FRI-UW-7822
December 1978

FISHERIES RESEARCH INSTITUTE
College of Fisheries
University of Washington
Seattle, Washington 98195

ASSESSMENT OF THE RESERVOIR-RELATED EFFECTS OF THE SKAGIT PROJECT ON DOWNSTREAM FISHERY RESOURCES OF THE SKAGIT RIVER, WASHINGTON

by

J P. Graybill, R. L. Burgner, J. C. Gislason,
P. E. Huffman, K. H. Wyman, Q. J. Stober,
T. W. Fagnan, and A. P. Stayman

Interim Report
for
City of Seattle
Department of Lighting
Seattle, Washington

Approved

Submitted December 29, 1978

Robert L. Burgner
Director

CONTENTS

Table No. | Page

LIST OF FIGURES

1.0 INTRODUCTION

1.1 History of the Skagit Project

The City of Seattle began development of the hydroelectric potential of the Skagit River in the early 1900's. The Lighting Department of the City undertook a staged development of three dams: Gorge, Diablo, and Ross, which were begun in 1919, 1927, and 1937, respectively. Plans for development included the multistage construction of Ross Dam which was completed to an elevation of 1,365 ft in 1940, to 1,550 ft in 1946, and to its present elevation of 1,615 ft in 1949. The presence and operation of these dams has altered the general streamflow and temperature patterns in the Skagit River downstream of the Skagit Project.

Operational constraints in addition to those specified by Federal license were implemented in 1972. By informal agreement between the Washington Department of Fisheries (WDF) and Seattle City Light (SCL), minimum flows were established during the period of peak juvenile salmon abundance in an effort to reduce the impact of dam operation on the downstream fisheries. These events and others affecting the downstream flow and temperature are listed in Table 1.1.

Present plans include raising the full pool elevation of Ross Reservoir from the present 1,602.5 ft to 1,725 ft and construction of Copper Creek Dam on the Skagit River 10.2 mi downstream of Gorge Powerhouse. Physical data for the present and proposed reservoirs are presented in Table 1.2.

1.2 General Study Objectives

The aim of these studies was to establish ecological baseline data for the aquatic environment of the Skagit River between Newhalem and Concrete. Studies were designed to contribute information relevant to three SCL projects: High Ross Dam, Copper Creek Dam, and relicensing of the Skagit Project. The results provide a basis to assess the present and predicted reservoir-related effects of the Skagit Project on the downstream fishery resources of the Skagit River.

1.3 Study Area

The Skagit River, with headwaters in Canada, flows south across the international boundary through a reservoir complex made up of Ross, Diablo, and Gorge reservoirs, then continues generally west where it enters saltwater near Mount Vernon, Washington. The Skagit is one of the largest streams flowing into Puget Sound. There are three major tributaries to the Skagit River: the Cascade River, which flows in at the town of Marblemount at river mile (RM) 78.1; the Sauk River, which enters near Rockport at RM 67.0; and the Baker River, which flows in at Concrete at RM 56.5. Numerous smaller tributaries enter the Skagit River also.

These studies were conducted primarily in the Skagit River between Newhalem and the confluence of the Sauk River, and in the lower Cascade

Table 1.1 **Events in the development of the Skagit Project affecting downstream flow and temperature patterns in the Skagit River. Adapted from Seattle City Light information.**

1919	Construction began on Gorge Dam
1924	Gorge Dam began generating (1st & 2nd generator)
1927	Construction began on Diablo Dam
1929	Gorge Dam generation expanded (3rd generator)
1936	Diablo Dam began generating
1937	Construction began on Ross Dam
1940	Ross completed to 1365 ft
1946	Ross completed to 1550 ft
1949	Ross completed to 1615 ft (full pool elevation = 1600 ft)
1950	Gorge crib dam replaced with concrete
1951	Gorge Dam generation expanded (4th generator)
1953	Spillway gates installed at Ross Dam
1959	Ross full pool elevation raised to 1602.5 ft
1960	Gorge Dam replaced by present dam
1972	Informal agreement with WDF on minimum flows during peak fry abundance

Table 1.2. Physical data for the present and proposed reservoirs on Skagit River. Data taken from SCL information.

Reservoir	Maximum Elevation (ft above mean sea level)	Length at Maximum Elevation (mi)	Total Capacity at Maximum Elevation (acre-ft)	Surface Area at Maximum Elevation (acres)
Ross	1,602.5	23.9	1,435,000	11,680
High Ross	1,725	29.5	3,450,000	20,000
Diablo	1,205	4.2	90,000	910
Gorge	875	4.4	9,760	241.2
Copper Creek (495 ft)	495	10.2	123,000	2,180
Copper Creek (480 ft)	480	9.7	92,500	1,834

and Sauk rivers. This area of the Skagit River immediately downstream of Newhalem is most affected by operation of present SCL dams and a portion of this area would be inundated by the proposed Copper Creek Dam. The Cascade and Sauk rivers represented natural (unregulated) systems for comparison with the Skagit River. In addition, some sampling was conducted in the Skagit River between the confluences of the Sauk and Baker rivers, in Gorge and Diablo reservoirs, and in selected small tributaries between Newhalem and Marblemount including Newhalem, Goodell, Thornton, Sky, Damnation, Alma, Copper, Bacon, and Diobsud creeks.

A map showing the general Skagit Basin study area is presented as Fig. 1.1. Also shown are the locations of U.S. Geological Survey (USGS) gaging stations, fish hatchery and rearing facilities operated by WDF, and river miles (RM).

1.4 Acknowledgments

This report presents the results of studies conducted by the Fisheries Research Institute (FRI), University of Washington, for the City of Seattle, Department of Lighting. The FRI personnel responsible for the studies reported herein are as follows:

Dr. R. L. Burgner, Principal Investigator

Dr. Q. J. Stober, Co-Principal Investigator

Mr. J P. Graybill, Project Leader

Mr. K. H. Wyman, Field Project Biologist, fry stranding and fish rearing

Mr. P. E. Huffman, Field Biologist and Research Assistant, fish rearing and zooplankton studies

Mr. T. W. Fagnan, Research Aide and Field Biologist, fish rearing and angler survey

Mr. J. C. Gislason, Pre-Doctoral Research Associate, periphyton and benthic insects

Mr. R. G. Gibbons, Research Assistant, incubation and emergence

Mr. K. W. Kurko, Research Assistant, spawning studies

Mr. A. P. Stayman, Research Assistant, experimental fry stranding studies

Other FRI personnel who provided field and laboratory assistance are Ms. L. Jensen and Mr. J. Glock.

The cooperation received from the Washington Departments of Fisheries (WDF) and Game (WDG) is greatly appreciated. Mr. R. Orrell from WDF's Skagit Lab provided information on Skagit River salmon and Messrs. Cook and Young, at the Skagit Hatchery, provided facilities and assistance for taking eggs and holding juvenile salmon. Messrs. Engman and Oppermann, WDG, conducted aerial surveys and provided other information about Skagit River game fish. Mr. O. Hettick, USGS, provided timely streamflow and temperature data from USGS gaging stations. Thanks are due Dr. E. Brannon, University of Washington Fisheries, for technical advice on salmon egg development and handling and Mr. G. Yokoyama, University of Washington Hatchery, for providing hatchery space and technical assistance for our incubation studies. Mr. B. Snyder, FRI, provided space and assistance for experimental stranding studies at Big Beef Creek Research

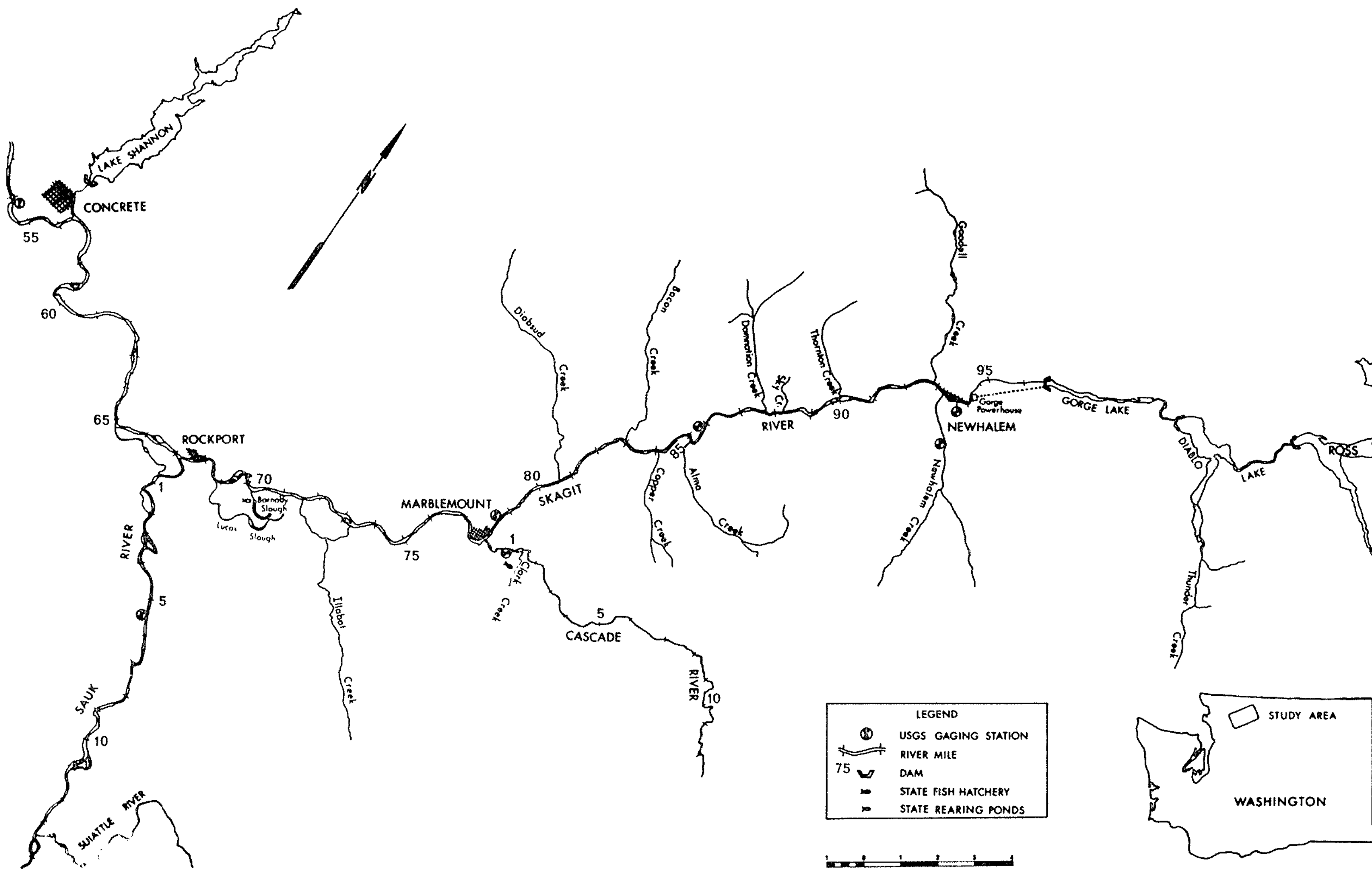

Fig. 1.1 Skagit Basin study area.

Station. Mr. C. Simenstad, FRI, and Ms. A. Litt, University of Washington Zoology Department, assisted by the loan of zooplankton sampling gear. We greatly appreciate the assistance of SCL personnel in the Engineering section and Office of Environmental Affairs by providing needed data and technical support, and the Power Control Center for providing flow information and controlled flows; we also appreciate the valuable support at Newhalem throughout our field studies.

2.0 PHYSICAL ENVIRONMENT

2.1 Discharge

The waters affected by the Skagit Project are the 94.2 river miles of the mainstem Skagit River between Gorge Powerhouse (near Newhalem) and Puget Sound. The three major tributaries of the Skagit River are the Cascade, Sauk, and Baker rivers with mean annual flows of 1,040, 4,428, and 2,700 cfs, respectively (U.S. Geological Survey--USGS). As a result of inflow from the smaller tributaries, the mean annual Skagit River discharge (USGS) increased from 4,511 cfs at Newhalem to 5,688 cfs above Alma Creek and to 6,580 cfs near Marblemount just above the confluence with the Cascade River. Continuing downstream the mean annual flow (USGS) at Concrete, just below the Baker River, was 15,280 cfs and finally became 16,980 cfs near Mount Vernon.

The long-term seasonal flow patterns for the Skagit at Newhalem (natural), Sauk, and Cascade rivers (Fig. 2.1) were characterized by high flows during late spring and early summer and by low flows during late winter and late summer. The effect of regulation by the Skagit Project on Skagit River discharge (Fig. 2.2) has been to reduce the unregulated flows during May, June, and July resulting primarily from snowmelt, and increase them for the remaining 9 months, particularly from November through March.

The 1974-1977 hydrographs (Figs. 2.3-2.6) for the Skagit (at Newhalem, Marblemount, and Concrete), Cascade, and Sauk rivers generally reflect the seasonal patterns where consistently higher flows usually occurred in May, June, and July while during late fall and winter, the high flow events were more transient in nature. Beginning in September 1976 (Fig. 2.5), the streamflows were markedly reduced from previous years reflecting the low flow conditions generally experienced in the Pacific Northwest. This general condition continued until late October 1977 (Fig. 2.6) when the more normal streamflow pattern was resumed.

Operation of hydroelectric power plants tended to make the Skagit River flow pattern more irregular than the flow patterns of the unregulated Cascade and Sauk rivers. Flow patterns at Newhalem gaging station were influenced by Seattle City Light's (SCL) Skagit Project while Concrete gaging station being downstream of the Baker River, was influenced by the discharges from Puget Sound Power and Light's Baker River developments as well. Skagit River flows were commonly lower on the weekends because of the reduced demand for power. The weekend periods are indicated in Figs. 2.3-2.6 by the dashes along the time axis.

The predominant features of the short-term Skagit River flow pattern were the hourly and daily flow fluctuations resulting from cycling the Skagit hydroelectric plants. Daily flow releases from Gorge Powerhouse usually reflected the typical power demand cycle by increasing in the morning, remaining high during the daytime period of peak demand, decreasing in the evening, and remaining low during the night. Figures 2.7-2.10 show the magnitude of the daily fluctuations in both gage

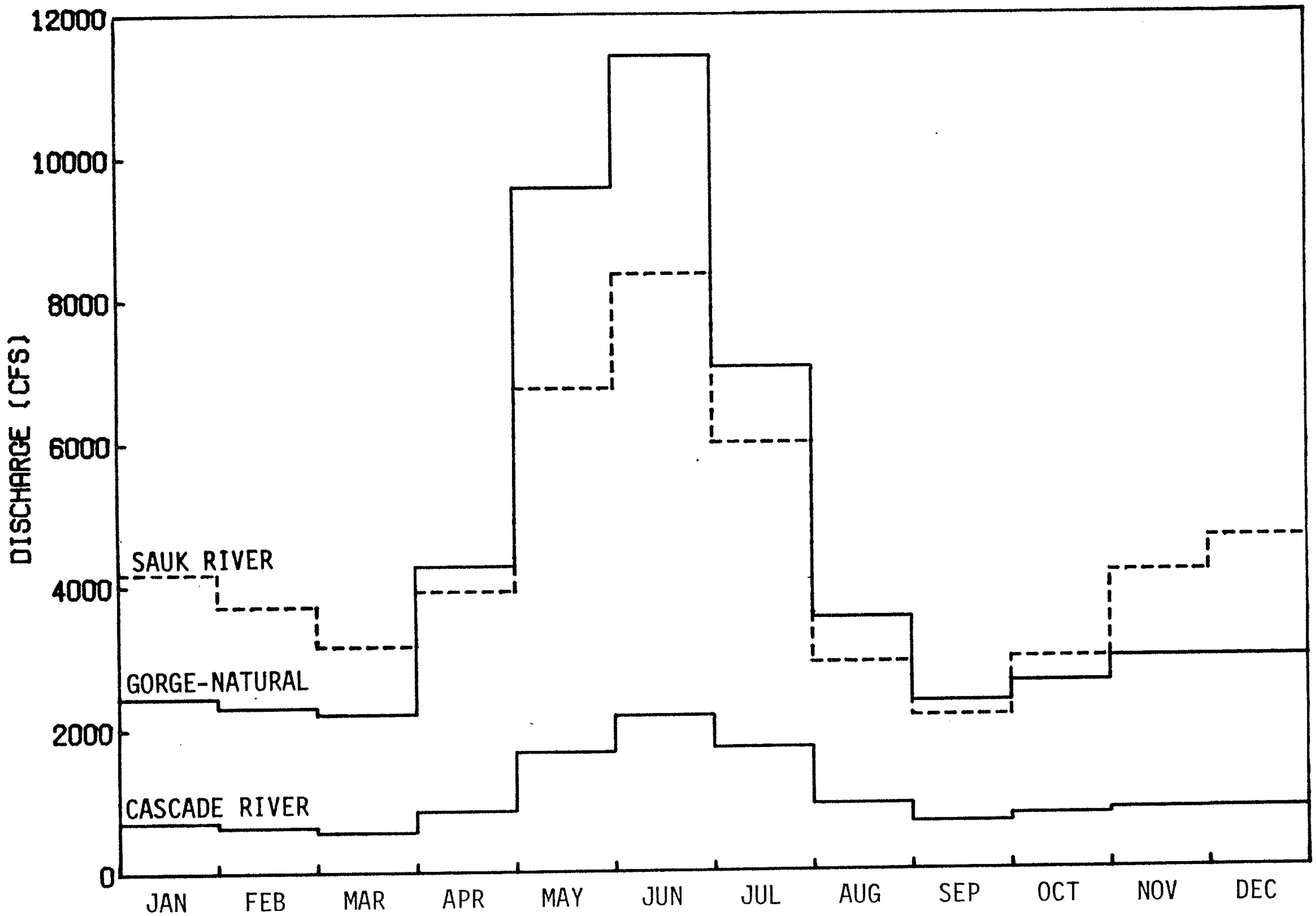

Fig. 2.1 Long-term natural streamflow patterns for Sauk and Cascade rivers (USGS 1929-1976) and for Skagit River at Newhalem (SCL 1910-1975).

