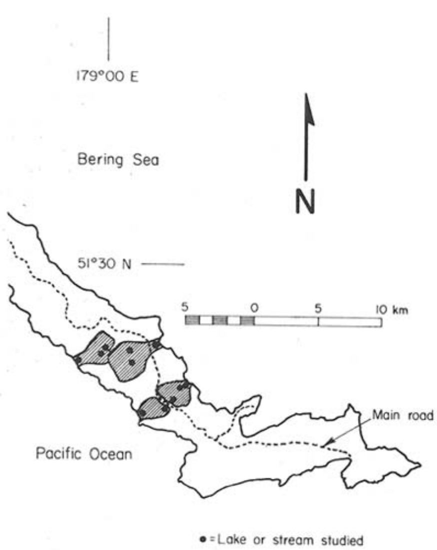


Fig. 1. The four watersheds studied (indicated by hatching) on the south end of Amchitka.

TABLE 1. Food items from threespine stickleback on Amchitka

General Food Category	Specific Food Category
Worms	Nematoda Oligochaeta
Zooplankton	Cladocera (*Pleuroxus* sp.) Ostracoda Copepoda
Crustaceans	Amphipoda (*Corophium spinicorne, Hyallella* sp.) Isopoda (*Gnorimosphaeroma lutea*) Mysidacea (*Acanthomysis*)
Mollusks	Pelecypoda (*Pisa* sp.) Gastropoda
Immature Insects	Chironomidae l[a] and p[b] Tipulidae l Simuliidae l and p Ephemeroptera l (Family Baetidae) Trichoptera l and p (Family Limnophilidae, Family Leptoceridae)
Adult Insects	Chironomidae Tipulidae Simuliidae
Fishes and Roe	Gasterostidae (*Gasterosteus aculeatus*) Cottidae (*Cottus aleuticus*)
Miscellaneous Organisms	Hydracarina (Family Frontipoda) Coleoptera (Family Dytiscidae) Collembola (Family Poduridae) Hemiptera (Family Corixidae)
Debris	Sand particles – 0.5 to 1.5-mm diameter Detritus Vegetation Plant Seeds (*Potamogeton* sp. and others) Algae

[a] l = larvae.

[b] p = pupae.

Results

Forms of Stickleback on Amchitka

Two distinct forms of threespine stickleback were found on Amchitka; a freshwater form and a marine, anadromous form. The more frequent freshwater form, the subject of this investigation, possessed a nearly naked body with drab olive-green markings, and resembles what Hagen (1967) called the form "leiurus" of *Gasterosteus aculeatus.* Miller and Hubbs (1969) suggested the subspecific name *G. aculeatus microcephalus.* Heuts (1947) earlier referred to this as form "A." A mode of 6 and a mean of 5.6 lateral plates were found in a sample of 65 of these freshwater stickleback from three inland lakes on Amchitka.

The marine form, on the other hand, exhibited a mode of 30 and a mean of 30.1 lateral plates, with a well-defined lateral keel on the caudal peduncle. Seventeen of these silver-colored, heavily plated forms were found in three streams near the intertidal zone in June and July. This form resembles that described by Heuts (1947) as the heavily plated form "B," and by Hagen (1967) as the form "trachurus" species *G. trachurus.* Miller and Hubbs (1968), in rebuttal to Hagen's work, have suggested the subspecific name *G. aculeatus aculeatus.*

Distribution

Freshwater threespine stickleback were more numerous in lakes and small ponds than in streams on Amchitka. They were observed in loosely organized schools, of 20 to as many as 2000 members, swimming slowly along shallow, rocky shorelines. Young-of-the-year were often seen in congregations of several hundred along lake shorelines in late summer among sedges and other aquatic plants in water ≤10 cm deep.

The threespine stickleback in streams preferred slower-flowing stretches of water, especially among growths of *Fontinalis* and *Hippuris* that were associated with a soft mud bottom.

