AMCHITKA BIOENVIRONMENTAL PROGRAM
FRESHWATER VERTEBRATE AND INVERTEBRATE
ECOLOGY OF AMCHITKA ISLAND, ALASKA

FINAL SUMMARY REPORT

and

PROGRESS REPORT

July 1, 1972 - September 30, 1973

by

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FRESHWATER VERTEBRATE AND INVERTEBRATE ECOLOGY OF AMCHITKA ISLAND

by

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ABSTRACT

Dolly Varden and threespine stickleback were the most abundant and well-distributed of the six freshwater species of fishes encountered on Amchitka. Small runs of pink salmon occurred in late August in about 15 streams on good (even) years and about 6 on poor (odd) years. Coho salmon and freshwater Aleutian sculpin were limited in distribution to five and one streams, respectively; sockeye salmon were rare. Dolly Varden accounted for the greatest biomass of the secondary and tertiary consumer levels on the Island.

The two underground nuclear tests (Milrow and Cannikin) affected only local populations of fishes. Deaths due to test-induced pressure changes occurred only as far as 2,000 m from SZ but these effects were specific to threespine stickleback since they were the only fish species with an air bladder intolerant to rapid pressure adjustment (physoclistores). The only loss of Dolly Varden resulted from watershed and pond alterations that drained streams and ponds during Cannikin.

More widespread and persistent effects on freshwater biota resulted from pretest construction and drilling activities. Detectable changes in fish and invertebrate populations resulted in four streams near the four drill sites from increased siltation and from the release of drilling residue. Two of the streams, White Alice and E-site Creek, were completely void of life subsequent to the spills; there is a possibility of recovery in the former. Clevenger Creek and Falls Creek demonstrated trends toward recovery of invertebrate and fish populations less than 2 years after spills.

INTRODUCTION

Battelle's Columbus Laboratories' Amchitka Bioenvironmental Program was organized to predict, document, and evaluate the effects of the U.S. Atomic Energy Commission activities on the biota and the environment of Amchitka Island; to recommend measures for minimizing adverse effects;

and to predict radiological hazards to man that might result from radionuclide transport through food chains, should there be an inadvertent release of radioactivity. The purpose of the freshwater vertebrate and invertebrate ecology study is to provide information on Amchitka's freshwater ecosystems to assist in accomplishing these objectives.

Since August 1967, biologists from Utah State University have conducted studies of Amchitka's freshwater ecosystems under Battelle's Columbus Laboratories' Bioenvironmental Program. Efforts during this study were concentrated on: (1) defining the status and dynamics of the freshwater ecosystems, (2) providing an ecological baseline for evaluating and documenting test-related and other effects, and (3) establishing a conceptual analogue model of the freshwater stream ecosystem of the Island.

This report addresses the results and interpretation of the study since August 1967 to specific tasks outlined in the original proposal and summarized by the preceding three points above.

Only those data, figures, and tables deemed pertinent to an ecosystem approach toward describing Amchitka's freshwaters and man's impact upon them are incorporated. A qualitative and quantitative description of the structure and function of each trophic level in the freshwater ecosystems is emphasized; the composition of the population and the density of each component (structure) as well as the birth, death, and growth rates, and interspecific relationships (functions) are also considered. Supplemental to these data are the annual progress reports in which more detailed field data are presented and methods of collection are fully described.*

STATUS OF FRESHWATER ECOSYSTEMS

A description of the structure of Amchitka's ponds and streams became the first objective of this study. It was necessary to describe, in qualitative and quantitative detail, each component in these ecosystems before functions and rates could be examined. This reconnaissance soon established the contrast between lowland and highland ponds and streams of Amchitka, particularly with respect to physical and chemical parameters. Figure 1 locates most geographical references in this report.

*See additional references at the end of the reference section.

FIGURE 1. AMCHITKA ISLAND, IDENTIFYING SOME COLLECTING STATIONS, PONDS, AND STREAMS REFERRED TO IN THIS REPORT, AND STREAMS USED BY SPAWNING PINK (PS), COHO (CS), AND SOCKEYE SALMON (SS)

Physical and Chemical

Ponds

The term "pond" is preferred over "lake" (Welch, 1952; Hutchinson, 1957) in describing each of the over 3,000 standing bodies of freshwater on Amchitka. About 75 percent of these ponds are located in the southeastern half of the Island where basins are generally shallow with less than 1 m of water. Fewer ponds were found in northwest Amchitka, but their basins tended to be deeper with maximum depth of about 3.5 m.

Amchitka surface area ponds generally range from about 0.2 to 27.0 ha. Most are irregularly shaped and have flat bottoms with either silt or soft mud substrates. The shorelines are either of angular rock and irregular rubble or continuous mud with sparse growths of sedges and rushes. Some of the larger ponds have a few open sand and gravel beaches, but most have deeply undercut banks due to wave action produced by the extensive and perennial Island winds. Detailed physical measurements of Amchitka ponds are presented by McCann (1962) and Palmisano (1971).

A variety of aquatic vegetation grows from the soft pond substrate (see Aquatic Macrophytes). Many ponds are rich in detritus which supports a benthic fauna composed primarily of immature insects and crustaceans (see Invertebrates).

Surface water temperatures in Amchitka ponds vary from 0 C in winter to about 13 C in August (Figure 2). Because of continuous wind action, no

FIGURE 2. AVERAGE MONTHLY WATER TEMPERATURES OF THREE PONDS AND ONE STREAM (BRIDGE CREEK) ON AMCHITKA DURING 1968

thermal stratification was recorded. Ice formed on many of the ponds from November to March but was not persistent because of the frequent above-freezing air temperatures and severe winds which continually broke the thin ice cover and piled it against the windward shore. The alternating freezing and thawing temperatures often created alternating layers of ice and slush. The thickest solid-ice cover found was about 30 cm (measured during the December 1968 sampling period), but in no case was ice believed detrimental to fish populations (i.e., no oxygen depletion).

Oxygen concentration in ponds was generally near saturation while pH varied from about 5.0 to 9.0. Most ponds tended to be slightly acidic or about pH 6.5. A summary of the limnological characteristics of Amchitka ponds is presented by Burkett (1974).

Streams

Amchitka's shoreline is broken by numerous small streams which drain perpendicularly to the longer axis of the Island, either into the Bering Sea or the Pacific Ocean. Drainages are generally only 3 to 4 km long. An Island-wide survey of Amchitka streams in August 1970 revealed 73 perennial streams with estimated flow in excess of $0.03 \text{ m}^3/\text{sec}$. At their effluence, 43 of these streams cascade over precipitous cliffs or are blocked there by gravel dikes, established during severe oceanic storms. A large number of small, ephemeral streams was also noted.

The slower flowing streams of southeastern Amchitka generally have soft, mud bottoms except for 100 m or so near the effluence where gravel and boulders predominate. These streams abound in aquatic vegetation that provides security and food for much of the aquatic fauna (see Aquatic Macrophytes).

The steeper gradient northwestern streams generally have gravel bottoms of varying depth, although in some sections the gravel is completely scoured away and the underlying bedrock exposed.

Stream temperatures of Bridge Creek in southeastern Amchitka in 1969 varied from 0 to 10 C with extremes in January and August, respectively. Similar temperatures were found in 1970. Temperatures in a northwestern stream, Midden Cove Stream, also taken in 1970, were generally cooler. Moderate winter air temperatures on the Island prevented surface ice from remaining on streams for more than a few days. Nevertheless, even anchor ice was found in February and March. Drifting snows from December to March often obliterated evidence of any stream channel, but more often, the streams clogged with slush and chunks of ice during frequent thawing temperatures.

Flow rates in Bridge Creek varied from a high of $0.24 \text{ m}^3/\text{sec}$ in December to a low of $0.02 \text{ m}^3/\text{sec}$ in May and June (Figure 3). Other streams, including Midden Cove Stream, generally followed the same pattern. Daily variations in stream flow were often great, particularly from September to February, during which time much of the Island's tundra mat was water saturated. Any rainfall at this time manifested itself in immediate rises in stream levels (Figure 2). As most of the rainfall from March to July was absorbed by the dry tundra, heavy amounts of rain usually resulted in only small increases in stream volume.