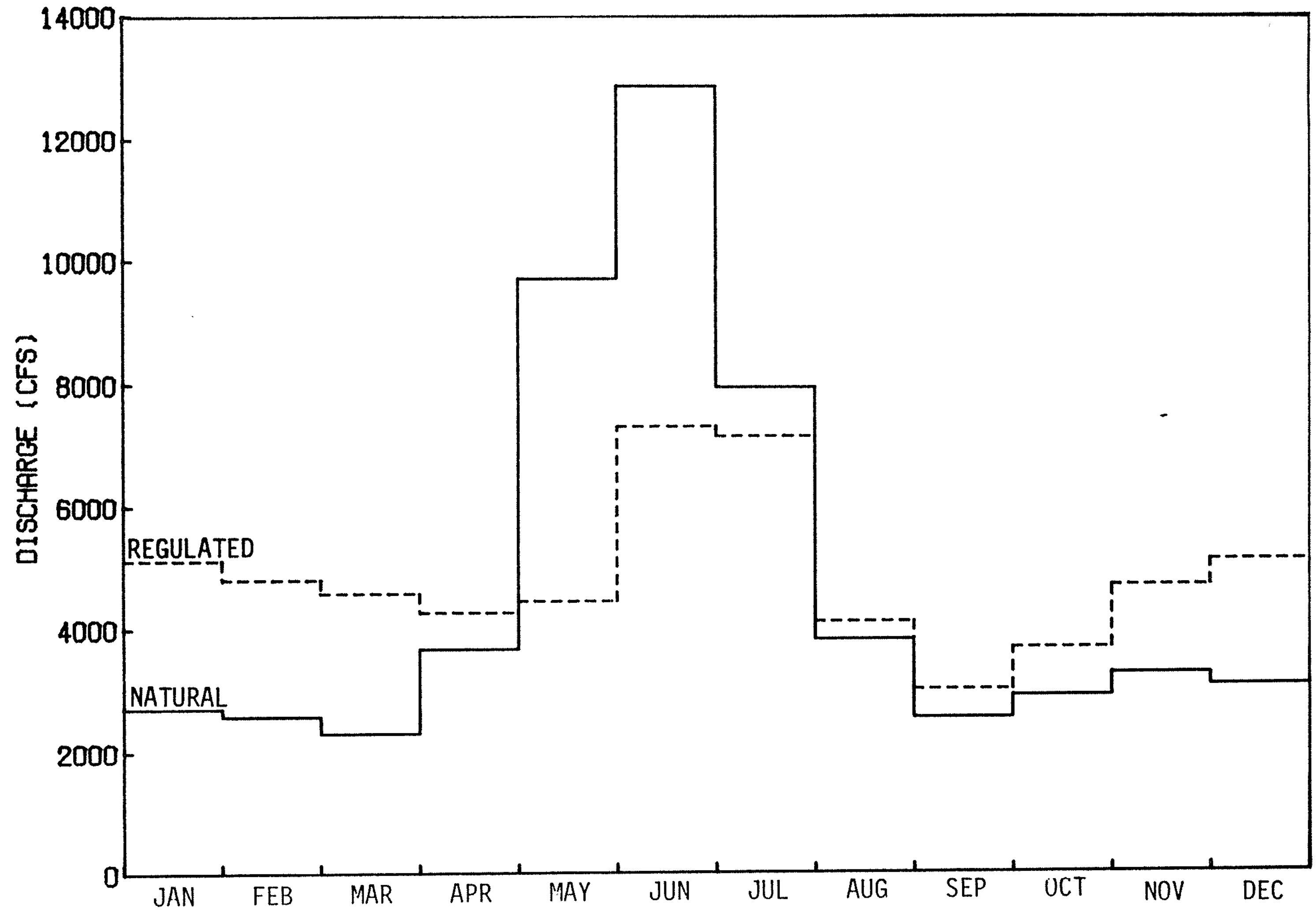

Fig. 2.2 Long-term natural and regulated streamflow patterns for Skagit River at Newhalem (1954-1975) (SCL and USGS).

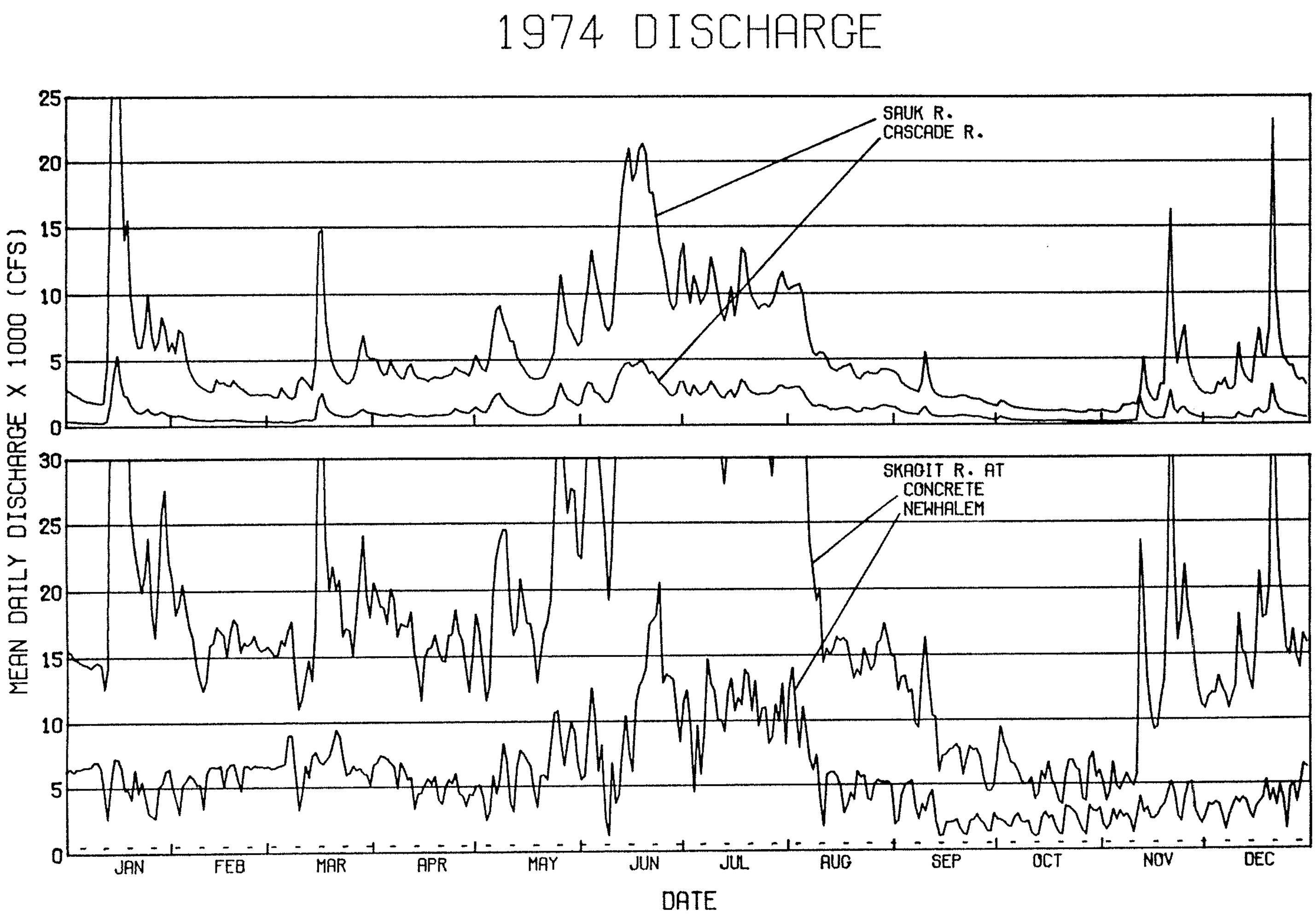

Fig. 2.3 Hydrographs of mean daily discharges at gaging sites on the Sauk, Cascade, and Skagit rivers for 1974 (USGS).

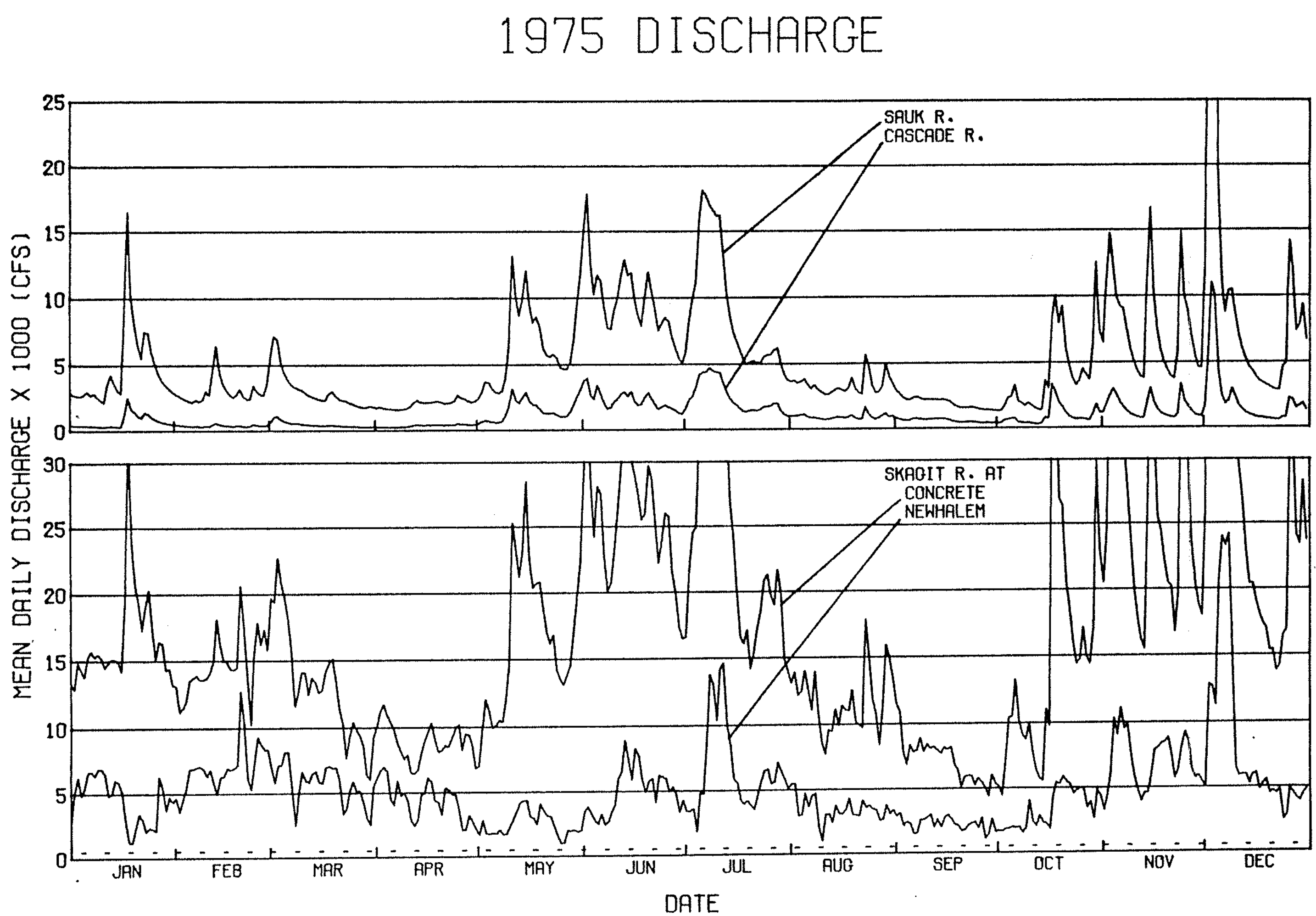

Fig. 2.4 Hydrographs of mean daily discharges at gaging sites on the Sauk, Cascade, and Skagit rivers for 1975 (USGS).

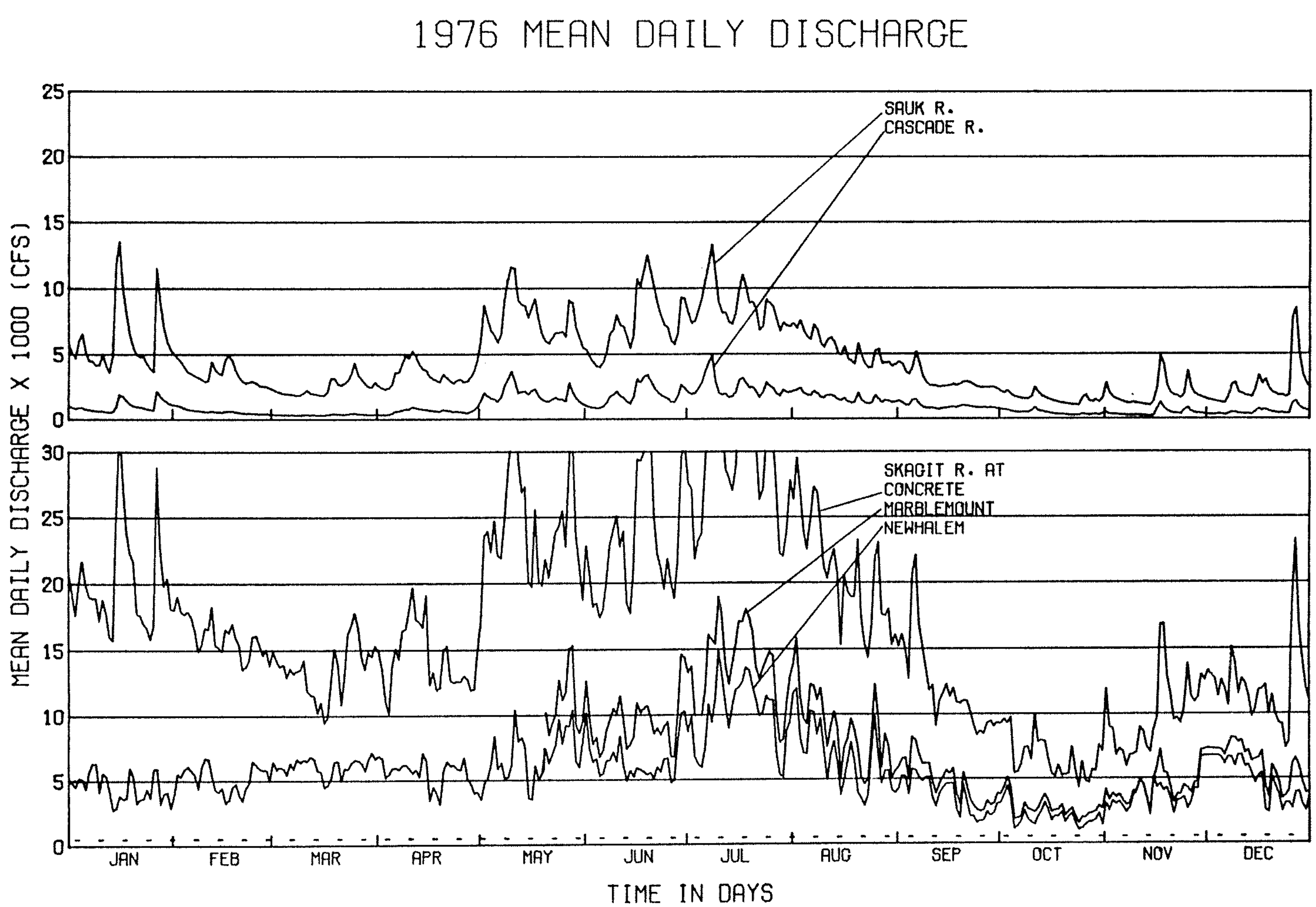

Fig. 2.5 Hydrographs of mean daily discharges at gaging sites on the Sauk, Cascade, and Skagit rivers for 1976 (USGS).