Diet

The 15 types of food items found in stomachs of 1793 threespine stickleback collected in June, July, August, and December were grouped into nine general categories (Table 1). The four most frequent foods, zooplankton, immature insects, crustaceans, and worms, made up 81.5% of the diet (Fig. 2). Immature insects, mostly midges (Chironomidae), and zooplankton constituted half of the diet.

Seasonal Variations in Diet

Zooplankton increased in the diet of threespine stickleback during subsequent sampling periods from June through December, and were more frequent than any other food in August and December (Fig. 3). Immature insects, on the other hand, were the primary food (30% of the diet) in June and July, dropping to 24% of the diet during August and to 10% by December, when zooplankton, at 30%, was most important. Worms (Nematodes and Oligochaetes) made up a nearly constant proportion (10-15%) of the stickleback's diet during the four sampling periods. Similarly, crustaceans and mollusks were consumed at a relatively constant level through the summer, increasing only slightly in December. Miscellaneous organisms (water mites and springtails) constituted less than 2% of the diet during any one month.

Diets Relative to Size of Fish

Young-of-the-year consumed proportionately more zooplankton (Cladocerans, ostracods, copepods) and immature insects than the older, larger fish which consumed more worms (nematodes and oligochaetes), crustaceans (amphipods and isopods), and mollusks (clams and snails) (Fig. 4). Adult insects were found only in the larger fish.

Small fish ate more immature insects and zooplankton while larger fish ate more larger, often harder, organisms such as worms, crustaceans, and mollusks. Food selection by different-sized stickleback seems to be related to the size and texture of food items, as suggested by Greenbank and Nelson (1959).

Diet by Watersheds

The relative importance of each food category to the stickleback in each watershed is presented both numerically and volumetrically (Tables 2 and 3). Zooplankton and immature insects dominated the diet numerically in three watersheds, while immature insects, crustaceans, and mollusks dominated volumetrically in all watersheds. Immature insects are very important in the stickleback's diet.

TABLE 2. Diets of threespine stickleback in four watersheds during June, July, August, and December 1968, from Amchitka

Watersheds	Silver Salmon	Bridge Creek	Ultra	Rifle Range
Collections	19	10	16	6
Total Fish Examined	601	327	564	301
Fish With Food	505	298	496	278
Mean Total Length	49.8	47.3	49.5	57.3
(range)	(27-77)	(25-69)	(28-72)	(30-82)