FIGURE 3. AVERAGE MONTHLY FLOW RATES OF BRIDGE CREEK AND CORRESPONDING PRECIPITATION MEASURED AT THE AMCHITKA AIR TERMINAL DURING 1968

(Data courtesy of U.S. Geological Survey.)

Oxygen in streams was generally at saturation level or higher (greater than 10 ppm). Hydrogen ion concentration, expressed as pH units, revealed slightly acidic conditions of 6.6 to 6.8.

Biological

In spite of topographic contrasts on Amchitka, aquatic vertebrate and invertebrate species composition is markedly uniform. Their distribution and density, however, are influenced by the physical nature of the watersheds;

most of the higher gradient northwestern streams with gravel substrate support primarily mayflies while the slower flowing lowland streams support primarily midges. Most highland ponds exhibit rocky shorelines which shelter an abundance of amphipods and isopods while most lowland ponds are shallower with mud bottoms that are preferred by midges. Aquatic vegetation also varies according to pond types.

Aquatic Macrophytes

At least 19 species of aquatic macrophytes representing 12 families were abundant in Amchitka ponds and streams (Table 1). Shacklette, et al. (1969) present a thorough description of these and other vegetative types of Amchitka. The large mosses and leafy liverworts, Fontinalis neomexicanus, Mnium sp., and Chiloscyphus sp. grow in nearly every stream sampled on the Island. F. neomexicanus was found to provide a vitally important habitat to many benthic and demersal invertebrates, which are fed upon by voracious young fishes seeking the shelter afforded by the plant. This form, abundant in low- and high-gradient streams, was most common in the latter because of its apparent preference for swift water and its propensity to attach firmly to submerged stones.

The buttercup and water milfoil families were the only other forms abundant in streams. Caltha palustris (marsh marigold) often grew with Hippuris vulgaris (mare's tail) in slow flowing, mud-bottom stream sections. Caltha's brilliant yellow flowers well marked its abundance in the southeastern streams in June and early July. Both species seemed to provide excellent habitat for threespine stickleback, Gasterosteus aculeatus, and Dolly Varden char, Salvelinus malma, residing in low-gradient streams.

Perhaps the most evident macrophytes in Amchitka ponds were members of the water milfoil family; Hippuris vulgaris and Myriophyllum spicatum. Both species grew well in many of the mud bottomed ponds, and their emergent nature emphasized their evident abundance. The "underwater forests" created by these milfoil plants appeared highly desirable to Dolly Varden and threespine stickleback.

The more abundant submergent forms in ponds include the pondweed, Potamogeton vaginatus; a member of the bur reed family, Sparganium sp.; and also one species of buttercup, Ranunculus trichophyllus. These three species form thick mats of underwater vegetation that persist through the summer and die back in winter. The tiny, delicate white flowers of R. trichophyllus were often evident on the surface of some ponds.

The forms Juncus balticus, Callitriche sp. and Isoetes braunii were limited in distribution to a very few ponds, but were very abundant where they occurred. Callitriche sp., for example, formed small windrows of vegetation on the windswept shores of Quonset Lake during severe winds.

TABLE 1. FAMILIES OF AQUATIC MACROPHYTES ENCOUNTERED
IN AMCHITKA FRESHWATERS

-
-
I.	Family: Characeae (algae: stonewort, muskgrass)
1. <u>Nitella</u> sp.
II.	Family: Cyanophyceae (blue-green algae)
1. <u>Nostoc</u> sp.
III.	Family: Hepaticae (mosses and leafy liverworts)
1. <u>Fontinalis neomexicanus</u>
2. <u>Mnium</u> sp.
3. <u>Chiloscyphus</u> sp.
IV.	Family: Equisetaceae (horsetail)
1. <u>Equisetum arvense</u> (scouring rush)
V.	Family: Isoetaceae (quillwort)
1. <u>Isoetes braunii</u>
VI.	Family: Sparganiaceae (bur reed)
1. <u>Sparganium</u> sp.
VII.	Family: Najadaceae (pondweed)
1. <u>Potamogeton vaginatus</u>
2. <u>P. crispus</u>
VIII.	Family: Cyperaceae (sedges)
1. <u>Carex macrochaeta</u>
2. <u>C. lyngbyaei</u>
IX.	Family: Juncaceae (rushes)
1. <u>Juncus balticus</u>
X.	Family: Rannunculaceae (buttercup)
1. <u>Ranunculus reptans</u>
2. <u>R. trichophyllus</u>
3. <u>Caltha palustris</u> (marsh marigold)
XI.	Family: Callitrichaceae (water starwort)
1. <u>Callitriche</u> sp.
XII.	Family: Haloragidaceae (water milfoil)
1. <u>Myriophyllum spicatum</u>
2. <u>Hippuris vulgaris</u> (mare's tail)
-
-

Perhaps the most novel of the aquatic plants on Amchitka was the large blue-green algae represented by the genus Nostoc. A few ponds on the Island contain many of these free-floating gelatinous balls of cells which were readily seen on the wave-swept beaches or in shallow water. Some, the size of tennis balls, were found in Silver Salmon Lake.

Invertebrates

Insects. A striking feature of Amchitka's aquatic invertebrate fauna is the complete absence of mosquitoes (Culicidae). Nevertheless, immature insects, either benthic or demersal, dominated the numbers and biomass of invertebrate fauna of most ponds and streams. The most common forms were: midges (Chironomidae), mayflies (Ephemeroptera), blackflies (Simuliidae), caddisflies (Trichoptera), water boatmen (Corixidae), and predaceous diving beetles (Dytiscidae). A number of less frequently occurring Diptera were found in stomachs of Dolly Varden and stickleback by Palmisano, 1971 and Valdez, 1971. Water boatmen and diving beetles inhabited the more shallow, stagnant ponds, generally not in coexistence with any fishes. Feeding experiments with threespine stickleback (Valdez, 1971) indicated this fish's voracity for these insects., so it may be that predation restricts their distribution. Both larval and adult forms of beetles were found.

Perhaps midges deserve the most attention in this analysis since their immature forms abound in bottom muds of both ponds and streams. Dense clouds of adult midges were often seen swarming over the heavily vegetated streams in July and August. Dolly Varden, threespine stickleback, Aleutian sculpin (Cottus aleuticus), and young coho salmon (Oncorhynchus kisutch) favored the midges in their diet (Valdez, 1971; Palmisano, 1971). The high density and extensive distribution of Chironomidae on Amchitka make the midges a very important factor in the primary consumer level.

Only one genus of mayfly, Pseudocloeon sp., was found on Amchitka; larval forms abounded only in rock or rubble-bottom streams with water velocity exceeding 0.75 m/sec. Many streams in the northwestern highlands support this form.

Both families of caddisflies found on Amchitka are casebuilders. Limnephilidae were abundant in both ponds and streams; larval cases were constructed of bits of twigs or leaves rather than small pebbles. The smaller Leptoceridae with their stony, horn-shaped cases, were found predominantly in rocky streams and along rubbly pond shores. It is probably the constant overturn and circulation in these ponds caused by the perennial Amchitka winds that enables this form to survive there.

Blackfly pupae and larvae are well distributed in slow-flowing, rubble-bottom streams, attached to the undersurface of rocks and debris, although these were never in great enough numbers to be considered a menace to human inhabitants (some species of simuliids are notorious for their painful bites).

Crustaceans. Few crustaceans were found in Amchitka streams except for amphipods of the genus Hyallela which frequented slow-flowing sections of stream. The amphipod, Corophium spinicorne, however, was very abundant along rocky pond shores, usually in association with attached filamentous green algae. This organism, in addition to midges, contributes much to the diet of pond fishes on Amchitka (Valdez, 1971; Palmisano, 1971).

Also abundant along the rocky shorelines was the isopod, Gnorimosphaeroma lutea, which was almost equal to the amphipod in dietary importance. This form is also called a pillbug because of its propensity to curl up, head to tail, when alarmed or disturbed.

A brackish water mysid, Acanthomysis awatchensis, was found in stomachs of Dolly Varden and threespine stickleback from Silver Salmon Lake. Since the pond is connected to the Bering Sea by a short stream, it was suspected that the fish may have moved into the intertidal zone to feed on the mysids. However, lack of fish movement through a fish trap did not support this theory. Instead, the euryhaline mysids apparently moved into the lake and were preyed upon there by the fishes.