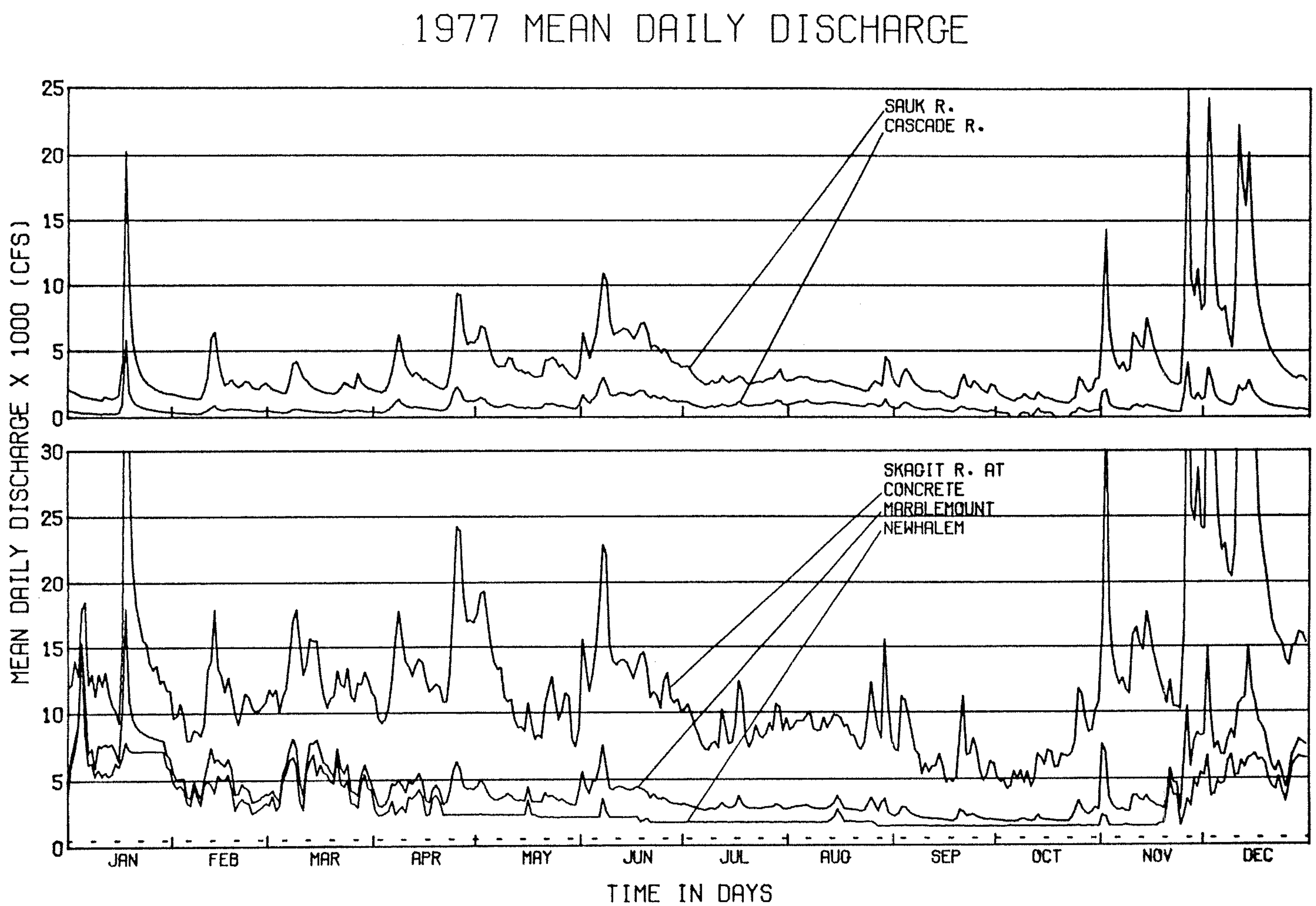

Fig. 2.6 Hydrographs of mean daily discharges at gaging sites on the Sauk, Cascade, and Skagit rivers for 1977 (USGS).

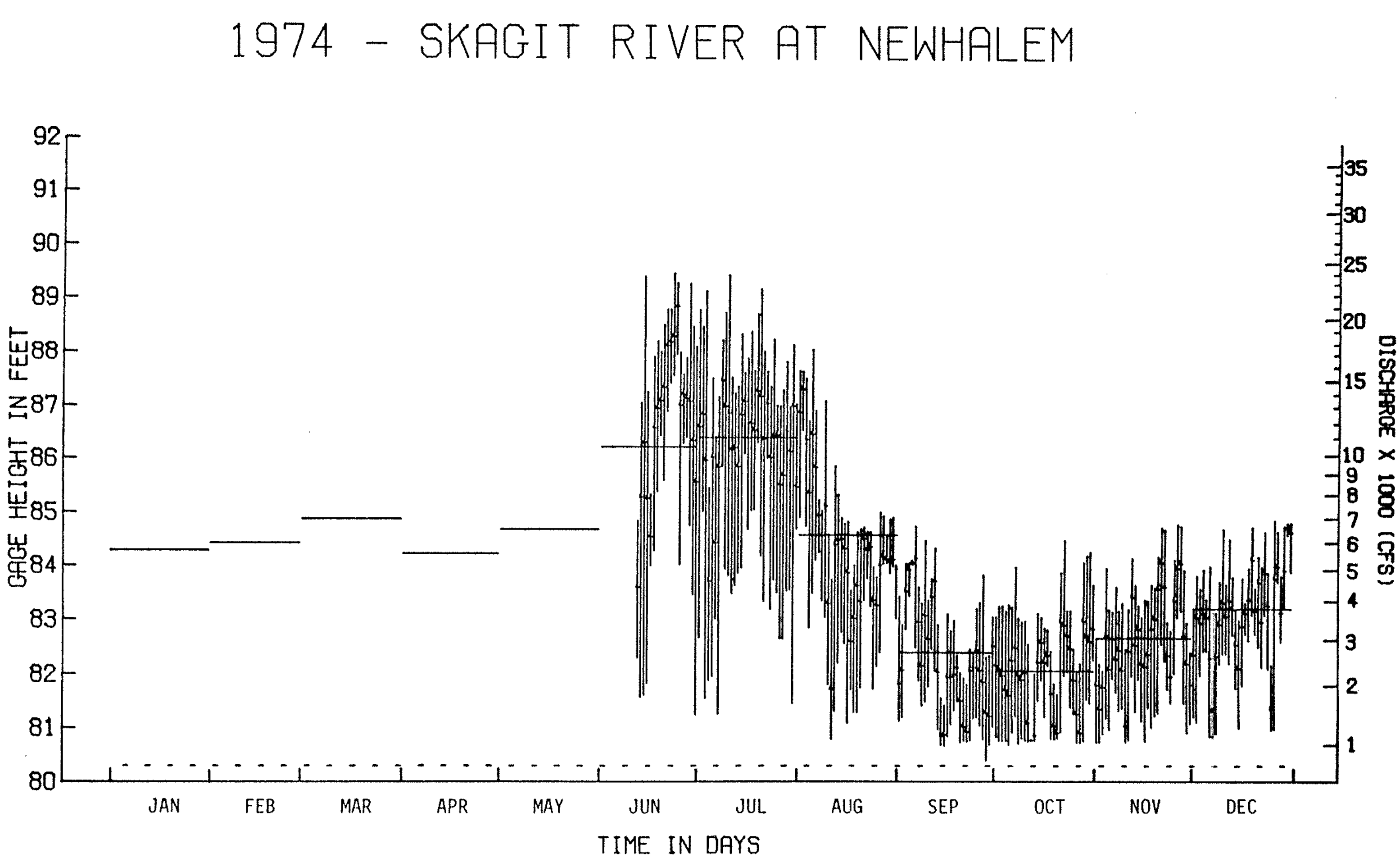

Fig. 2.7 Daily range of flow fluctuations in ft and cfs for Skagit River at Newhalem (USGS) for July through December, 1974. The mean daily discharges for this period and the mean monthly discharges for the year are also shown.

GAGE HEIGHT DAILY RANGE
1975 - SKAGIT RIVER AT NEWHALEM

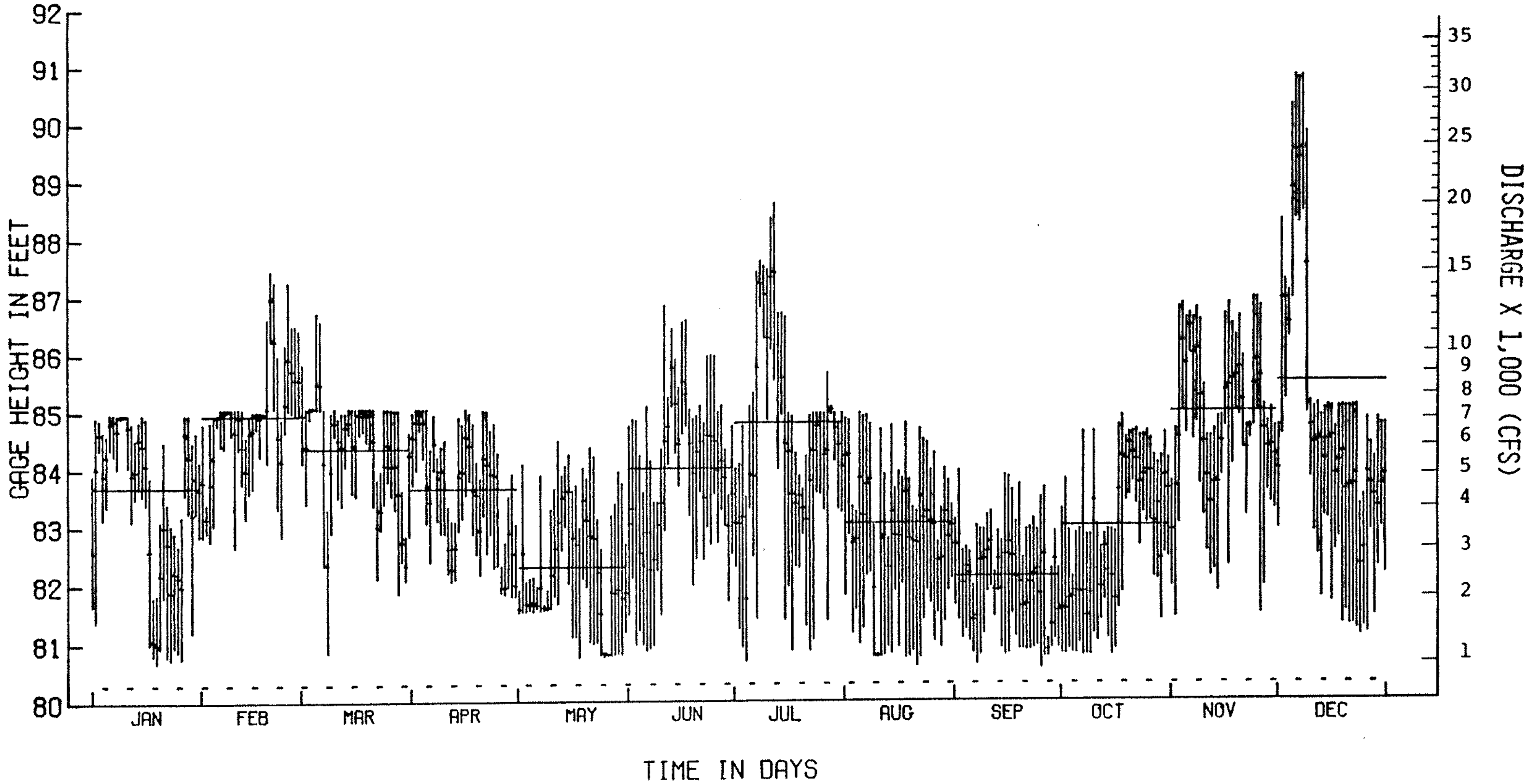

Fig. 2.8 Daily range of flow fluctuations in ft and cfs for Skagit River at Newhalem (USGS) for 1975. The mean daily discharges and the mean monthly discharges are also shown.

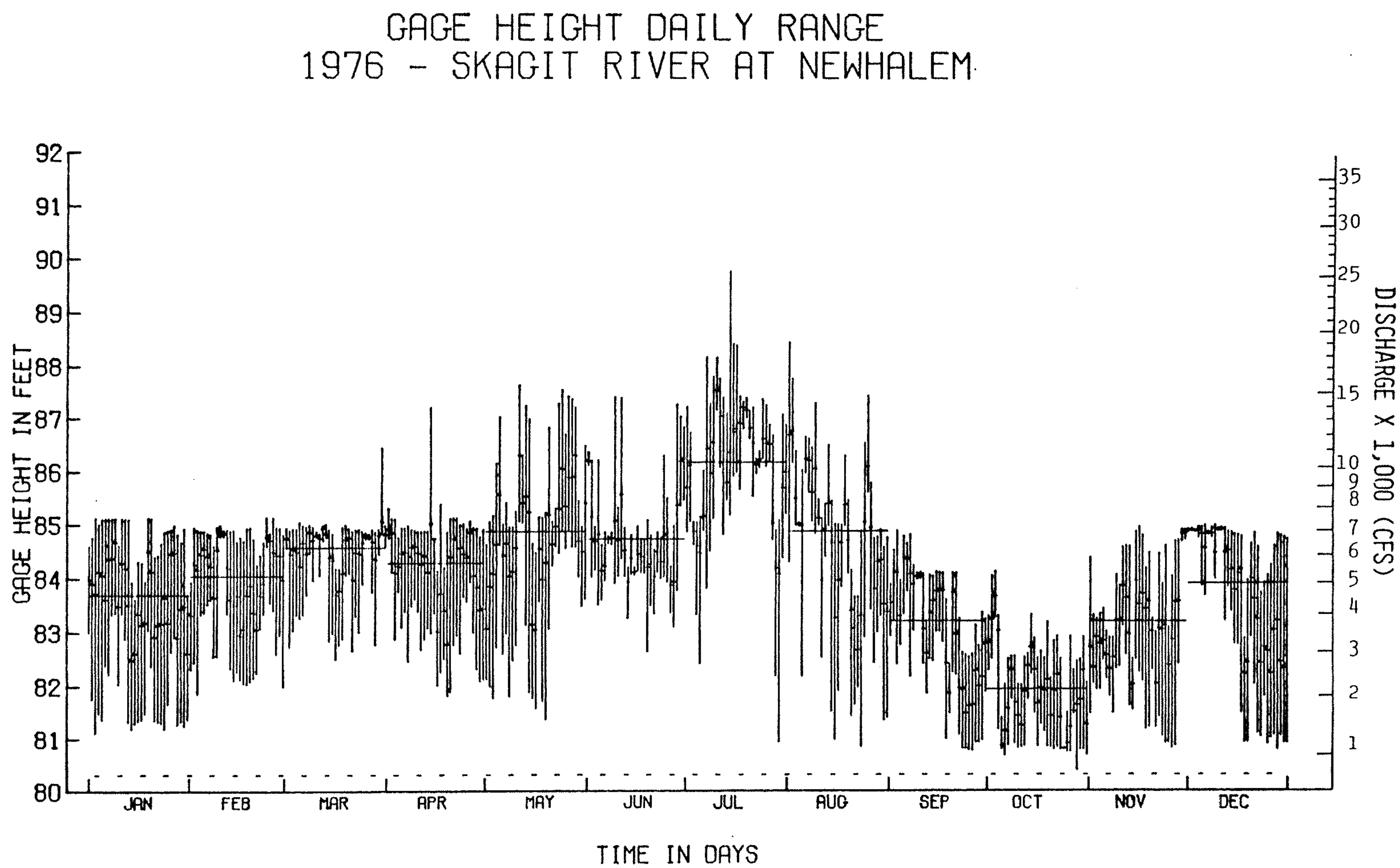

Fig. 2.9 Daily range of flow fluctuations in ft and cfs for Skagit River at Newhalem (USGS) for 1976. The mean daily discharges and the mean monthly discharges are also shown.