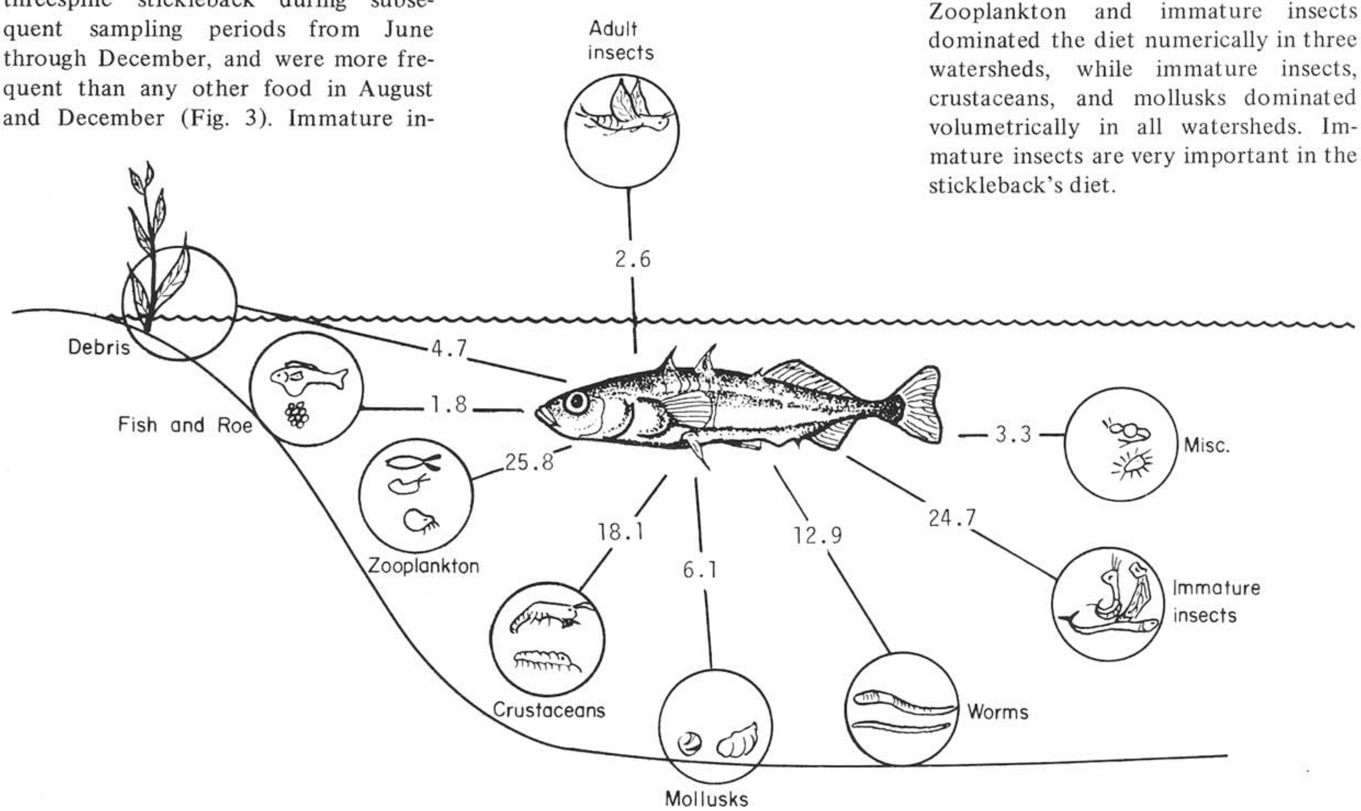


Fig. 2. Diagrammatic food web of threespine stickleback on Amchitka. Numbers are percent frequency of occurrence.

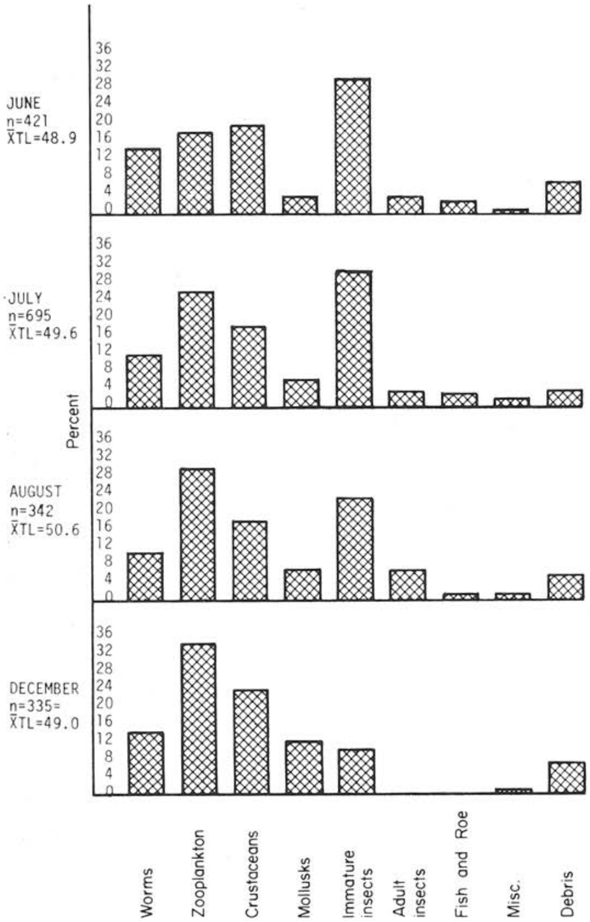


Fig. 3. Diets of threespine stickleback by percent occurrence from four watersheds on Amchitka. N = 1793.