The molluscan forms, pelecypoda and gastropoda, occurred in muds of all nine intensively sampled ponds, but were abundant in only three. The pelecypods were represented by fingernail clams (Sphaeriidae) and the larger Anodonta beringiana, while the gastropods were represented by a small, short snail (Lymnaeidae).

The mollusk, Anodonta beringiana, was found in only one pond in Amchitka, aptly named thereafter, Clam Lake. Densities in the pond were as high as three clams per square meter of mud bottom. Empty shells and associated activity of birds indicated some predation from sea gulls along one shallow beach of this pond.

The genus, Anodonta, has an interesting association with coinhabiting fishes when in its larval or "veliger" stage of development. Also known as the glochidium, the larva is small and bivalve in appearance but possesses hooks by which to live out a parasitic existence on any one of various external structures of fish. The glochidium attaches itself to the fish and encysts to gain nutrition from its host. Eventually, the immature clam ruptures the cyst, settles to the bottom of the pond, and burrows into the mud where normal filter feeding ensues (Barnes, 1968). Coinhabitants of the pond were threespine stickleback and Dolly Varden.

Fishes

Six species of freshwater fishes were encountered in Amchitka waters. Four are anadromous salmonids, including three Pacific salmon (coho, Oncorhynchus kisutch; pink, O. gorbuscha; and sockeye, O. nerka) and one char (Dolly Varden). The fifth and sixth species are the threespine stickleback and the freshwater Aleutian sculpin (Cottus aleuticus).

All six of these species of fishes are capable, at least for short periods, of a euryhaline existence, and so the way in which each arrived on this Aleutian Island is apparently related and of interest. The presence of these forms indicates postglacial dispersal from either the Bering or Pacific refuges, sometime after the Wisconsin glaciation, about 10,000 years ago (McPhail and Lindsay, 1970). There is strong evidence that C. aleuticus and G. aculeatus survived in the Pacific refuge and dispersed northward along the coast. Apparently the freshwater form of the latter arose postglacially subsequent to the arrival of the marine form.

The remaining three species of Oncorhynchus and one species of Salvelinus are believed to have survived in more than one refuge, but dispersal to the Aleutians is probably from the more proximate Bering refuge.

Master of Science theses were written on the threespine stickleback (Valdez, 1971) and the Dolly Varden (Palmisano, 1971; Nordmeyer, 1973) on Amchitka. Virtually all of the information on these species is taken from these three works.

Dolly Varden. Palmisano (1971) counted gill rakers, pyloric caeca, scales, and vertebrae of 200 Dolly Varden from Amchitka to verify which form of the Salvelinus alpinus complex described by McPhail (1961) inhabits Amchitka waters. Data from these four characters indicated that only Dolly Varden, S. malma, was encountered on Amchitka.

The precipitous Amchitka shoreline, particularly in the northwest end, renders many streams and ponds inaccessible to anadromous salmonids. As a result, two morphologically and habitually distinct populations of Dolly Varden were found in Amchitka waters; a dwarf, landlocked form residing in these inaccessible ponds and streams, and a euryhaline, anadromous form which in adulthood fattens at sea and spawns in the accessible streams. The two forms were also encountered in sympatric existence in accessible streams, but the density of the anadromous form far exceeded that of the landlocked form, except above impassable waterfalls.

The origin of these two forms on Amchitka is conjectural, but apparently, the dispersal of the anadromous form from the Bering refuge gave rise to a landlocked form when changes in terrain, and thus stream effluences, isolated them from the marine environment. All of the approximately 70 perennial streams sampled and about half of the 60 or so ponds were inhabited by one of the two forms of Dolly Varden.

The landlocked form is usually a dark olive with brilliant orange vermiculation and yellow margination of the ventral fins. The anadromous form, even when immature, exhibits a light greenish dorsal sheen and bright silvery sides. Both forms possess parr marks as juveniles.

Threespine Stickleback. Like the Dolly Varden, two morphologically and habitually distinct forms of threespine stickleback were found on Amchitka (Valdez, 1971). These are distinguished by their distribution and the number of lateral plates on the body. Unlike the two forms of Dolly Varden these two forms are distinct enough to be considered subspecies (Miller and Hubbs, 1969) or perhaps even separate species (Hagen, 1967). The most common form inhabits freshwater ponds and streams, and differs from the other, a marine form, in possessing fewer lateral plates on the body (mean of 5.6). The marine form exhibits a mean of 30.1 lateral plates and a lateral, horizontal keel on the caudal peduncle. It was frequently encountered in the quiet, sheltered coves of the intertidal zone around the Island and in freshwater streams in June and July during spawning time. The freshwater form was encountered in 80 percent of the ponds sampled, most of which were in the southeastern lowlands, but in only about 25 percent of the perennial streams sampled. Noticeably fewer threespine stickleback were found in the landlocked ponds and the steeper gradient streams of the northwestern highlands. Only the freshwater form was abundant on Amchitka.

Salmon. The pink salmon or "humpback" was the most abundant and widely distributed of the three Pacific salmon species found on Amchitka. During the period of the study, spawning adults were encountered in 21 streams, but usually in not more than 15 streams in a single year. They never numbered more than 1,000 for the entire Island and were most abundant in even years (1970, 1972) - generally in ascending streams in late August and early September.

Fewer coho salmon were found spawning in five streams while sockeye salmon were found in only one freshwater system. Figure 1 indicates streams used by spawning salmon.

Sculpin. Aleutian sculpin were abundant only in Jones Creek and were rare in two other streams and two ponds. Little is known of the sculpin's role in the freshwater ecosystems since its scarcity permitted relatively little study. Estimated density of sculpin in Jones Creek in August, 1968 was 800 fish.

DYNAMICS OF A FRESHWATER ECOSYSTEMPrimary Production

A primary-productivity measure evaluates an ecosystem's capacity to build up both radiant and chemical primary compounds at the expense of external energy. The rate of energy transfer or the transformation of this potential to high system levels indicates an estimate of the system's efficiency in converting these chemical compounds into plant and animal tissue.

As the first step to evaluating the energetics of a representative stream community of Amchitka, primary productivity in Bridge Creek was estimated using chlorophyll *a* extractions (Beers and Neuhold, 1968). Weighted plastic bags, left in the stream for a known period of time, were used as substrates for periphyton growth. The equations of Strickland and Parsons (1965) were used to arrive at quantities of chlorophyll *a* in terms of milligrams of pigment per square meter of stream substrate. This value was converted to milligrams of carbon by multiplying by a constant of 0.45 (Odum, 1971).

A curve for gross primary productivity in Bridge Creek (Neuhold, 1971) shows that a low level of 0.3 mg of carbon/m²/hr occurred, as expected, during the winter and a higher level of 1.5 mg of carbon/m²/hr occurred in May, June, and July (Figure 4). Integration of this productivity

FIGURE 4. GROSS PRIMARY PRODUCTIVITY IN BRIDGE CREEK DURING 1968

curve (to determine the area under the curve) yielded an approximation of annual gross primary production of 4 g of carbon/m²/yr. Employing a constant of 10.94 (Odum, 1971) with this value, the estimated gross primary production for this stream in energy units was 43 kcal/m²/yr.

This method of extracting chlorophyll from artificial substrates tends to bias measurements in favor of benthic periphyton and does not account for vascular plant production. In an attempt to account for this, average monthly dry weights (60 C to constant weight) of vascular plants in Bridge Creek were measured, and estimates of their production were computed by methods commonly used in fish production (Ricker, 1968). Accordingly, little grazing on green vascular plants was assumed and any increase in biomass was interpreted as production. The final estimate of production, 22 g dry matter/m²/yr, as the value of benthic periphyton production, was converted to energy units (X 0.45 and X 10.94) to yield 100 kcal/m²/yr. The summation of benthic periphyton production and aquatic vascular production yielded total gross primary production of 143 kcal/m²/yr. Available solar radiation on Amchitka was estimated at 60 kcal/m²/yr (Merritt, 1973).

Vascular plant production was nearly three times that of periphyton production. This is not too surprising considering the heavy canopy of vascular plants in this stream which shades much of the substrate, and the predominance of mud bottom.