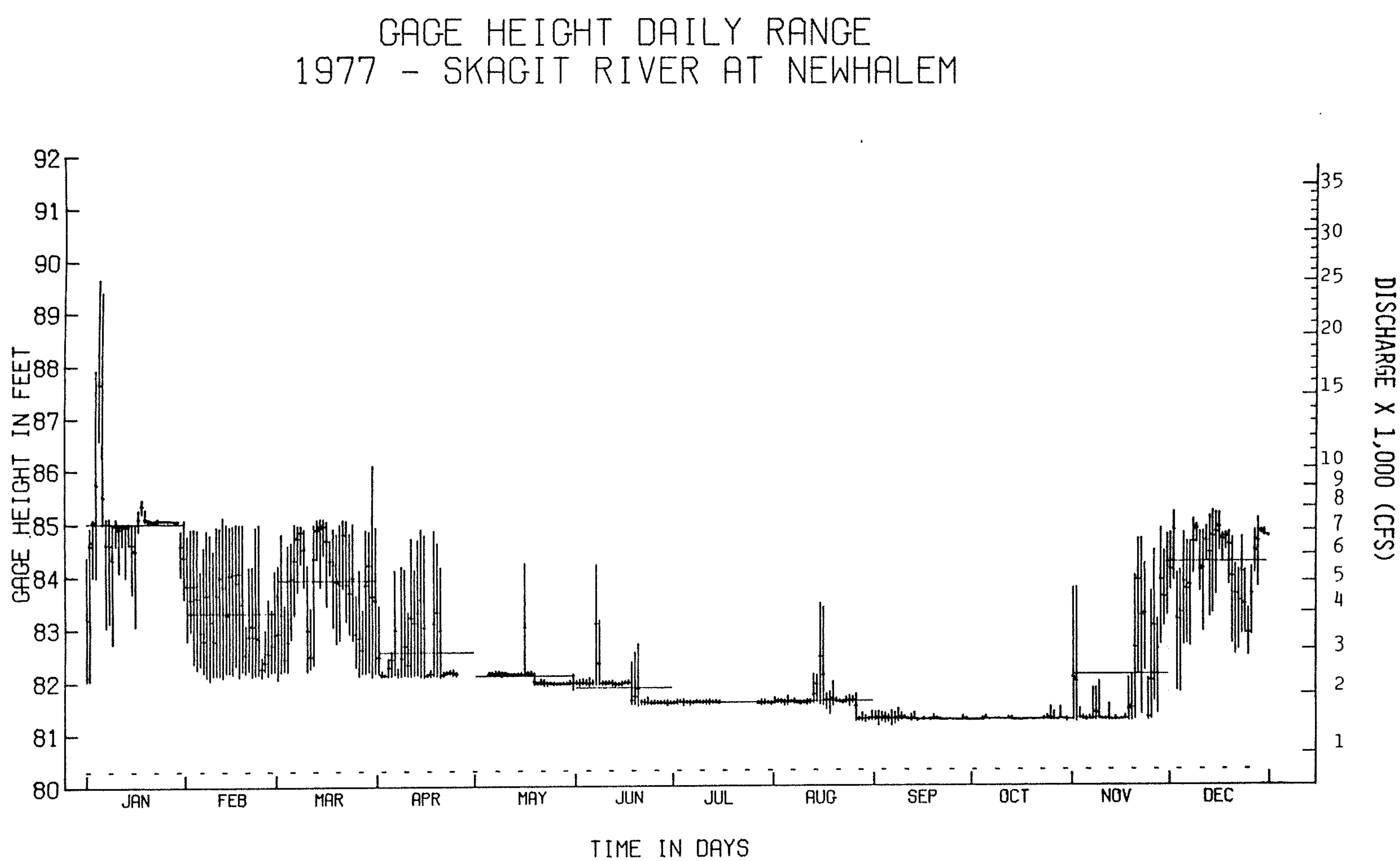

Fig. 2.10 Daily range of flow fluctuations in ft and cfs for Skagit River at Newhalem (USGS) for 1977. The mean daily discharges and the mean monthly discharges are also shown.

height and discharge for the Skagit River at Newhalem (USGS) for 1974-1977. Daily fluctuations at the USGS gaging station near Marblemount are shown in Figs. 2.11 and 2.12 for 1976 and 1977. For the period from June to December 1976 the mean daily range in water level was 1.76 ft at Newhalem, 1.38 ft above Alma Creek, and 1.01 ft near Marblemount. The potential effect on aquatic life of flow regulation by the Skagit Project would be greatest, therefore, at Newhalem, and would become progressively dampened downstream as inflow increased.

The flow patterns in the Sauk and Cascade rivers resulted entirely from natural factors such as precipitation and snowmelt. The magnitudes of the daily Sauk (Figs. 2.13-2.16) and Cascade (Figs. 2.17-2.20) river fluctuations in gage height and discharge are shown for 1974-1977. The mean difference between daily maximum and minimum water levels during 1976 was 1.89 ft in the Skagit (at Newhalem) while it was 0.30 ft in the Sauk River.

Beginning in mid-April 1977, flow releases from Gorge Powerhouse were essentially nonfluctuating until mid-November (Fig. 2.10). Releases were stepped down during this period beginning at about 2,300 cfs and then successively reduced to about 2,100, 1,700, and finally 1,400 cfs. These measures were carried out by SCL because of the general water shortage in the area and to protect fish life from fluctuating flows to low levels.

The Skagit Project provides flood control for the Skagit River below Newhalem by reducing the flows resulting primarily from snowmelt during May, June, and July. During the remainder of the year, the Skagit Project generally augments streamflow, but it can also be used to reduce the peak flows resulting from transient storm events. The estimated "natural" streamflow at Newhalem is compared to the regulated flow pattern at Newhalem in Figs. 2.21-2.24 for 1974-1977. "Natural" streamflow data were obtained from SCL which were calculated by progressively adjusting the discharge at the three dams by the changes in elevation in the respective reservoirs.

The extreme daily discharges were compiled from USGS and SCL records for the Skagit (regulated and natural) and Sauk rivers for water years 1970-1976 (Table 2.1). The ratio of maximum to minimum discharge was calculated to show relative stability of systems. The effect of Skagit dams has been to lessen the extremes so that the regulated discharge at Newhalem was more stable with a ratio of 15:1 than the natural streamflow with a ratio of 41:1. The improved stability came about by reducing the maximum flows as well as by increasing the minimum flows.

The flow stability of Sauk River with a ratio of 25:1 was intermediate to the Skagit regulated and natural flows at Newhalem. The difference between ratios for Sauk and Skagit-regulated resulted from the difference between maximum discharge while the difference between ratios for Sauk and Skagit-natural resulted primarily from differences between minimum discharge.

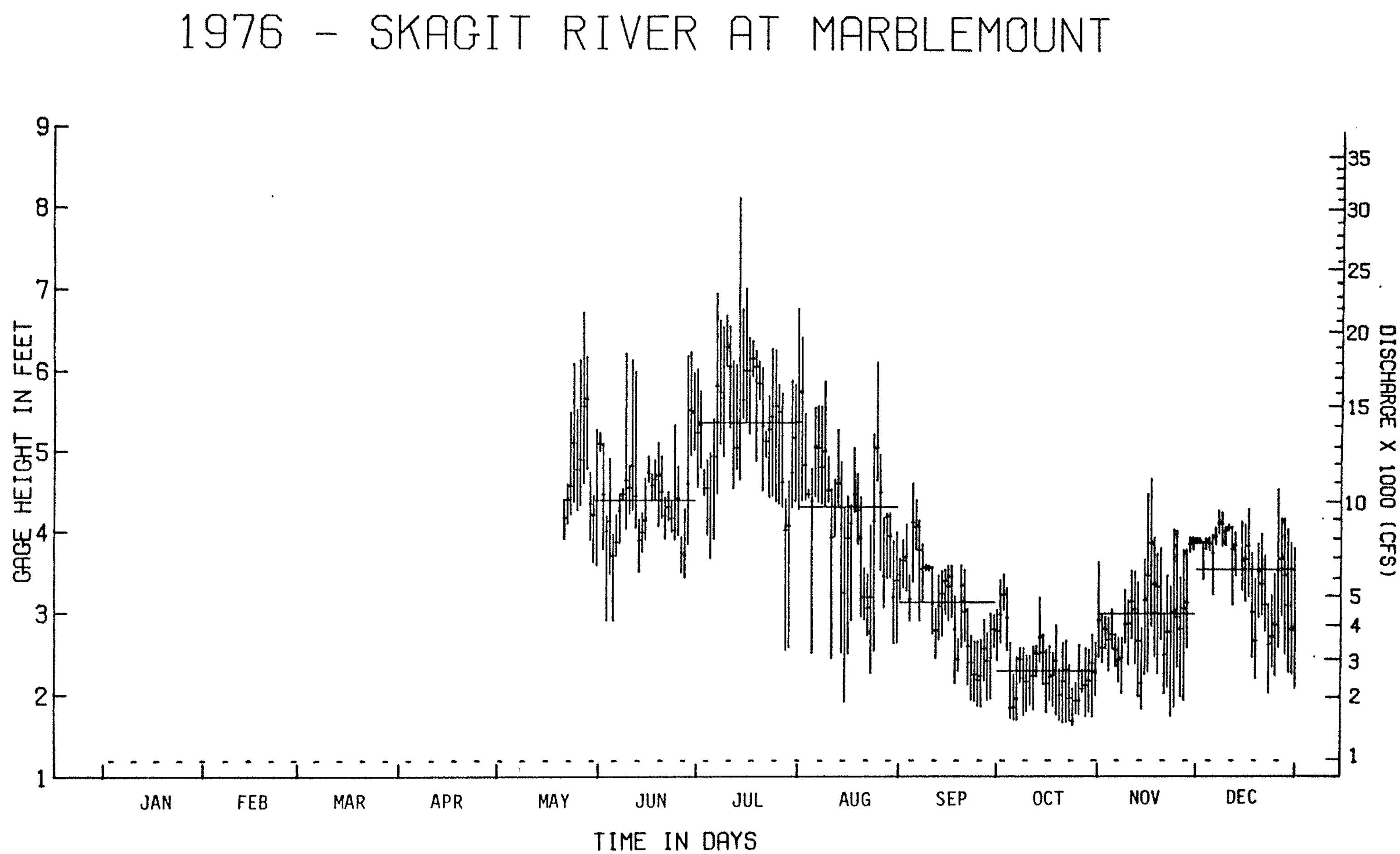

Fig. 2.11 Daily range of flow fluctuations in ft and cfs for Skagit River at Marblemount (USGS) for June through December, 1976. The mean daily discharges and mean monthly discharges are also shown.

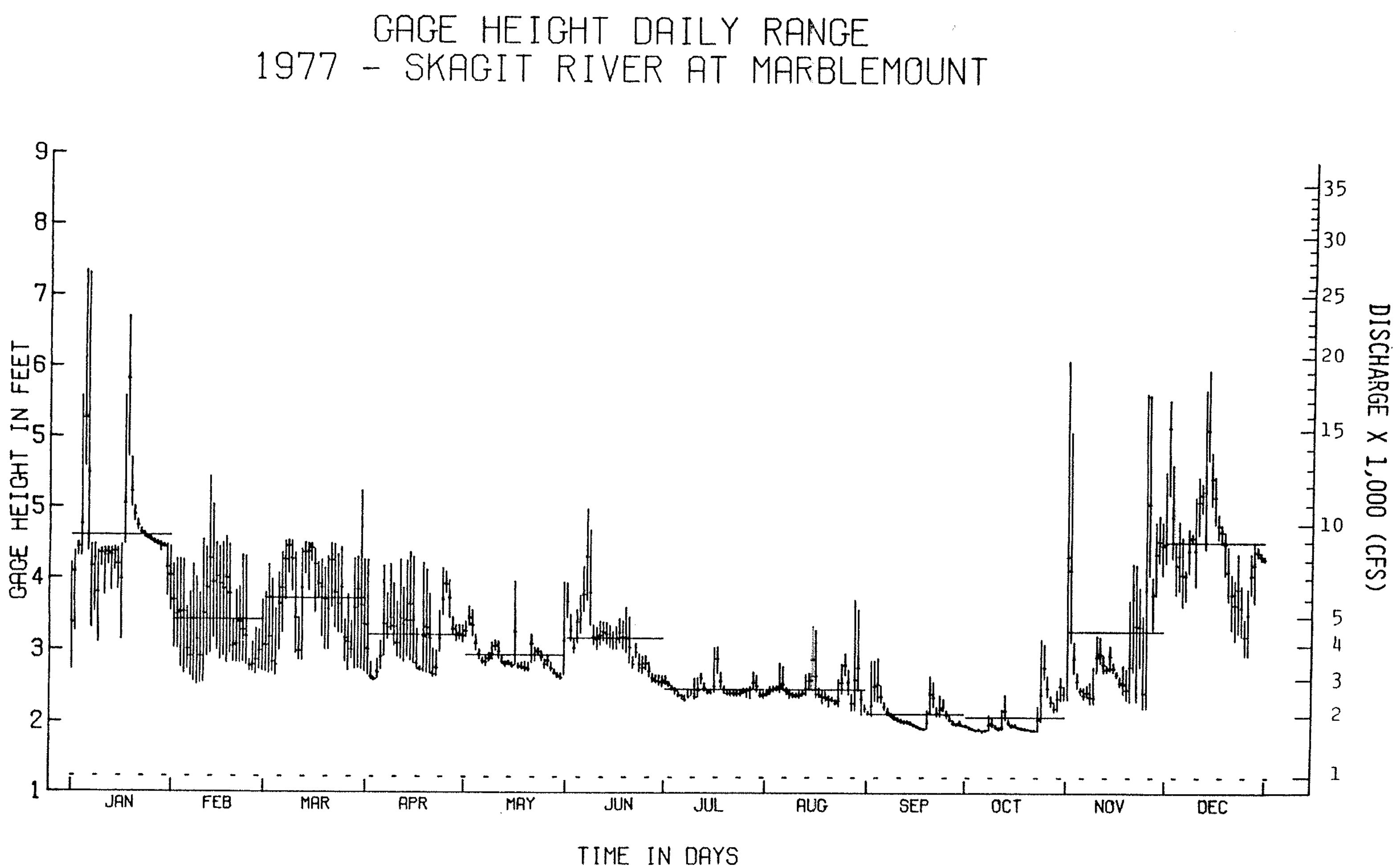

Fig. 2.12 Daily range of flow fluctuations in ft and cfs for Skagit River at Marblemount (USGS) for 1977. The mean daily discharges and the mean monthly discharges are also shown.