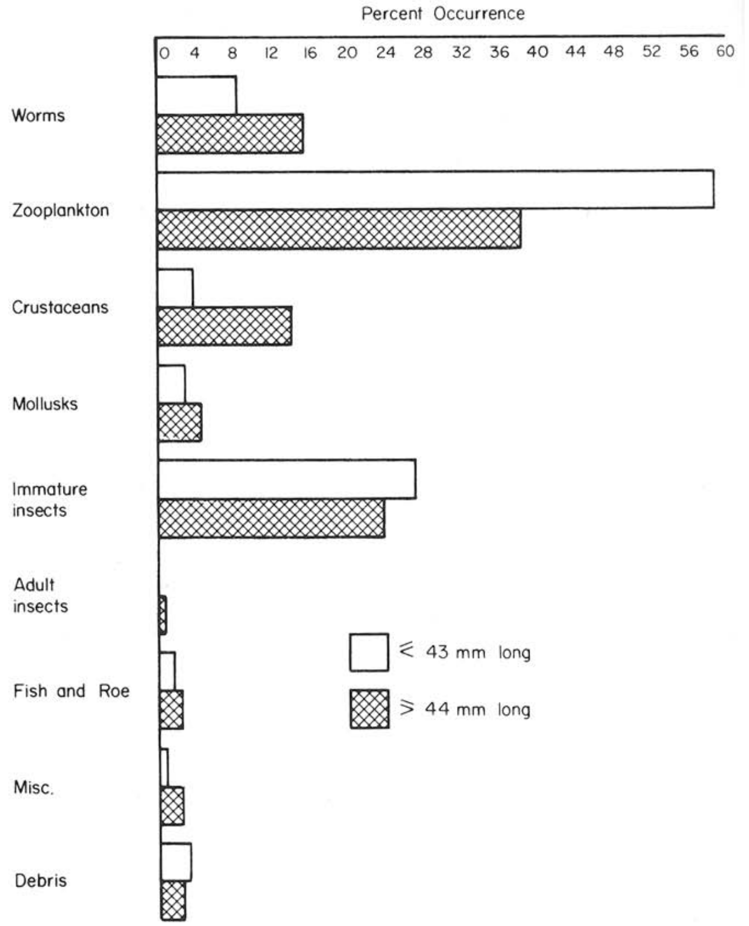


Fig. 4. Food habits of two size groups of threespine stickleback from a sample of 138 collected during July 1968, from Amchitka.

Relationship to Other Fishes

In a concurrent study of the same watersheds, Palmisano[2] reported that threespine stickleback constituted 3% of the diet of Dolly Varden (4% in lakes and 1% in streams) considered in the current study. Predation on stickleback was heaviest (18% occurrence in the diet) in lakes that were essentially landlocked.

By contrast, lakes with access to the sea had significantly fewer Dolly Varden in summer due to emigration, and thus the rate of predation on stickleback was lower. Palmisano also reported that small Dolly Varden relied primarily on cladocerans, copepods, immature insects, isopods, and amphipods for their food. Since this diet is similar to that of the threespine stickleback, there is possibly some competition for food between small Dolly Varden and adult stickleback.

[2] John F. Palmisano, Freshwater food habits of *Salvelinus malma* (Walbaum) on Amchitka Island, Alaska. M.S. Thesis, Utah State University, Logan, Utah, 1970.

Summary

Threespine stickleback are the most numerous secondary consumer in Amchitka's freshwater ecosystem, sharing this trophic level with Dolly Varden. The two species are responsible for the bulk of energy flow in this simple ecosystem. Basic knowledge of their ecology is important for understanding the bioenergetics of Amchitka, and for applying this understanding to more complex systems in other areas.

Effects of Milrow

Live boxes were placed in eight locations, ranging from 650 to 5550 m from SGZ: Clam Lake (650 m), Pratfall Lake (1200 m), Clevenger Creek (1600 m), Quonset Lake (1800 m), Silver Salmon Lake (3000 m), Silver Salmon Creek (3050 m), Bridge Creek (3650 m), and Ultra Creek (5550 m). A total of 73 Dolly Varden, one coho salmon *(Oncorhynchus kisutch)*, and one sockeye salmon *(Oncorhynchus nerka)* were held in the live boxes during Milrow. Preshot stocking of boxes was started late on D-3, and a final count and check of all boxes was made on D-1.