Organic concentrations in stream waters appear to be related to the rate of stream flow; a low concentration of 13 mg dry matter per liter was measured in August and a high of 19 mg dry matter per liter in December and April (Neuhold, 1971). A combination of the dissolved concentration with flow rates integrated over the year, and multiplied by the proportion of detritus to dissolved organic concentration (0.25) and then by the settling rate, resulted in an estimate of the detritus input into the stream of 870 g dry matter/m²/yr. Net energy input via detritus was thus 4,283 kcal/m²/yr.

Invertebrates

The primary consumer level of Bridge Creek was dominated by a few invertebrate forms. Annual production of these was calculated to approximate the efficiency of the system and to establish the paths of energy from the primary producers to the primary consumers.

The mean annual crop of invertebrates in Bridge Creek was found to be 5 g dry weight/m², 73 percent of which was chironomids and oligochaetes (Neuhold, 1971). However, when the total production of invertebrates was considered, chironomid production was much higher (29 g dry weight/m²/yr) than that of oligochaetes, (6 g dry weight/m²/yr) and it became evident that midges were the most important invertebrate form in this stream.

The aquatic invertebrate fauna of ponds and streams on Amchitka exhibited low diversity indexes (Table 2). These were determined by the Shannon index (Shannon and Weaver, 1959):

$$\bar{H} = \sum p_i \log p_i ,$$

where

$$p_i = n_i/N$$

n_i = importance value of each species in terms of numbers, production, or biomass

N = total of importance values.

TABLE 2. SPECIES DIVERSITY INDEXES OF BENTHIC INVERTEBRATE FAUNA OF REPRESENTATIVE PONDS AND STREAMS OF AMCHITKA

Station	Invertebrate Groups											Diversity Index $\bar{H}$	
	Chironomidae	Ephemeroptera	Trichoptera	Simuliidae	Nematoda	Oligochaeta	Pelecypoda	Amphipoda	Isopoda	Platyhelminthes	Arachnida		Ostracoda
Midden Cove Stream	X	X	X	X	X								0.375 ± 0.076
Bridge Creek	X	X	X		X	X	X			X	X	X	1.155 ± 0.093
Lake CO	X				X	X		X	X			X	1.071 ± 0.083

In the lowland stream, chironomids were the most abundant form of invertebrate; mayflies often dominated the fauna of the highland streams.

Total invertebrate production in Bridge Creek, including that of chironomids, oligochaetes, caddisflies, clams, and mayflies was estimated at 42 g/m²/yr or 205 kcal/m²/yr (42 x 0.45 x 10.94).

FishesDolly Varden

Of the two forms of Dolly Varden found on Amchitka, the anadromous form in the maritime stream situation provided a more opportune case for examining bioenergetics representative of the Island's freshwaters. All of the larger streams supported this anadromous form, and many of these streams were easily accessible. As the streams nearest the event sites supported primarily this form, it was expected to be affected most by a detonation. The bioenergetics of this segment of the freshwater ecosystem is of specific interest because it represents a link with the marine ecosystems via the anadromous Dolly Varden and pink salmon. Biomass of coho salmon is too small and insignificant to consider in this analysis.

The dwarf form of the Dolly Varden certainly plays an important role in the total ecosystem, but emphasis of the present analysis is on the representative lowland stream, Bridge Creek.

Migratory Habits. The first vital step to understanding the significance of the Dolly Varden in a maritime freshwater system such as that of Amchitka is knowledge of its anadromous habits and its role in the marine and freshwater ecosystems.

Fish traps to capture individuals moving up or downstream were maintained in several streams during prolonged periods each year of the study. Very definite seasonal patterns in numbers and sizes of moving Dolly Varden were found. The most significant single factor initiating movement in all streams appeared to be increased stream flow. Most fish movement occurred in synchrony with this phenomenon in spring and fall (Nordmeyer, 1973).

The anadromous Dolly Varden on Amchitka fatten at sea in the summer and spawn in the streams in winter. The young char spend the first 3 or 4 years of their life in the stream before first descending to sea. The relatively large number of Age Group IV Dolly Varden leaving Amchitka streams for their first seaward descent indicated that the majority of Dolly Varden smoltified at that age. This is shown in histograms of trap catches in Midden Cove Stream (Figure 5), where this age group comprised 75 percent of the catch in July 1971. Of these downstream migrants, 23 percent belonged to Age Group III, but only an insignificant number to Age Groups II and V. Continuous monitoring below each trap indicated movement of Age Group II fish was local and was not a seaward descent. Armstrong (1970) also reported a predominance of Dolly Varden of the Age Groups III and IV migrating from Hood Bay Creek and Eva Lake in southeast Alaska.

The similar downstream movement of maturing Dolly Varden in Bridge Creek was represented by fish ranging from 85 to 169 mm standard length (from the tip of the snout to the end of the hypural or tail bone). Thus, total energy represented by juveniles leaving the stream, most of which left in July, was about 4 kcal. This is in addition to the 14 kcal due to overwintering adults, which descended primarily in June.

Parr marks began fading from the smolts even before they reached the sea. In salt water, their voraciousness took advantage of the abundance of intertidal invertebrates and small littoral fishes. Stomachs of Dolly Varden sampled intertidally from the effluence of Midden Cove Stream, Bridge Creek, Jones Creek, and Clevenger Creek in July and August 1971 and 1972 showed a striking similarity in diversity of organisms in the diet as well as the relative percentage of occurrence of each. Therefore, the samples were grouped and an analysis is presented on all fish captured intertidally (Table 3). The importance of amphipods, mysids, and especially small fishes, is apparent since all these occurred in nearly half the fish.

TABLE 3. OCCURRENCE OF FOOD ITEMS IN SEA-RUN DOLLY VARDEN FROM AMCHITKA

Organism	Frequency	
	Number	Percent
Aleutian alligatorfish	11	17.74
Amphipods (assorted)	21	33.87
Cottidae	4	6.45
Euphausiids	3	4.84
Greenling	26	41.93
Isopoda (Idothea)	1	1.61
Mysids	18	29.03
Nematodes	1	1.61
Prickleback	5	8.06
Ronquil	1	1.61
Sandlance	8	12.90
Unidentified fish	2	3.22
Blenny	1	1.61
Shrimp	5	8.06
Kelp fly larvae	1	1.61
Stomach empty	7	11.29

The number and volume of each category of organisms represented in each stomach were determined. From this and a determination of the digestive rate of Dolly Varden, a measure of daily consumption per fish was calculated (Gerking, 1967). A constant of 1.05 was used to convert volume in milliliters to weight in grams, and the digestive rate used was

FIGURE 5. LENGTH-FREQUENCY HISTOGRAMS FOR SEAWARD DOLLY VARDEN AND COHO SALMON SMOLTS FROM A FISH TRAP AT MIDDEN COVE STREAM IN JULY 1971

1.2 (20 hours). This value, determined experimentally with live Dolly Varden on Amchitka, represents the time required for the stomach to completely empty itself. The product of this value and the food in a fish at time of capture (at or near feeding peak) yielded a value of daily consumption in grams. The daily ration, or the percentage of body weight ingested daily by each fish, was then calculated. Mean daily ration was found to be 1.5 ± 0.1 percent of wet fish weight.

Trap catches and tag returns showed that anadromous Dolly Varden of Amchitka spent an average of 73.5 ± 13.5 days at sea during which average weight gained per fish was 182.1 ± 12.0 g wet weight and average increase in length was 26.6 ± 13.0 mm (Table 4).

TABLE 4. PARAMETERS^(a) OF ANADROMOUS DOLLY VARDEN FROM MIDDEN COVE STREAM

Days Spent	Wet Weight Change, g/fish	Standard Length Change, mm
	<u>At Sea</u>	
73.5 ± 13.5	$+ 182.1 \pm 12.0$	$+ 26.6 \pm 13.0$
	<u>In Stream</u>	
286.5 ± 8.5	$- 157.6 \pm 15.8$	$+ 4.2 \pm 1.6$

(a) All numbers given are population means (95 percent confidence limits).

A value of assimilation efficiency was determined by employing daily consumption of each fish to determine total intake at sea (489.2 g wet weight/fish) and comparing this value to actual weight gained per fish (182.1 g wet weight). Efficiency of converting food to fish biomass was an estimated 37 percent.