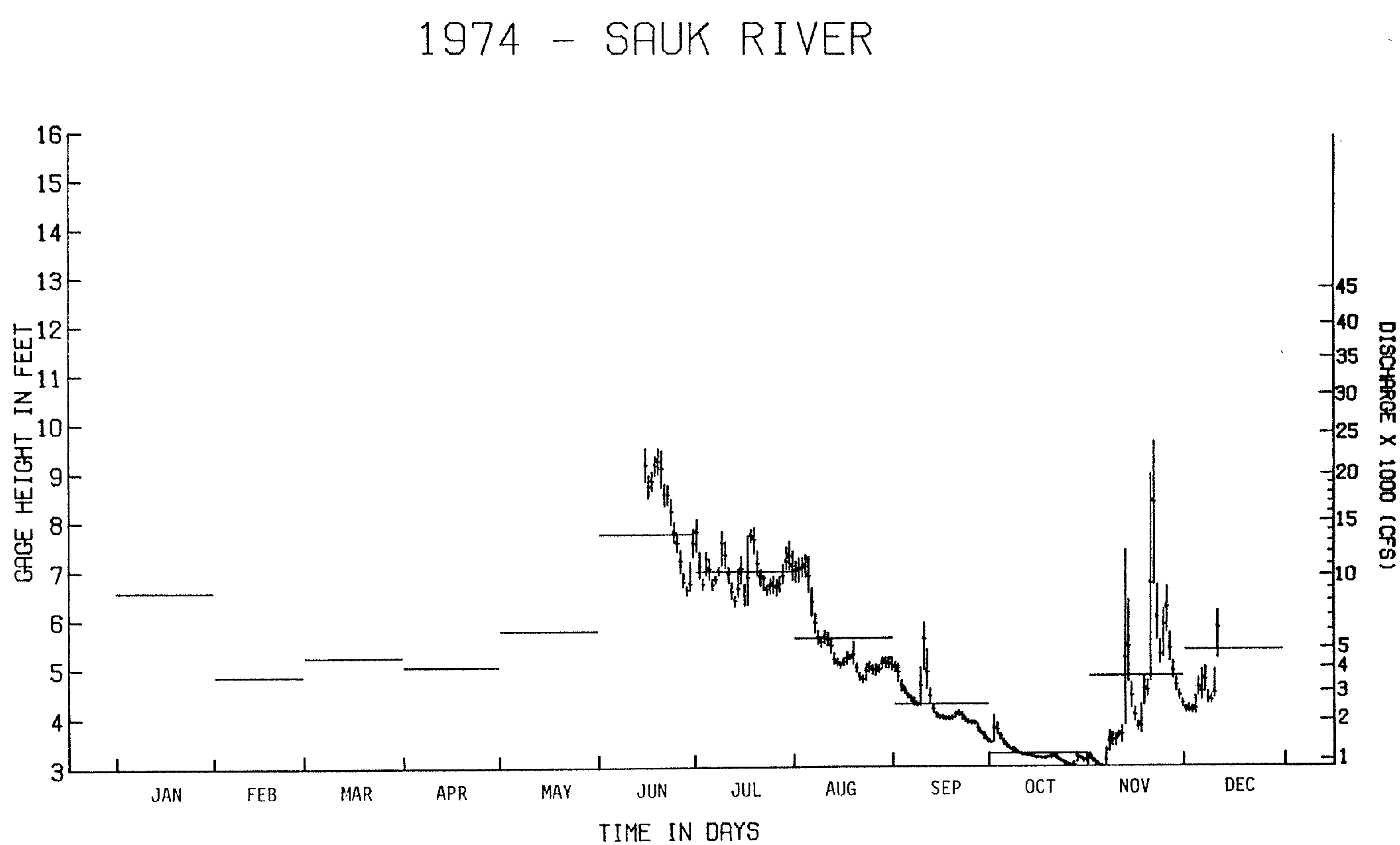

Fig. 2.13 Daily range of flow fluctuations in ft and cfs for Sauk River (USGS) for July through November, 1974. The mean daily discharges for this period and the mean monthly discharges for the year are also shown.

1975 - SAUK RIVER

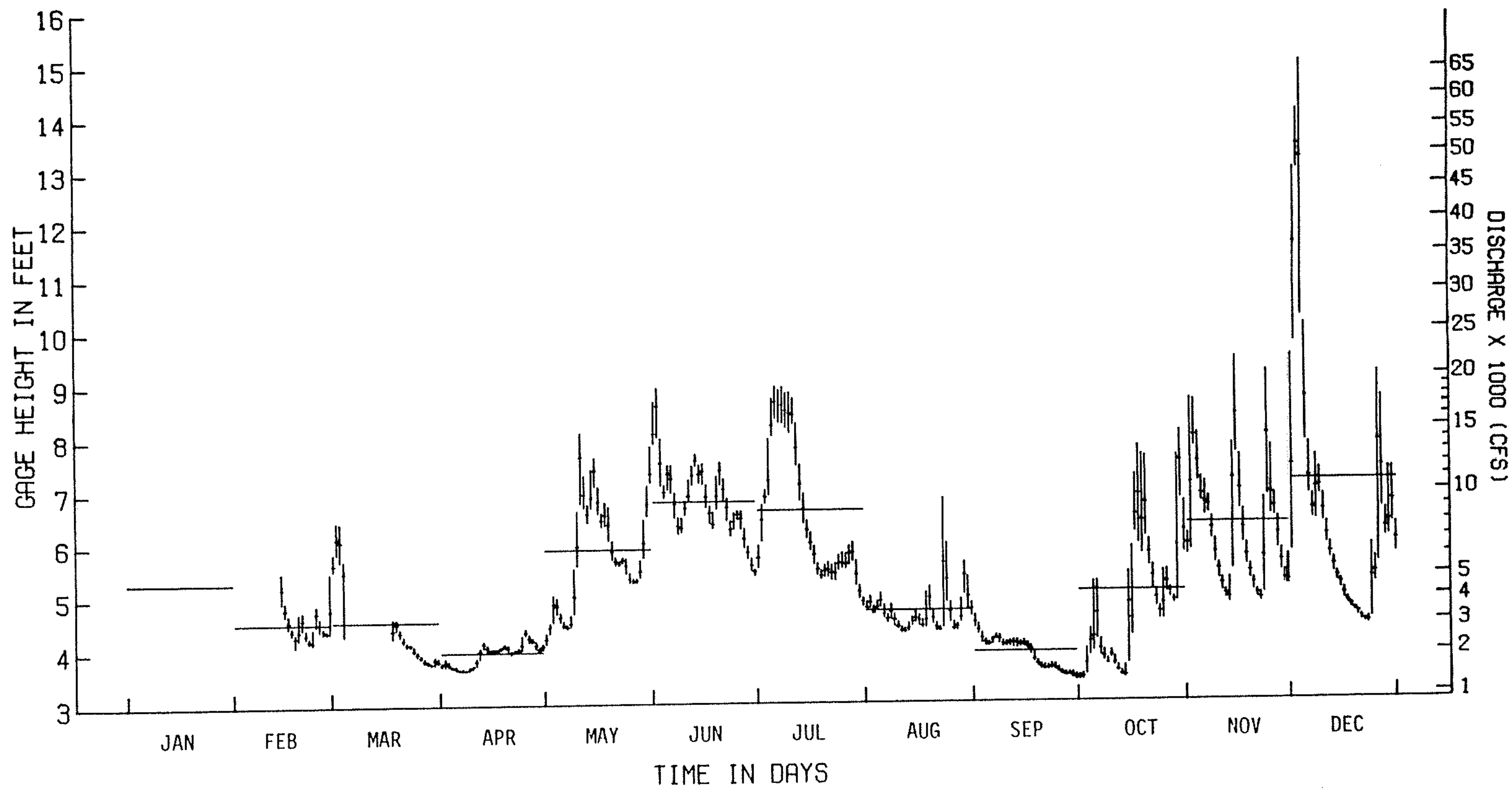

Fig. 2.14 Daily range of flow fluctuations in ft and cfs for Sauk River (USGS) for 1975. The mean daily discharges and the mean monthly discharges are also shown.

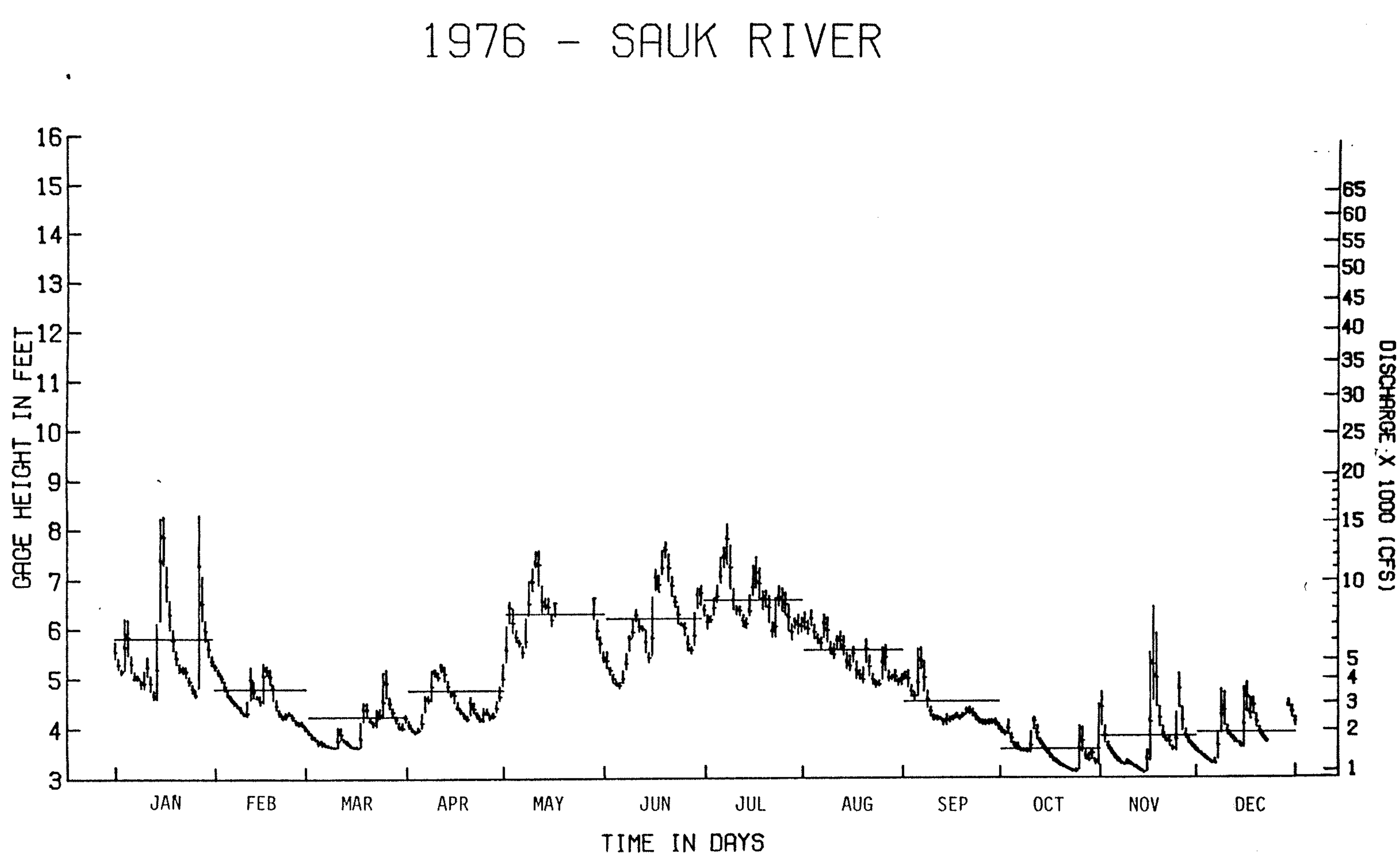

Fig. 2.15 Daily range of flow fluctuations in ft and cfs for Sauk River (USGS) for 1976. The mean daily discharges and mean monthly discharges are also shown.

GAGE HEIGHT DAILY RANGE
1977 - SAUK RIVER

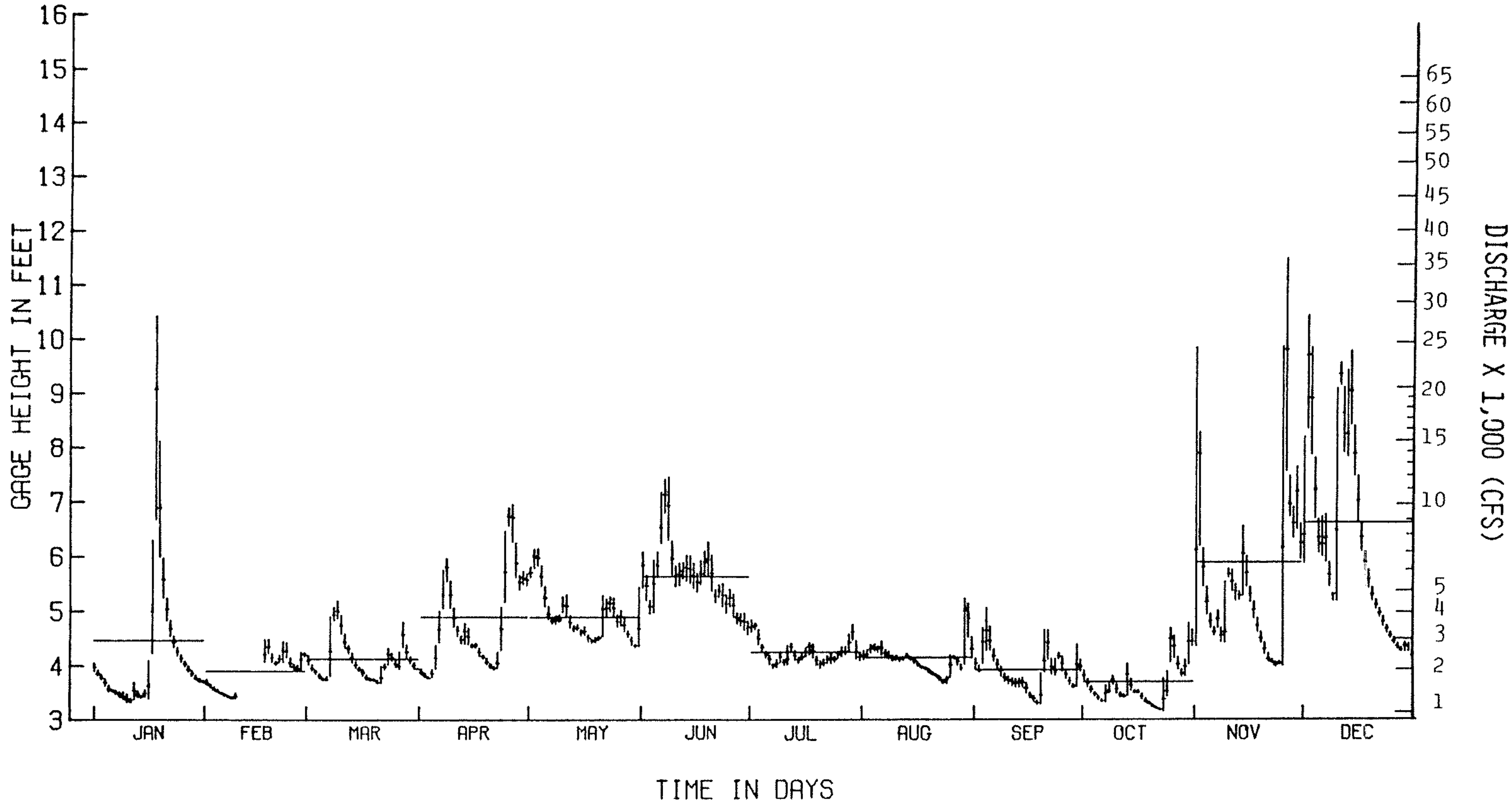

Fig. 2.16 Daily range of flow fluctuations in ft and cfs for Sauk River (USGS) for 1977. The mean daily discharges and the mean monthly discharges are also shown.