Postshot examination of all live boxes began at H+3 hours, 9 minutes and was completed at H+4 hours, 54 minutes. One Dolly Varden in the Silver Salmon Lake box appeared weak at this time.

A second examination of all boxes was made on D+1 (H+22 hours, 34 minutes). The weak Dolly Varden in the Silver Salmon Lake box was dead. Cause of death could not be determined. All other caged fish apparently were unaffected by the event.

On D+2, all fish were released or preserved for subsequent study. The alertness, orientation, and stability of these confined fish indicated no immediate adverse effects.

Dead threespine stickleback were found near SGZ, on the shore and bottom of Clam Lake (525 to 775 m from SGZ) and Lake AM (725 to 950 m

TABLE 3. Food item distribution of threespine stickleback during June, July, August, and December 1968, from Amchitka

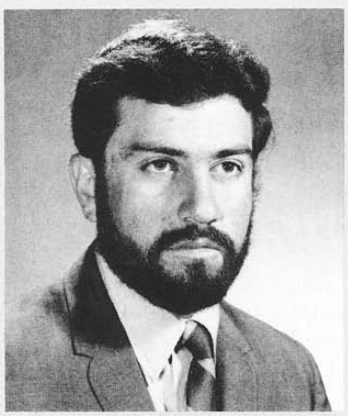
	Percent Occurrence	Percent Dominance		Percent Occurrence	Percent Dominance		Percent Occurrence	Percent Dominance		Percent Occurrence	Percent Dominance	
		No.	Vol.		No.	Vol.		No.	Vol.		No.	Vol.
Worms	15.7	6.0	5.0	5.6			12.4	8.9	0.9	13.2	15.2	
Zooplankton	13.8	42.5	0.5	42.3	92.6	6.4	21.1	55.3	5.6	36.4	74.3	2.1
Crustaceans	29.3	1.2	48.8	0.3			21.5	12.7	31.8	15.8		42.2
Mollusks	2.9			10.2		26.1	8.6		21.2	4.8		8.8
Immature Insects	25.6	47.9	30.0	28.0	7.4	51.7	28.0	23.1	38.1	21.9	10.5	41.2
Adult Insects	2.9	0.6	10.0	3.1		4.7	4.3		1.5	1.8		2.2
Fish and Roe	2.2		2.9	4.3		9.5	0.8			0.6		1.0
Miscellaneous Organisms	1.1	1.8		1.2			0.6		0.9	1.2		1.5
Debris	6.5		2.9	5.0		1.6	2.7			4.3		1.0

from SGZ). Dolly Varden in Clam Lake, both free and caged, apparently were not affected by the test. As many as 27 dead threespine stickleback were found washed up on the bank in a 30-m section of shoreline in Clam Lake. Dead threespine stickleback were also found on the shore of a lake 1155 to 1340 m from SGZ. Probably these fish were merely sloshed up on shore where they died.

Dead threespine stickleback, found near shore on the bottom of Clam Lake and Lake AM, had not washed out onto the bank, but apparently died in the lake. Most dead fish had ruptured air bladders, internal hemorrhage, and pale gill filaments, a pathological combination which could result from sudden change in pressure.

The zone of mortality of threespine stickleback extended from 525 to 950 m from SGZ. No dead fish were found in three other lakes from 1150 to 1400 m from SGZ, nor in other lakes even farther from SGZ. There is some evidence that shock effects were attenuated toward the distal end of Lake AM, 950 m from SGZ.

Comparative quantitative sampling of threespine stickleback in Clam Lake yielded 86 fish per haul before Milrow, but only 8 fish per sample after Milrow. Continued sampling has not been feasible because of an increase in water level caused by subsidence in the lake basin.



Valdez

Helm

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