Offshore gill netting, purse seining, and long lining for immature salmon by the University of Washington failed to capture any Dolly Varden farther offshore than about 400 m (Isakson, J., personal communication). Apparently Amchitka Dolly Varden do not move offshore. They may not even stray far from their natal stream since many fish tagged in a stream were often observed feeding near its effluence (Nordmeyer, 1973).

Heavy rains in August and September (Figure 3) increased the flow in small Island streams and apparently made them more favorable for ascent by the anadromous Dolly Varden, now accompanied by adult pink salmon. Large movements of these fishes occurred only during the sudden

freshets caused by heavy rains. Streamward migrating Dolly Varden had bright silvery sides with light green backs and were in excellent condition. These adults represented about 43 kcal of energy ascending Bridge Creek and the biomass of pink salmon ranged from 0 to 8 kcal depending upon the year.

Dolly Varden began to darken after about one week in the stream, and, by spawning time in October and November, the males turned a bright green atop with blood red sides and belly. This, and the development of a kype on the mandible distinguished the males from the more drab, greenish females.

Immediate degeneration of robustness occurred when these Dolly Varden returned from the sea because they appeared to fast during their stream residence from September to June. Table 4 shows that weight lost by each fish in this 8 to 9 month fast was very marked (157.6 ± 15.8 g wet weight); a loss nearly equivalent to the 182.1 g gained during residence at sea.

Mortality was high among spawning Dolly Varden; only about 50 percent of these adults survived to descend seaward in June with the maturing smolts. Dolly Varden on Amchitka were found ascending to spawn for a third time in a 3-year period.

Length-Weight. Most members of the genus Salvelinus demonstrate very marked seasonal weight changes (McFadden, 1961; Hunt, 1966). The anadromous habit of Dolly Varden apparently further enhances this dynamic phenomenon in the adults. By relating length to weight as:

$$K = \frac{W \times 10^5}{L^3},$$

where

K = condition factor

W = weight in grams

L = standard length in millimeters,

a numerical description of the condition of a fish is possible; the higher the value, the fatter or plumper the fish, and thus the better his condition (Figure 6). The June sample represents adult Dolly Varden still in the stream at the end of overwinter fasting. From July to September, The Dolly Varden fed actively at sea and increased their robustness. The condition, however, rapidly declined starting with their upstream ascent in September.

The relationship of length to weight for Dolly Varden taken at Amchitka was described by the formula (Sigler, 1953; Lagler, 1956):

$$\log W = a + b \log L,$$

where

a and b are empirical constants.

FIGURE 6. CONDITION FACTORS FOR 356 SEA-RUN DOLLY VARDEN FROM MIDDEN COVE STREAM

The relationship in June 1972 for both immatures and adults of the anadromous form is shown in Figure 7. At this time, a fish 340 mm standard length weighed 454 g. By August, however, after 3 months at sea, a fish of the same length weighed about 659 g.

Age-Growth. Growth during the first 3 years of life for the anadromous Dolly Varden was strikingly slow. The juveniles were forced to feed on a sparse invertebrate fauna and to live in stream temperatures which rarely exceeded 10 C. Thus, a Dolly Varden that smoltifies at Age Group IV is expected to be only about 103 mm standard length.

Growth rate rapidly accelerated while the Dolly Varden were at sea (Figure 8), and if it were not for the short stay at sea and long overwinter fast in the streams, much larger Dolly Varden would be expected on Amchitka, with perhaps greater longevity. The anadromous habit probably imparts severe physiological stress on the adults, particularly the females, and so maximum age of Dolly Varden handled on Amchitka was 9 years

FIGURE 7. LENGTH-WEIGHT RELATIONSHIP OF SEA-RUN DOLLY VARDEN FROM MIDDEN COVE STREAM JUNE 1972

FIGURE 8. GROWTH OF DOLLY VARDEN IN BRIDGE CREEK

of age (Age Group IX). The largest Dolly Varden recorded in this study, however, was an 8-year-old female, 469 mm standard length that weighed 1,475.5 g.

Dolly Varden were aged by examining annulus rings on otoliths or inner ear bones. An otolith-to-standard-length relationship was described by the third degree polynomial (Sigler, 1953; Lagler, 1956):

$$L = b_0 + b_1 R + b_2 R^2 + b_3 R^3,$$

where L = standard length (mm)

R = otolith radius (micrometer units as measured on a binocular dissecting scope)

b = empirical constants.

Using this formula, the length of a fish at any annulus formation was back-calculated.

Fecundity and Spawning. Fecundity or the number of eggs carried by a female Dolly Varden is an important parameter in evaluating the reproductive capacity of the species and its ability to repopulate polluted waters (Ricker, 1968). A mean egg count of $1,207.9 \pm 202.1$ was found for anadromous Dolly Varden of Amchitka. Fiducial limits (95 percent) were large because the sample included females of Age Groups V through IX with ranges in standard length of 227 to 441 mm. A definite relationship exists between fecundity and fish length (Figure 9).

FIGURE 9. FECUNDITY OF ANADROMOUS DOLLY VARDEN FROM AMCHITKA

Most adults returning to the streams from their oceanic stay exhibited slightly enlarged gonads, but proliferation of these did not become marked until the first part of October. Spawning was observed in Midden Cove Stream and Bridge Creek from mid-October to late November when water temperatures were 2 to 3 C. It was expected to have continued into January. The earliest spawning activity noted on Amchitka was a male and female observed in a small gravel bar immediately below the bridge of Bridge Creek on September 30, 1969.

Most Dolly Varden redds examined in November in Midden Cove Stream and Bridge Creek were encountered about 800 m and 1,000 m, respectively, upstream from the intertidal zone. However, a successful redd was found in Clevenger Creek only 300 m upstream. The upstream movement of Dolly Varden spawners was in all cases restricted by impassable falls. An abundance of spawners was found in October, 1971, immediately below an 8-m waterfall approximately 2,600 m from the intertidal zone in Midden Cove Stream. A waterfall in Bridge Creek about 2,400 m upstream also acted as a barrier. A second factor appearing to restrict the area used by Dolly Varden for spawning is the sparsity of gravel in many streams.

Diet. Palmisano (1971) encountered over 50 food items in stomachs of 3,672 freshwater Dolly Varden taken from Amchitka during the period extending from September 1967 to November 1968. Aquatic insects, predominantly chironomids, were the most frequently occurring food items (Table 5). Also, about 40 percent of the fish stomachs contained crustaceans (mainly amphipods and isopods).

TABLE 5. MAJOR FOOD CATEGORIES IN DIETS OF FRESHWATER DOLLY VARDEN FROM AMCHITKA

Category	Percentage Occurrence
Immature insects	80
Crustaceans	40
Mollusks	10
Fish and fish eggs	5

The diet of Dolly Varden differed greatly with age and size of fish as well as season, and especially habitat type. Stream fish relied more heavily on immature insects while pond fish concentrated primarily on crustaceans such as amphipods and isopods.

Pink Salmon

Island-wide estimates of pink salmon for 1970-1972 ranged from 100 to 743 adults (Table 6). Far greater numbers returned in 1970 and 1972 than in 1971, although the numbers to each stream were not comparable for the two years. Midden Cove Stream, a highland stream in northwestern Amchitka, supported the largest runs of pink salmon in all years surveyed.

Mean lengths and weights of female pinks were greater for the small run in 1971 than for the much larger runs of the two even years (Table 7). Males, on the other hand, were smaller in 1971.

Average fecundity of pink salmon females for the three years they were examined ranged from 1,699 to 3,333 eggs per fish (Table 8).