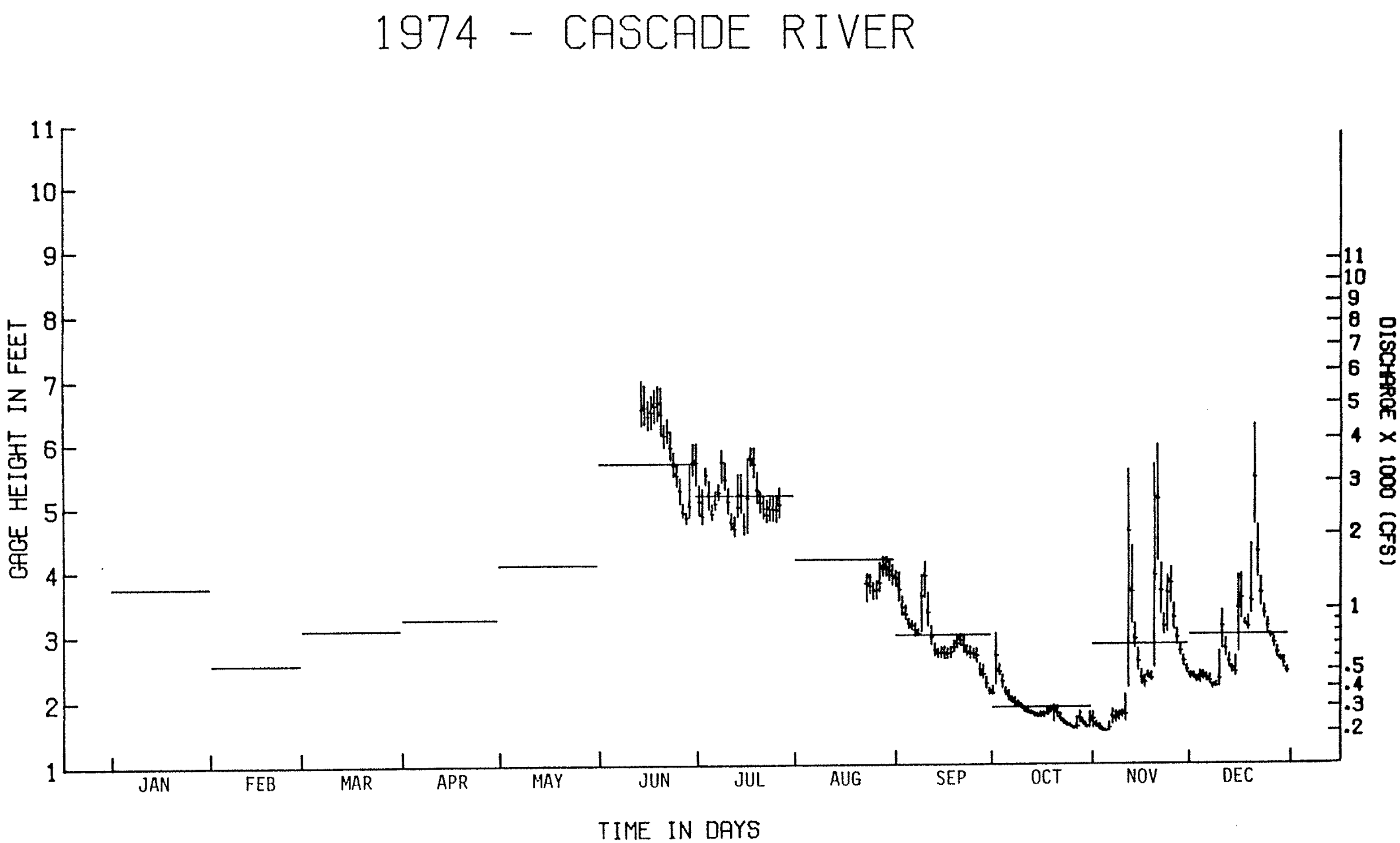

Fig. 2.17 Daily range of flow fluctuations in ft and cfs for Cascade River (USGS) for July through December, 1974. The mean daily discharges for this period and mean monthly discharges for the year are also shown.

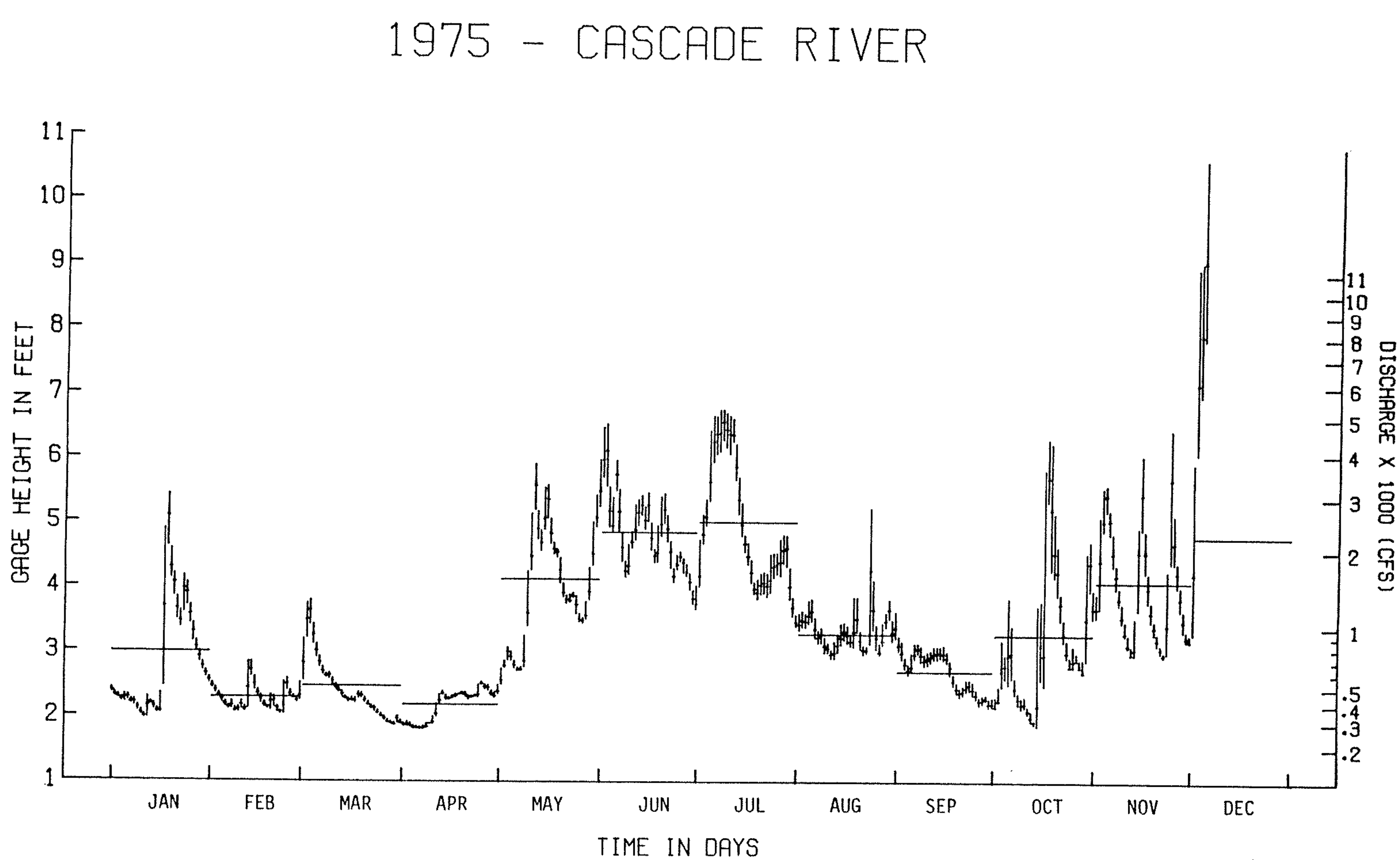

Fig. 2.18 Daily range of flow fluctuations in ft and cfs for Cascade River (USGS) for January through November, 1975. The mean daily discharges for this period and the mean monthly discharges for the year are also shown.

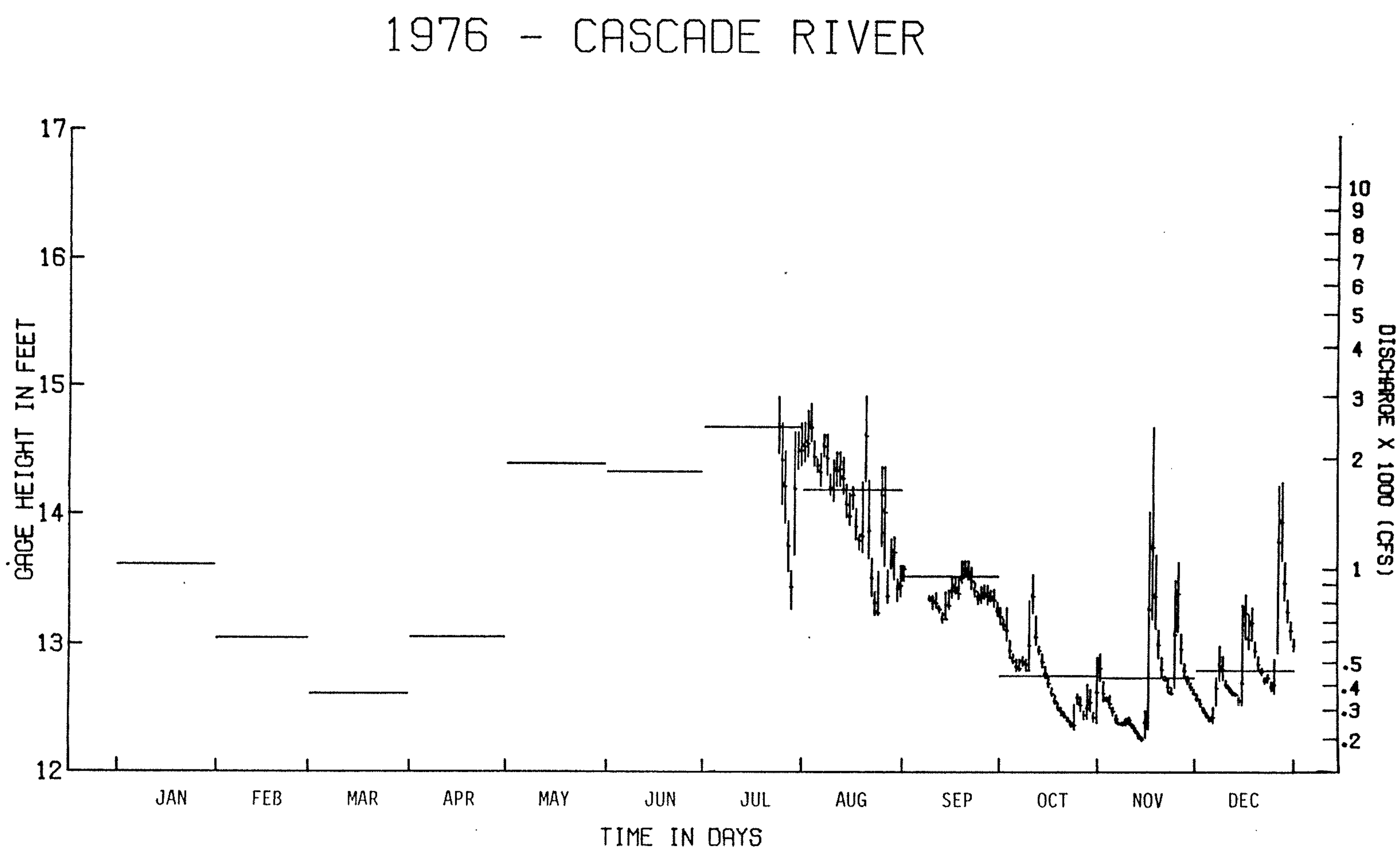

Fig. 2.19 Daily range of flow fluctuations in ft and cfs for Cascade River (USGS) for August through December, 1976. The mean daily discharges for this period and the mean monthly discharges for the year are also shown.

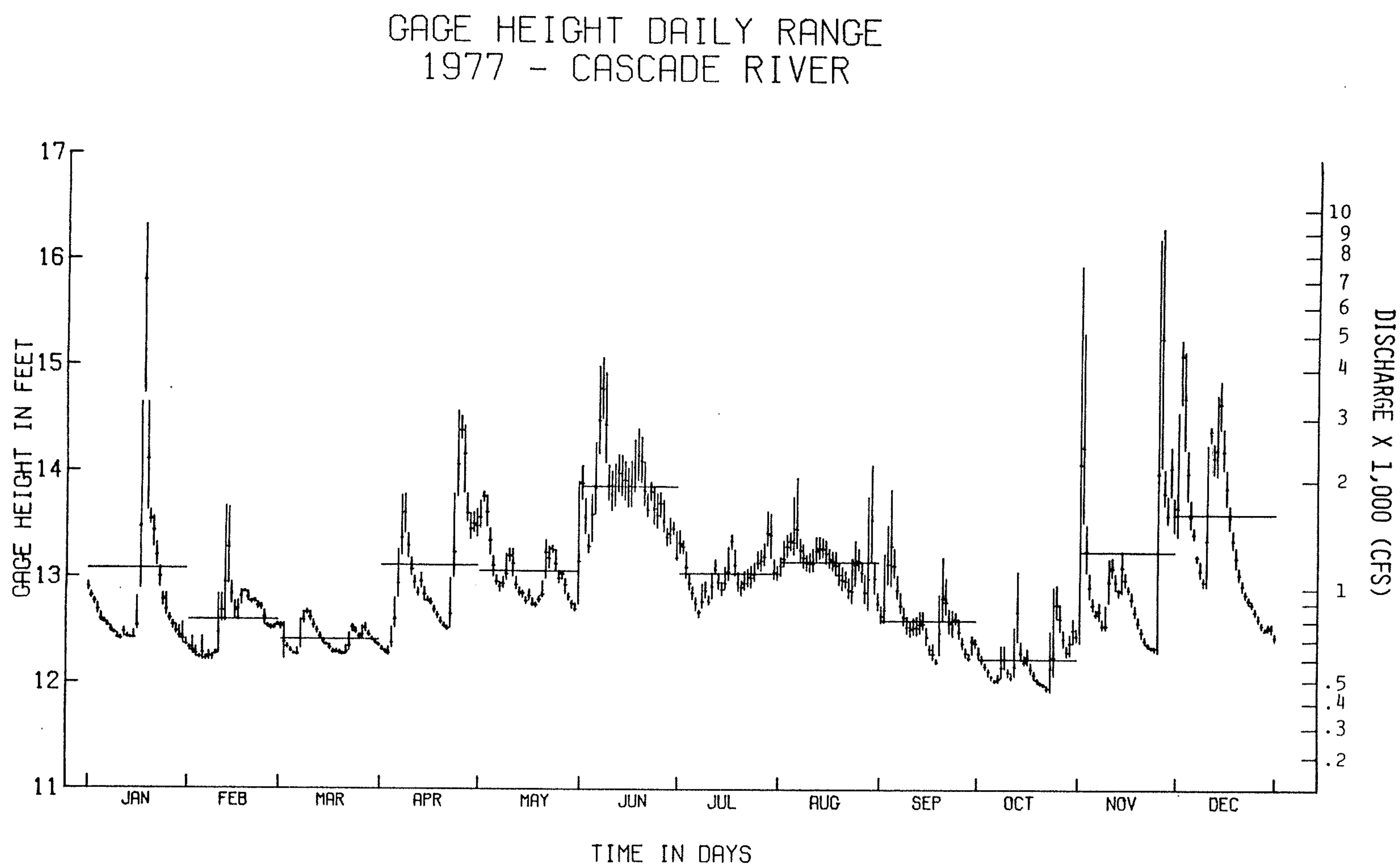

Fig. 2.20 Daily range of flow fluctuations in ft and cfs for Cascade River (USGS) for 1977. The mean daily discharges and the mean monthly discharges are also shown.