Threespine Stickleback

Length-Weight. The length-weight relationship for 200 threespine stickleback from Amchitka (Figure 10) is represented by the equation:

FIGURE 10. LENGTH-WEIGHT RELATIONSHIP FOR 200 THREESPINE STICKLEBACK FROM AMCHITKA

TABLE 6. ESTIMATES OF THE NUMBER OF ADULT PINK SALMON
IN AMCHITKA STREAMS FOR THREE YEARS

Location ^(a)			Estimated Adult Pink Salmon		
Map Number		Effluence Coordinates	1970	1971	1972
2023 I	NE	636-972 (Roller Coaster)	10	0	10
2023 I	NW	510-968 (Clevenger)	12	0	12
2023 I	NW	504-979 (Duck Cove)	6	0	0
2023 I	NW	546-993 (Silver Salmon)	30	0	0
2023 I	NW	552-946 (Clevenger Lake)	25	0	0
2023 I	NW	522-021 (Bridge Creek)	15	0	0
2023 I	NW	465-001 (Ultra)	12	0	2
2023 I	NW	442-021 (BR)	10	0	0
2024 III	SE	427-037 (Teal)	6	0	10
2024 III	SE	367-099 (Limpet)	6	0	15
2024 III	NE	356-115	6	0	0
2024 III	NW	281-200 (Chapel Cove)	50	0	15
2024 III	NW	270-205 (North of Chapel Cove)	5	0	7
2024 III	NW	234-208 (Midden Cove)	300	80	600
2024 III	NW	206-218 (Burr House Creek South)	20	0	0
2024 III	NW	200-216 (Burr House Creek North)	30	5	12
2024 III	NW	316-136 (Fumarole)	35	15	35
2024 III	NW	303-148 (White House)	6	0	5
2024 III	NW	273-159 (Sandy Cove)	60	0	20
2024 III	NW	224-165	5	0	0
2024 III	NW	222-168 (Signal Cove)	25	?(b)	0
Total			674	100	743

(a) Map numbers and coordinates are U.S. Army Corps of Engineers, Aleutian Island (Amchitka) designation.

(b) Three redds were found in September.

TABLE 7. LENGTHS AND WEIGHTS OF ADULT PRESPAWNING PINK SALMON
COLLECTED IN 1970, 1971, AND 1972

	Sample Size			Mean Total Length, mm			Mean Body Weight, g		
	1970	1971	1972	1970	1971	1972	1970	1971	1972
Total	22	85	67	501.70	512.84	519.70	1311.61	1304.44	1325.02
Males	12	48	35	527.75	511.06	528.91	1446.18	1272.89	1420.10
Females	10	37	32	484.00	515.13	509.63	1146.60	1345.37	1301.30

TABLE 8. EGG COUNT AND RETENTION OF FEMALE
PINK SALMON AFTER SPAWNING ON
AMCHITKA

Year	Egg Count		Egg Retention	
	Weighted Mean	Range	Weighted Mean	Range
1970	3,333	1,875 - 4,000	25.0	0 - 186
1971	2,000	1,750 - 2,157	13.3	4 - 29
1972	1,699	1,441 - 1,927	16.4	0 - 45

$$\log W = -5.367 + 3.219 \log L ,$$

where

W = weight in grams

L = length in millimeters,

with a coefficient of determination (R^2) of 0.97. Thus a threespine stickleback of 46.5 mm total length weighed 1 g. As seasonal changes in weight, and thus condition, of threespine stickleback were not observed, the above relationship is a reasonable year around approximation of weight from length.

Age-Growth. The Peterson method (Ricker, 1968) using length-frequency histograms was used to determine the age composition of threespine stickleback on Amchitka (Valdez, 1971).

These data indicate that most threespine stickleback on Amchitka die after their third summer of life (about two and one-half years of age), although a few apparently survive into their fourth summer. The oldest and largest threespine stickleback captured on Amchitka in these studies was in her fourth summer of life, and was 82 mm in total length. By the above formula the 82 mm fish would weigh 6.2 g.

The young of the year, after hatching in June, grow rapidly during June, July, and August, slowly in December, and negligibly from December to June.

Instantaneous growth rate (G) calculated from mean fish weight of samples in each month indicated that growth rate was greatest in the first year of life between July and August ($G = 0.42$). Growth in the second year of life was greatest between June and July ($G = 0.20$). Monthly instantaneous growth rate was calculated by the formula (Ricker, 1968):

$$G = \frac{\log_e W_2 - \log_e W_1}{\Delta t},$$

where

G = instantaneous growth rate

W_1 = weight (g) at beginning of period

W_2 = weight (g) at end of period

Δt = time interval (1 month).

The value of G provides a rate or regression of weight change over time, essential to computing production estimates.

Fecundity and Spawning. Sexual dimorphism was exhibited by sexually mature threespine stickleback on Amchitka. Spawning males were distinguished from females by bright nuptial colors; a brilliant red-orange abdomen, dark blue-green back and a conspicuous turquoise iris. Females exhibited distended abdomens but lacked any bright coloration.

The declining number of spawning threespine stickleback after the first seine collections were made on June 5, 1968, indicated that spawning by freshwater threespine stickleback on Amchitka probably peaked on or before that time. In contrast, Hagen (1967) reported that spawning of the freshwater form, "leiurus", in British Columbia peaked April 12-16 and ended July 10 or about one month later than on Amchitka.

Fecundity of 15 gravid females varied from 41 to 270 eggs per female for a mean of 123 ± 33.1 eggs (95 percent confidence interval). Gravid females carried about 40 eggs per gram of fish weight.

Diet. The diets of 1,793 threespine stickleback taken from ponds and streams of Amchitka were examined by Valdez (1971) to determine the position and role of this species in the bioenergetics of the freshwater ecosystems. Food items were classified and grouped according to nine categories, and their percentage of occurrence in each sample of fish noted (Figure 11).

There was a predominance of immature insects (30 percent), primarily chironomids, in the diet in early summer, but this continually declined until December (10 percent). In a reverse trend, zooplankton, primarily copepods, cladocerans and ostracods, were found in only 18 percent of the fish in June, but increased to 35 percent occurrence in December. Ivlev's (1961) electivity index was employed in which:

$$E = \frac{r - p}{r + p} ,$$

where

E = electivity index

r = relative content of any ingredient
in the diet

p = relative content of that same ingredient
in the environment.

With this index, existing benthic invertebrate fauna was compared to food in the stomachs. Threespine stickleback were found to actually select for immature insects only in June ($E = +0.22$) and to avoid them in December ($E = -0.37$), demonstrating a seasonal switch in diet.

In summation, 81.5 percent of the diet of the threespine stickleback studied at Amchitka from June to August and during December was composed of zooplankton, immature insects, crustaceans, and worms. The first two categories each contributed about 25 percent of the diet.

The threespine stickleback was not a significant component of the Bridge Creek stream system and so is not considered in this discussion of energetics, but is presented because of its abundance and vital role in pond systems.

Aleutian Sculpin

The small Aleutian sculpin was abundant only in Jones Creek. The few stomachs that were examined showed that this species had similar food habits to the threespine stickleback. The same organisms were encountered in sculpin stomachs as in those of threespine stickleback, except that the proportion of crustaceans such as isopods and amphipods was greater in relation to immature insects.

FIGURE 11. DIETS OF THREESPINE STICKLEBACK ON AMCHITKA

($\bar{x}TL$ = Mean Total Length of Fish.)

FRESHWATER ECOSYSTEM MODEL

A compartmental representation of the energy flow in Bridge Creek shows that the system is strongly dependent on allochthonous input and chironomid production (Figure 12). Production of benthic periphyton and vascular plants is a small contribution from the primary producer level, while detritus and dissolved carbon input are very significant. Undoubtedly, the reduced solar radiation on the Island due to frequent overcast and the low water temperatures influence the rate of photosynthesis.

The invertebrate populations dominated the primary consumer level. Immature insects accounted for over 75 percent of the energy available to the freshwater fish of the next trophic level.

The stream system described, although low in diversity of species, is a hardy and tolerant system capable of moderate to rapid recovery from perturbations. As most of the energy into the system is via its own flow, unless the upper watershed was denuded of vegetation or the volume of flow was greatly reduced, energy supplies to higher trophic levels would be sustained.

The key to fish production in the stream is the productivity of immature insects. Disturbances to other streams on Amchitka have affected this trophic level most markedly, but because most of these insects are aerial, populations were quickly replenished by individuals from adjacent streams. As long as the stream was thoroughly flushed, repopulation by insects became most feasible.

The anadromous Dolly Varden is actually dependent upon the freshwater stream as a nursery in which it lives its first 3 or 4 years of life. The actual energy source for reproduction is acquired by the fish in the marine ecosystem. Ascents by adults are for deposition of eggs and sperm; as little or no feeding ensues, the stream food is utilized almost entirely by the young fish. The system would be very short lived if the adults were to feed in the stream as they do at sea.

The simplicity of the freshwater stream communities on Amchitka (i. e., the low number of species) gives the appearance that the ecosystem is potentially highly unstable (Odum, 1971). Effects to a part of this ecosystem, represented by a few streams, indicates that the streams themselves exhibit low tolerance to perturbation but, as long as there remain adjacent unaffected streams or ponds, the recovery is rapid. This is because a community of few species and with few channels in its food web can reestablish itself much more rapidly than a community of high complexity. The absence of highly competitive and tolerant species further enhances this recovery. In other words, there are no suckers and minnows on Amchitka capable of dominating a system in case Dolly Varden and salmon numbers become low.

FIGURE 12. COMPARTMENT MODEL OF THE PRINCIPLE FOOD WEB IN BRIDGE CREEK

Estimates of energy input (I) at each trophic level (i) are in kilocalories per square meter per year. Values in each block represent mean annual standing crop in grams dry weight per square meter. G = monthly instantaneous growth rate (weight change in grams per unit time).

EVENT EFFECTS

Immediate effects of the Milrow and Cannikin detonations on the fresh-water environment were studied by (1) documenting preevent fish and invertebrate populations, and (2) by conducting holding-pen experiments with life fishes.

Milrow

Preevent Populations

Aquatic faunal densities were estimated in the streams of the Clevenger and Silver Salmon watersheds. During preparations for the Milrow event of October 2, 1969, several hundred barrels of drilling mud tailings escaped into Clevenger Stream. The impact on invertebrate and fish populations was dramatic, as densities of both plunged to zero from the smothering and alkaline effect of the spill (Figure 13). It was shortly after the spill that the detonation occurred.

FIGURE 13. POPULATION TRENDS OF DOLLY VARDEN IN CLEVANGER CREEK, AMCHITKA BEFORE AND AFTER MUD-TAILING SPILLS IN 1968 AND 1969 FROM SITE B (MILROW SZ)

enhancing the adverse effect by releasing tailings trapped in stream muds and streamside vegetation. Evidence of recovery of invertebrates was seen in the following summer. Dolly Varden populations were estimated 65 percent recovered by 1971. The slight decrease in populations in the spring of 1972 was probably from overwinter mortalities and the absence of young of the year from the sampling gear. This slight drop in populations occurred shortly after the Cannikin event, but is interpreted as only coincidental and not an effect of the detonation (Valdez, 1974).

Holding Pen Experiments

To determine the effects of changes generated by Milrow, 73 live Dolly Varden and 2 pink salmon were held in small pens during the test. These pens were placed in four ponds and four streams at varying distances and directions from SZ. All of the test fish survived the experiment, but unpenned threespine stickleback found in the same experimental ponds were found dead from ruptured air bladders, effects believed due to the pressure changes wrought by the explosion. Many dead threespine stickleback were found in Clam Lake, 600 to 675 m from SZ, and some were encountered in another nearby pond 685 to 930 m from SZ. An average of 27 dead sticklebacks were found for every 30 m of shoreline of Clam Lake.

As Dolly Varden in the same waters were unaffected, it is believed that the physostomous fish were able to withstand changes better than the physoclistous threespine stickleback.

An estimated 85 percent of the threespine stickleback in Clam Lake were killed by pressure changes or suffocation caused by Milrow.

Cannikin

Prior to Cannikin, fish and invertebrate populations were surveyed in twelve ponds and five streams located within a 2,000-m radius of SZ. Threespine stickleback, Dolly Varden, and spawning pink salmon were encountered in these ponds and streams. As prior to Milrow, drillings and mud tailings escaped from holding ponds prior to Cannikin. Several such spills resulted in heavy mortality of invertebrates and fishes in White Alice Creek.

An estimated 10,700 freshwater fishes were killed by the Cannikin event. These included both Dolly Varden and threespine stickleback and, as with Milrow, only threespine stickleback were killed by pressure differentials. However, in no pond were more than 15 percent of the threespine stickleback killed in this manner as compared with the large percentage killed by Milrow in Clam Lake. Also, the greater ground motion of the

Cannikin event resulted in many fish being literally tossed out of the water and many others being stranded in drained ponds.

Dolly Varden killed by Cannikin were either tossed from the ponds or stranded when these drained.

Holding Pen Experiments

As with the Milrow event, live fish were held at varying distances and directions from SZ to measure the effect of overpressure. This time, in addition to Dolly Varden, threespine stickleback and pink salmon eggs were also held in pens. Nearly all pens were accompanied by passive accelerometers and/or pressure gauges.

Severe winds the night before the Cannikin event of November 6, 1971, killed many of the experimental fishes and none of the fish holding pen experiments were conclusive, although mortalities of threespine stickleback not penned indicated which populations were affected.

The pink salmon eggs held in solid plastic or plastic mesh containers were not significantly affected by the detonation. Hatching success of these eggs afterward under hatchery conditions supported this. A χ^2 test of significance was conducted between each batch of eggs held during the test and a control. Hatching success varied from 88 to 95 percent. The control batch had a 99 percent hatch. No difference in hatching was found on the basis of the 5 percent level of significance.

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APPENDIX A

A SPECIAL REPORT ON ACTIVITIES ON AMCHITKA FOR
THE PERIOD AUGUST 21-28, 1973

APPENDIX A

A SPECIAL REPORT ON ACTIVITIES ON AMCHITKA FOR
THE PERIOD AUGUST 21-28, 1973INTRODUCTION

A one-week visit was made to Amchitka by two U.S.U. scientists to locate and count adult pink salmon, Oncorhynchus gorbuscha, in streams. The visit was timed for late August since spawning peaked during this time in the previous three years. As the run in 1971 (from which this year's run was spawned) was relatively small, the return of their progeny in 1973 was expected to be about the same number of fish (100). Streams near roads were visited periodically, but only those relatively inaccessible streams known to have sizeable runs in previous years were visited since no helicopter was available for access to off-road streams.

Two experimental gill nets were set in Cannikin Lake to determine what fish, if any, were present and also to collect fish samples for examination. Also, the portion of White Alice Creek now draining Cannikin Lake was electrofished to determine if fish were present. Fish collected from the lake and stream were saved for radiological analysis by the Laboratory of Radiation Ecology, University of Washington.

SALMON SURVEY

Eleven Amchitka streams known to support spawning pink salmon in the past three years were visited from August 21 to 27 (Table A-1). Access to six of these streams had to be by foot since no helicopter was available as in previous year's surveys. The other five streams were near roads where they could easily be reached.

Each stream was examined by at least two men (one walking in the stream and the second along the bank). Fish encountered in these shallow streams were identified and counted. Attempts to capture fish were aided by long handled nets. A 20-foot beach seine was carried for use in collecting fish. Captured fish were weighed, measured and released.

Only five pink salmon (one in Fumarole stream and four in Midden Cove Creek) were observed. Only one fish, a female (from Fumarole stream), was captured (total length = 532 mm, weight = 1513 g). This fish

TABLE A-1. ESTIMATES OF THE NUMBER OF ADULT PINK SALMON IN AMCHITKA STREAMS FOR FOUR YEARS

Location(a)			Estimated Adult Pink Salmon			
Map Number		Effluence Coordinates	1970	1971	1972	1973(b)
2023 I	NW	636-972 (Roller Coaster)	10	0	10	0
2023 I	NW	510-968 (Clevenger)	12	0	12	0
2023 I	NW	504-979 (Duck Cove)	6	0	0	0
2023 I	NW	546-993 (Silver Salmon)	30	0	0	0
2023 I	NW	552-946 (Clevenger Lake)	25	0	0	0
2023 I	NW	522-021 (Bridge Creek)	15	0	0	0
2023 I	NW	465-001 (Ultra)	12	0	2	--
2023 I	NW	442-021 (BR)	10	0	0	--
2024 III	SE	427-037 (Teal)	6	0	10	--
2024 III	SE	367-099 (Limpet)	6	0	15	--
2024 III	NE	356-115	6	0	0	--
2024 III	NW	281-200 (Chapel Cove)	50	0	15	0
2024 III	NW	270-205	5	0	7	0
2024 III	NW	234-208 (Midden Cove)	300	80	600	4
2024 III	NW	206-218 (Burr House)	20	0	0	--
2024 III	NW	200-216 (Burr House)	30	5	12	--
2024 III	NW	316-136 (Fumarole)	35	15	35	1
2024 III	NW	303-148 (White House)	6	0	5	--
2024 III	NW	273-159 (Top Side)	60	0	20	0
2024 III	NW	224-165	5	0	0	--
2024 III	NW	222-168 (Signal)	25	0	0	--
Totals			674	100	743	5

(a) Map numbers and coordinates are U.S. Army Corps of Engineers, Aleutian Island (Amchitka) designation.