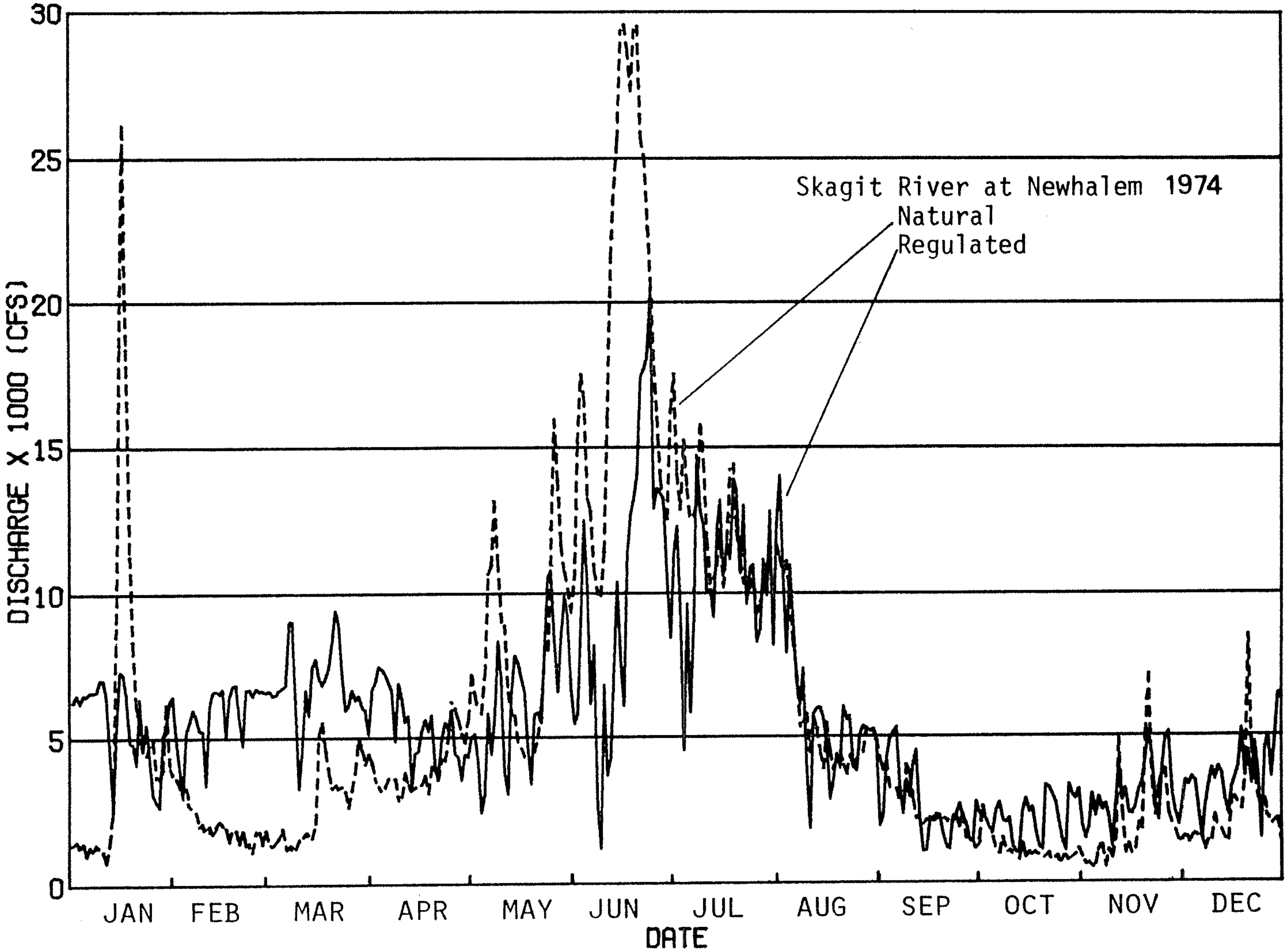

Fig. 2.21 Natural and regulated streamflows in cfs for Skagit River at Newhalem for 1974 (SCL and USGS).

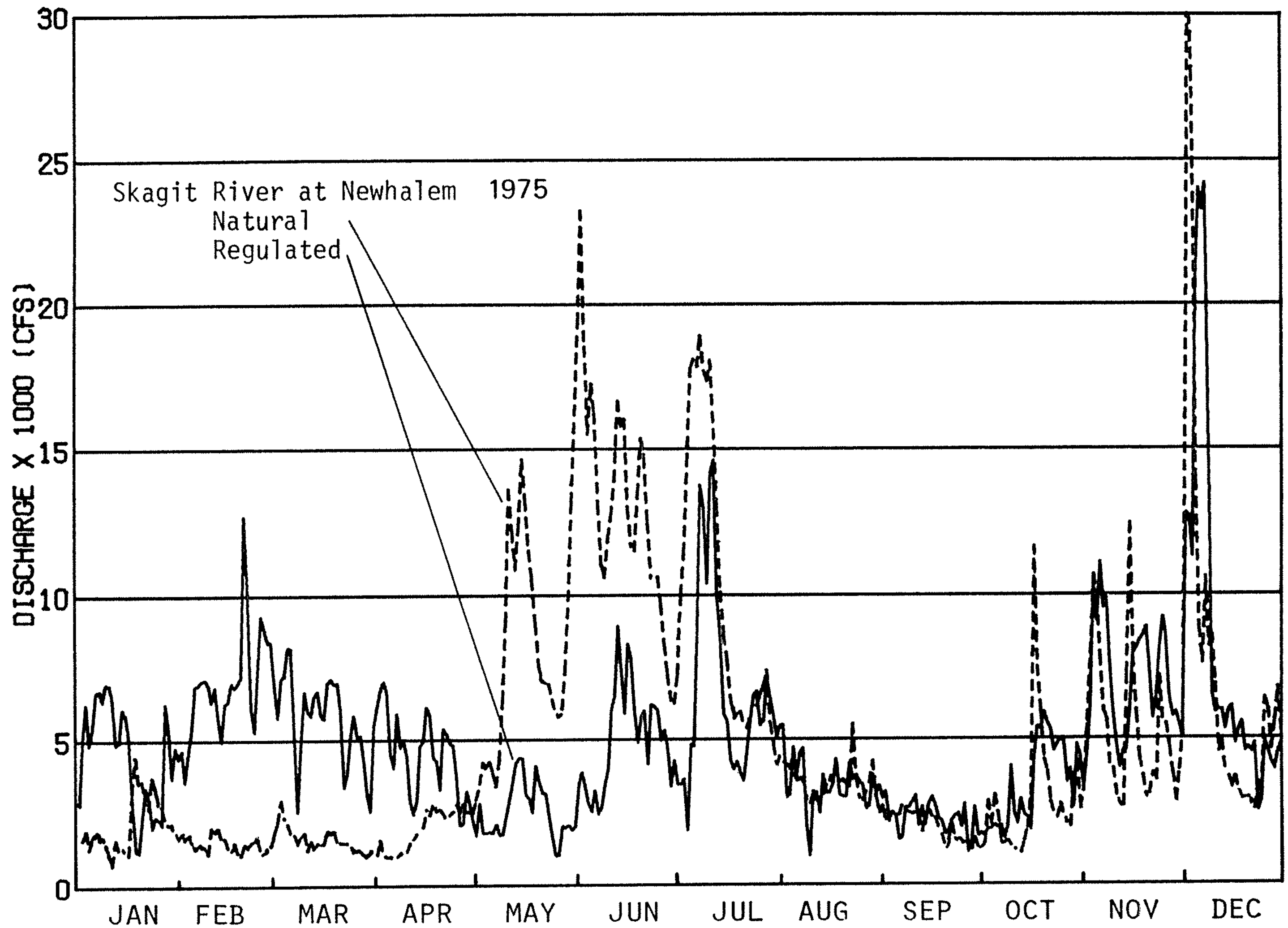

Fig. 2.22 Natural and regulated streamflows in cfs for Skagit River at Newhalem for 1975 (SCL and USGS).

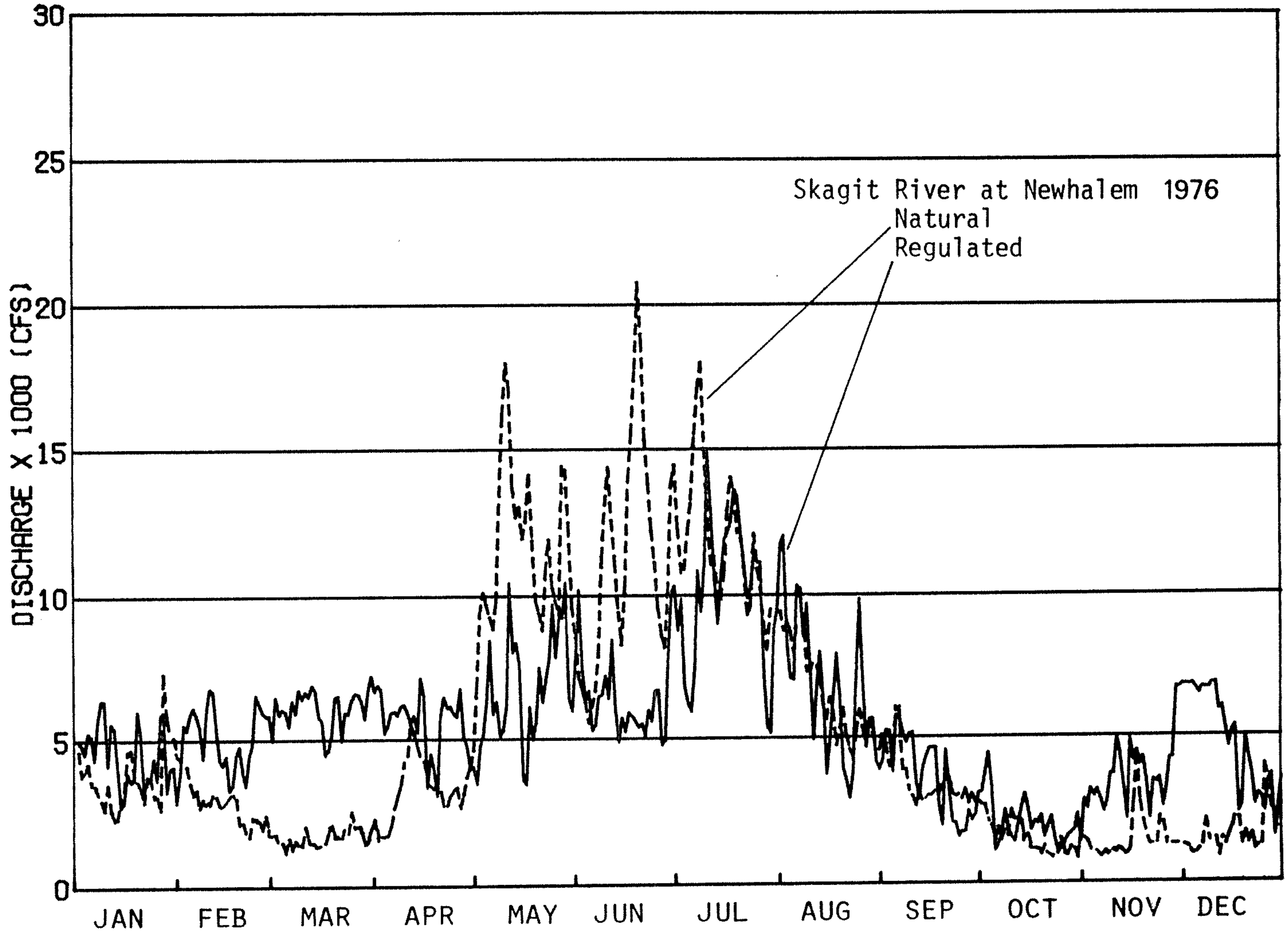

Fig. 2.23 Natural and regulated streamflows in cfs for Skagit River at Newhalem for 1976 (SCL and USGS).

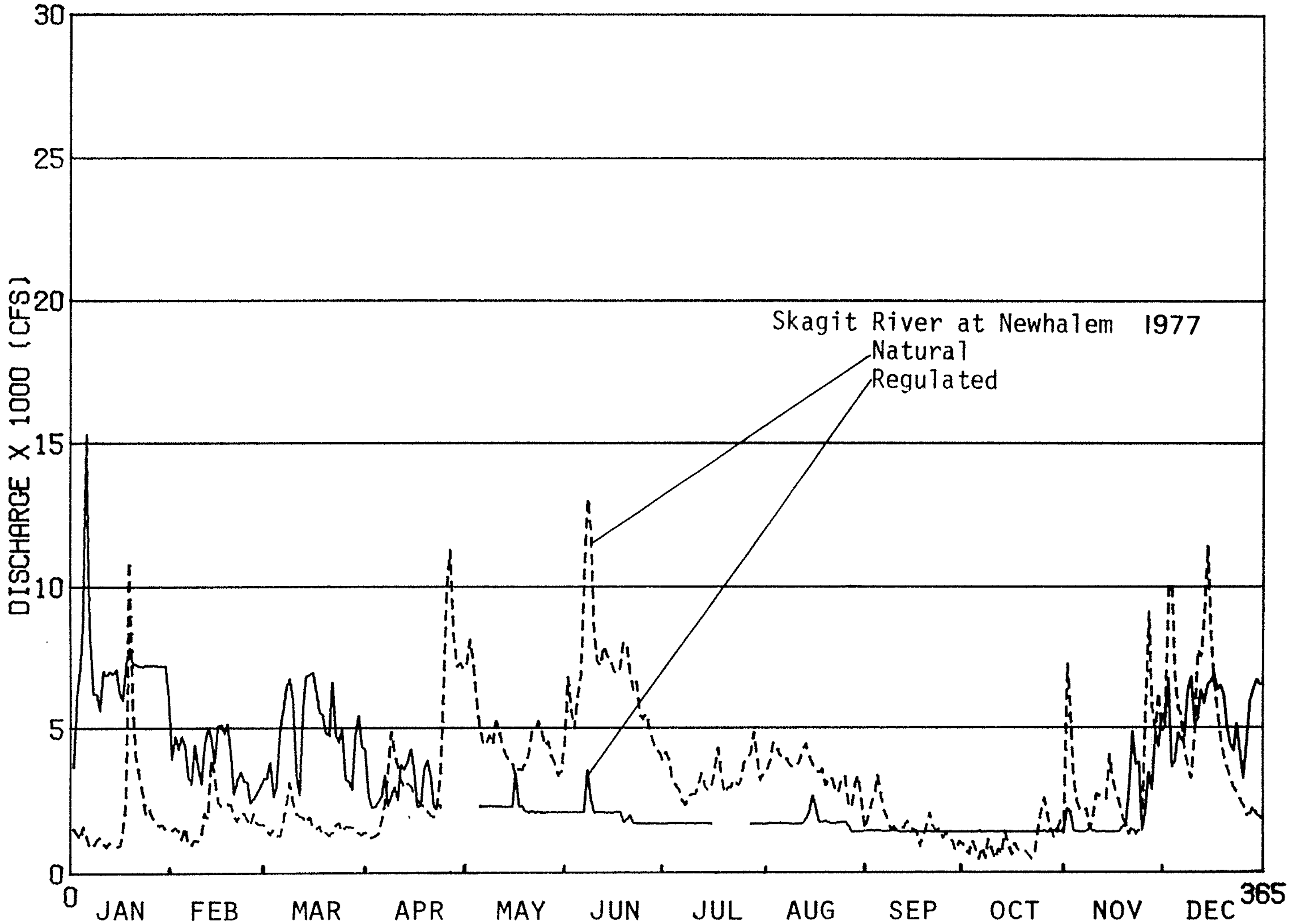

Fig. 2.24 Natural and regulated streamflows in cfs for Skagit River at Newhalem for 1977 (SCL and USGS).

Table 2.1 Compilation of extreme daily discharges and ratio of maximum to minimum discharge for water years 1970 to 1976. Skagit regulated and Sauk River discharges obtained from USGS records while Skagit natural are from SCL records.