(b) Counts were made during a one-week period. Previous year's sampling periods extended throughout the entire spawning season.

and the four from Midden Cove Creek were found on the second and fourth days of the visit. All appeared to have recently ascended; no additional fish were seen on other visits made to each stream during the week.

The abundance of adult pinks observed in Amchitka streams this year was substantially less than that observed 2 years before. This situation may be accounted for by one or a combination of explanations.

- (1) The survey was not as extensive as in previous years and may have been conducted too early and over too short a period of time. Peaks of spawning the previous 3 years were late August to early September. It is unlikely that the spawning had already occurred by the time of this survey since there was no evidence of this (i.e., redds, carcasses, etc.).
- (2) Stream flows lacked sufficient volume for a favorable ascent by the adults. This stream condition will delay or even prevent upstream migration even when the fish are sexually mature. There are no stream-gauge data available at this time to support the possibility that this was a major factor but the volume of the streams was less than it was during previous years in late August. Although the streams could be considered accessible, it has been noted in past years that ascent usually occurs immediately after a large amount of rain swells the streams. One rain occurred during this visit but stream response was less than expected.
- (3) A severe mortality may have been imposed on the fish at any stage of their development. Since only 100 adults (80 of which were in Midden Cove Creek) returned in 1971, a lower than normal survival of their eggs and progeny would severely reduce the number of returnees to nearly eliminate the run for that year.

There is little likelihood that Cannikin produced egg mortality because the detonation occurred on November 6, 1971 (peak of spawning occurred August 25-28, 1971), and because egg-holding experiments during Cannikin testtime closer to ground zero indicate damage to salmon eggs from pressure shock would not be expected. Mortality of the pink salmon of Midden Cove Creek could have resulted from a study conducted on that stream in 1971. Although several of the 80 spawning adults in this stream were handled by scientists, it does not seem that this should have affected spawning success because the fish were observed later to have spawned successfully and live eggs were found in redds.

CANNIKIN LAKE

Cannikin Lake has an estimated area of 30 surface acres with maximum depth of 31 feet (Gonzalez, Wollitz, and Brethauer, 1974*). It receives surface drainage from the northwest branch of White Alice Creek (also impounded near SZ) and empties into the main White Alice Creek. The water is turbid from bank decay and wind, but there is no odor of oil or evidence

* Gonzalez, D. D., L. E. Wollitz, and G. E. Brethauer. 1974. Bathymetric reconnaissance of Cannikin Lake, Amchitka Island, Alaska (pending Director's approval).

of the drilling mud which was released into the lake basin during drilling operations and then again from sumps by Cannikin.

Two 125-foot experimental gill nets were set for 24 hours (0800 hours to 0800 hours) in Cannikin Lake proper. A surface set was made in about 6 to 8 feet of water near the lake outlet and a bottom set in the lake center as near to the old stream bed as possible (15-20 feet depth).

Four Dolly Varden were caught in the two gill nets (Table A-2). All were taken in the two frames with smallest mesh (1/2 and 1 inch square mesh) indicating that few, if any, large Dolly Varden are present in the lake.

TABLE A-2. DOLLY VARDEN TAKEN IN TWO GILL NETS FROM
CANNIKIN LAKE AUGUST 26, 1973

Fish	Total Length, mm	Standard Length, mm	Weight, g	Sex	Stomach Contents
1	152	131	38	Immature male	Annelids, midges, crane fly, beetle larvae
2	162	137	49	Male	Annelids, midges
3	163	139	48	Immature male	Annelids, midges
4	148	125	36	Immature female	Annelids, beetle larvae, midges

All of the fish captured in the lake were the dwarf form of Dolly Varden, probably having gained access from stream sections not affected by drilling muds before Cannikin. The form is morphologically and habitually distinct from the larger searun form and resides in streams such as White Alice Creek which have no access to the sea. Unless dwarfism of these residents on Amchitka is genetic, these small fish should take advantage of their new enlarged habitat and grow substantially larger than those fish still restricted to the stream. Growth and maximum size will depend on a planktonic food source for the young, an insectivorous source for the young adults, and perhaps a forage fish for the larger individuals to feed on. A supply of phytoplankton and zooplankton (copepods, rotifers) has already begun to establish itself in the lake (personal communication, Dr. R. Burkett, BCL). Stomachs of these four fish contained a few insect forms (chironomids, coleopterans, and tipulids) indicating establishment of an insect fauna (Table A-2). Also, between 15 and 50 annelid worms were found in each fish stomach examined. These worms were not parasitic but were ingested by the

Dolly Varden. They are probably associated with the decaying organic matter in the new lake basin (personal communication, Mr. David Minor, U.S.U. Zoology Department).

WHITE ALICE CREEK

Few fish (Dolly Varden) remained in White Alice Stream after the introduction of drilling muds in 1969 and a chronic series of spills in 1970 and 1971. Sections of the stream nearest SZ were most affected, but apparently a small number of Dolly Varden survived in the lowermost sections near the outlet. The rechanneling and surface disturbance created by Cannikin surely allowed access of pond fishes into White Alice Creek.

Two 300-foot sections of White Alice Creek below Cannikin Lake were electrofished. The first was immediately below the lake outlet where eight Dolly Varden were captured and the second section just above the U.S.G.S. stream gauge near the effluence where four fish were captured (Table A-3). All but one of the fish appeared to belong to the dwarf form. As this one was larger than the rest and lighter colored, it may have originated from a nearby pond.

Stomachs of all 12 fish were more than half full of immature and adult forms of midges (chironomids). A good food source is apparently established in this stream below Cannikin Lake.

These fish have access to Cannikin Lake and appear to be a good source for populating the lake. A subsequent visit to Cannikin Lake in the fall of 1974 should yield further information on the numbers of fish in the lake, their growth and condition, as well as that of the invertebrate fauna.

E-SITE STREAM

The stream draining E-site was visited to examine any possibilities of recovery of fish or invertebrate populations. Although the entire substrate remains denuded of vascular plants, a number of invertebrates were found on the undersides of rocks in the stream bed. A rock about six inches in diameter was lifted from the stream bed and returned to the laboratory in a water-filled plastic bag. An estimated 150 chironomid larvae, and about 25 small mayfly larvae were found on this rock. The chironomid larvae is the basis of this food chain in Amchitka freshwaters and is therefore a significant finding. The presence of mayflies indicates that many of the muds and oil residues have been flushed out of the stream.

TABLE A-3. DOLLY VARDEN TAKEN BY ELECTROFISHING
FROM WHITE ALICE STREAM AUGUST 26, 1973

Fish	Total Length, mm	Standard Length, mm	Weight, g	Sex	Stomach Contents
<u>Below Outlet</u>					
1	235	202	142	Male	Midge larvae, and pupae
2	148	125	40	Male	Midge larvae, and pupae
3	130	111	23	Immature male	Midge larvae, and pupae
4	132	111	27	Male	Midge larvae, and pupae
5	120	99	18	Immature male	Midge larvae, pupae, adults
6	153	128	44	Male	Midge larvae, and pupae
7	144	122	34	Male	Midge larvae, and pupae
8	116	96	18	Immature male	Midge larvae, and pupae
<u>Near Stream Gauge</u>					
1	148	126	40	Male	Midge larvae, pupae, adults
2	126	108	22	Male	Midge larvae, pupae, adults
3	136	117	31	Male	Midge larvae, and pupae
4	119	98	19	Immature female	Midge larvae, and pupae

RADIOLOGICAL SAMPLES

Both collections of Dolly Varden, the four fish from Cannikin Lake, and the 12 fish from White Alice Creek were kept for radiological analysis by the Laboratory of Radiation Ecology, University of Washington. Collections of Dolly Varden were also made intertidally at the mouth of Silver Salmon stream.

In addition, about 2 pounds of threespine stickleback, Gasterosteus aculeatus, were seined from a pond near Milrow for the same purpose.