Water year	Skagit at Newhalem regulated			Skagit at Newhalem natural			Sauk River		
	Max. discharge (cfs)	Min. discharge (cfs)	Ratio of max. to min.	Max. discharge (cfs)	Min. discharge (cfs)	Ratio of max. to min.	Max. discharge (cfs)	Min. discharge (cfs)	Ratio of max. to min.
1970	7,000	1,030	7:1	22,500	750	30:1	14,500	1,010	14:1
1971	17,900	1,060	17:1	24,250	550	44:1	26,500	1,190	22:1
1972	24,700	1,130	22:1	34,575	675	51:1	24,300	1,320	18:1
1973	7,560	1,060	7:1	16,625	525	32:1	20,700	1,170	18:1
1974	20,500	1,070	19:1	29,550	550	54:1	40,800	1,120	36:1
1975	14,600	1,020	14:1	23,250	500	47:1	23,200	860	27:1
1976	24,100	1,580	23:1	31,950	850	38:1	50,600	1,330	38:1
Mean	16,622	1,136	15:1	26,100	629	41:1	28,657	1,143	25:1

The mean annual discharges for the 1970-1976 period were 4,751 cfs for the Sauk, 4,683 cfs for Skagit-regulated, and 4,634 cfs for Skagit-natural.

The watershed upstream of Newhalem was drier on the average than downstream drainages including the Cascade, Sauk, and Baker rivers. Discharge per square mile of drainage area was calculated from USGS data for sites along the Skagit downstream of Newhalem and for key tributaries (Tables 2.2 and 2.3). Comparison of discharge per square mile of drainage area showed that the drainage upstream of Newhalem had the lowest value, 3.8 cfs/mi^2. Because of inflow from generally wetter drainages the discharge per square mile gradually increased to 5.6 cfs/mi^2 at Concrete.

2.2 Temperature

2.2.1 General Discussion

Long-term temperature regimes for the Skagit (above Alma Creek), Sauk, and Cascade rivers (Fig. 2.25) were characterized by high temperatures from July through September and low temperatures from December through March. Skagit River temperature was significantly warmer than Sauk and Cascade temperatures beginning in October and September, respectively, and extending to mid-February. During this period the Skagit temperature was influenced by the stored heat in the upstream reservoirs (primarily Ross), and, therefore did not fall as rapidly as it did in the other rivers. From mid-February to mid-May Skagit temperature was cooler than Sauk or Cascade temperatures reflecting the cool and homothermic condition of the reservoirs. In May, as Ross Reservoir began to stratify, Skagit temperatures began to increase more rapidly than before and were intermediate to Sauk and Cascade temperatures through mid-July. All three reach their peaks in August with the Skagit being coolest.

Temperature patterns for the Skagit (above Alma Creek), Sauk, and Cascade rivers in 1976 and 1977 (Figs. 2.26 and 2.27, respectively) were generally similar to the long-term temperature regimes (Fig. 2.25) except during summer. During the drought year of 1977 the peak summer temperatures were 3^o-5^{o}F higher than average. In addition in both 1976 and 1977 the Cascade River summer temperature was the coolest of the three rivers while for the long-term mean the Skagit was coolest.

A longitudinal temperature gradient was present in the Skagit River between Newhalem and Rockport (Fig. 2.28). From mid-January to mid-October, downstream temperature was generally warmer than upstream temperature and from mid-October to mid-January, the opposite was generally the case. These patterns in part reflect the thermal condition of the upstream reservoirs. The cooler upstream temperature from January to April resulted from the cool and generally homothermic reservoirs coupled with the radiational warming that occurs as the Skagit flows through its course from Newhalem to Rockport. Even after May, when the reservoirs (particularly Ross) begin to thermally stratify, solar

Table 2.2 Mean annual discharge, drainage area, and discharge per square mile of drainage area for selected sites on the mainstem Skagit River. Shows incremental increases between sites. Based on USGS records.

Gage location	Mean annual flow (cfs)	Inflow between sites (cfs)	Drainage area (mi^2)	Additional drainage area (mi^2)	Flow per mi^2 (cfs/mi^2)	Flow per mi^2 between sites (cfs/mi^2)
Newhalem	4,511		1,175		3.8	
		1,177		99		11.9
Alma Creek	5,688		1,274		4.5	
		892		107		8.3
Marblemount	6,580		1,381		4.8	
		8,700		1,356		6.4
Concrete	15,280		2,737		5.6	
		1,700		356		4.8
Mt. Vernon	16,980		3,093		5.5	

Table 2.3 Mean annual discharge and drainage area for selected Skagit River tributaries.

Tributary	Mean annual flow (cfs)	Drainage area (mi^2)	Flow per mi^2 (cfs/mi^2)
Newhalem Creek	181	27.9	6.5
Cascade River	1,040	172	6.0
Sauk River	4,428	714	6.2
Baker River	2,700	297	9.1

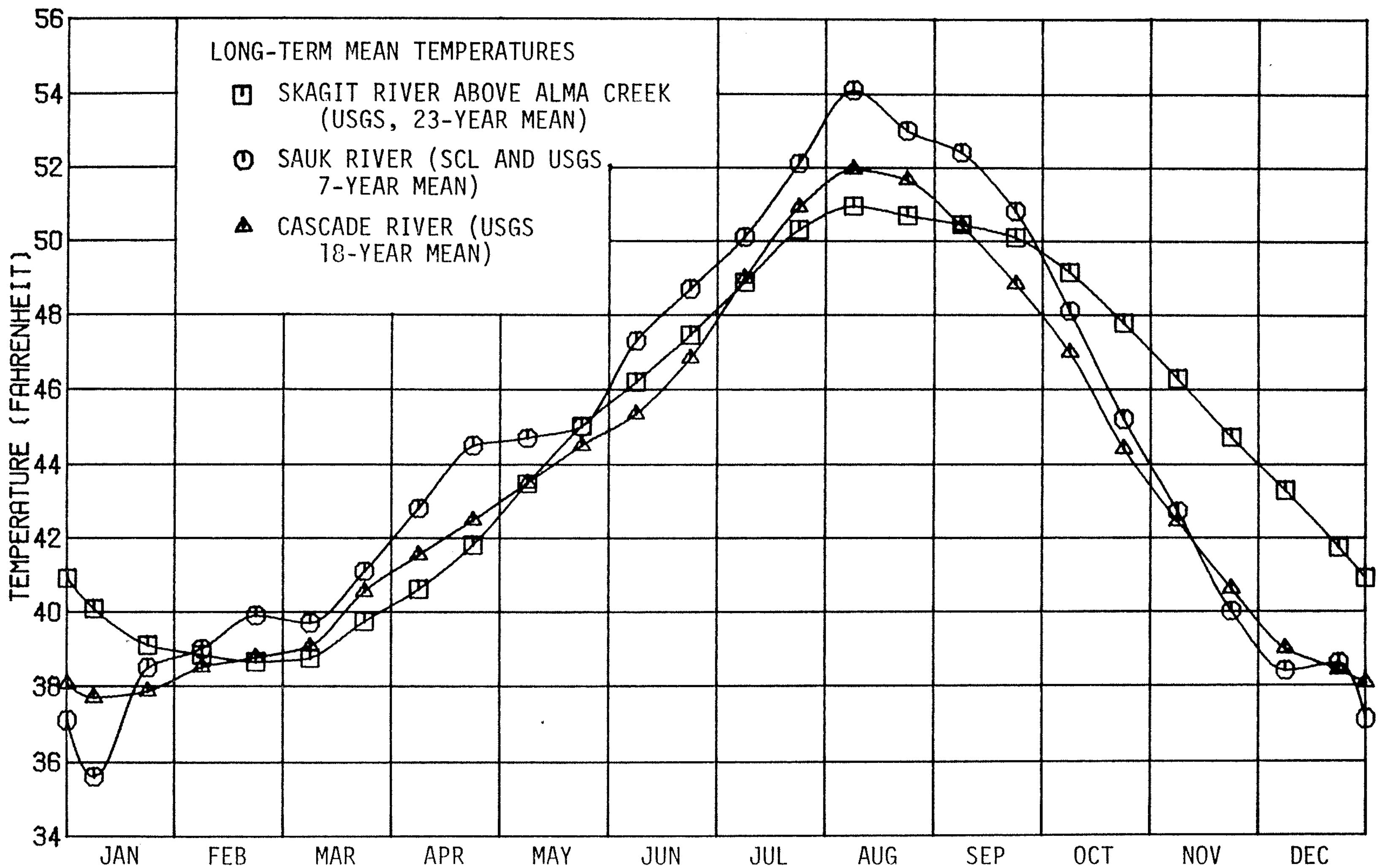

Fig. 2.25 Long-term mean water temperatures for Skagit River above Alma Creek (USGS, 23-year mean), Sauk River (SCL and USGS, 7-year mean) and Cascade River (USGS, 18-year mean).

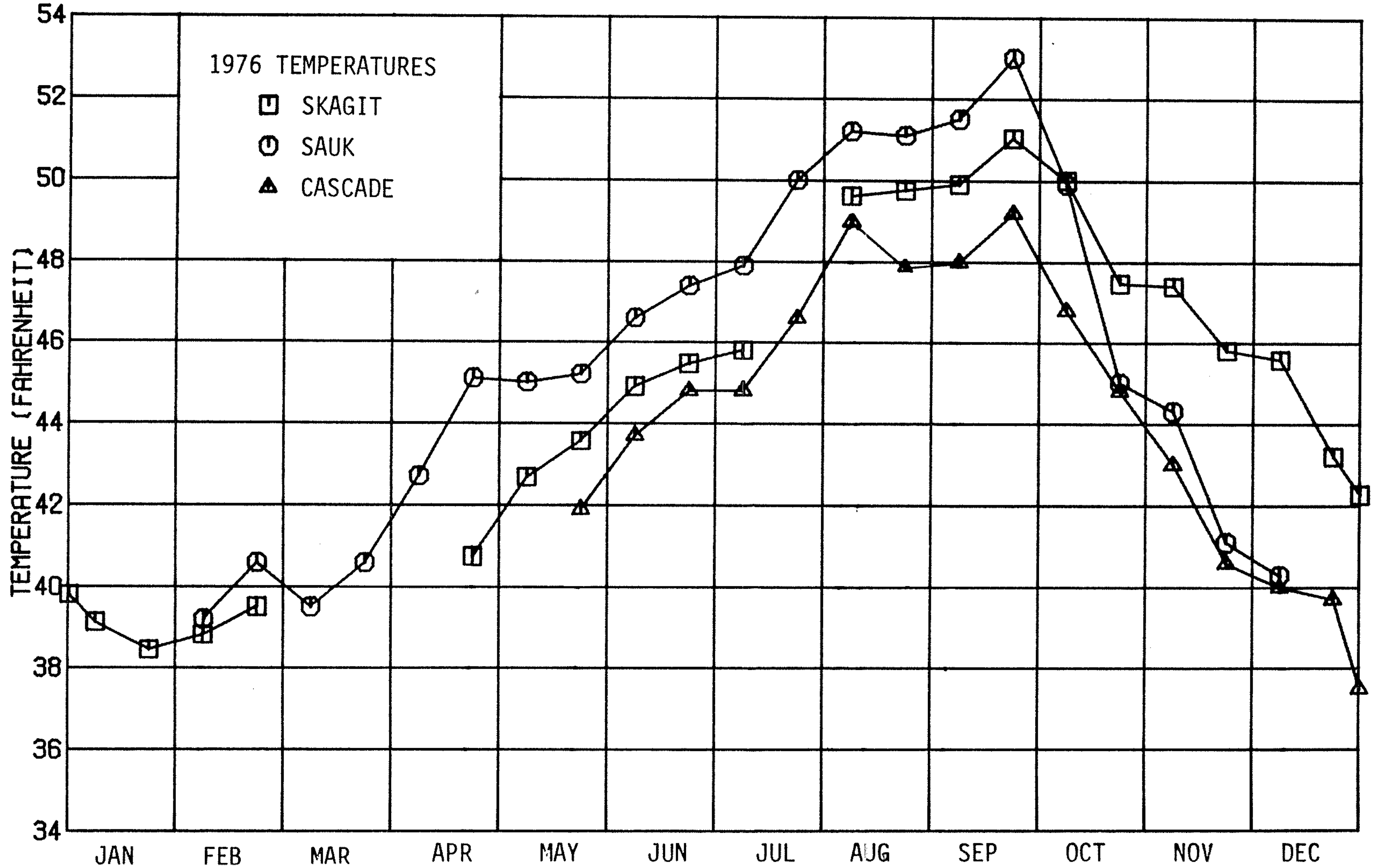

Fig. 2.26 Semi-monthly water temperature (°F) for Skagit (above Alma Creek), Sauk, and Cascade rivers during 1976 (SCL).

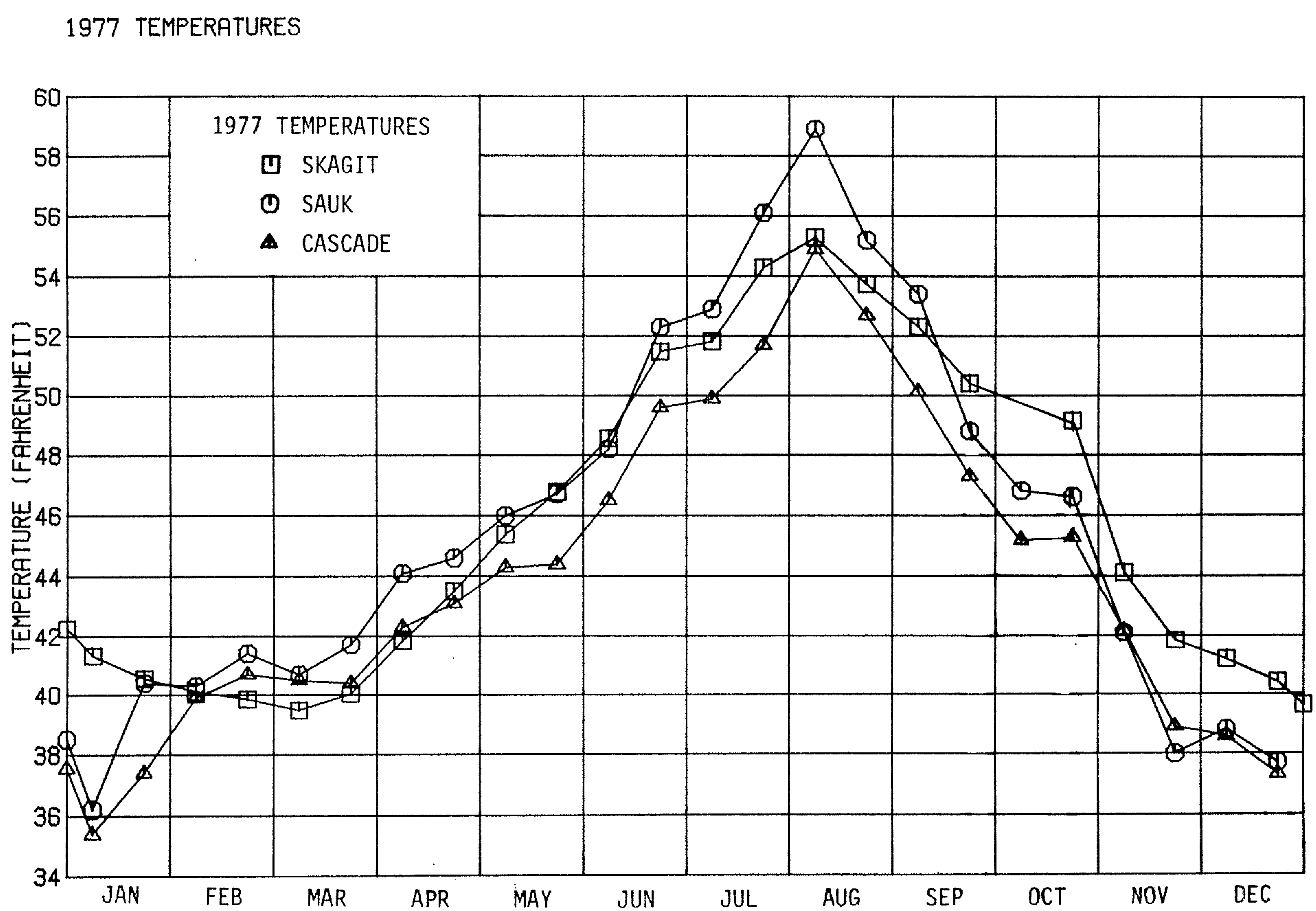

Fig. 2.27 Semi-monthly water temperature (°F) for Skagit (above Alma Creek), Sauk, and Cascade rivers during 1977 (SCL).

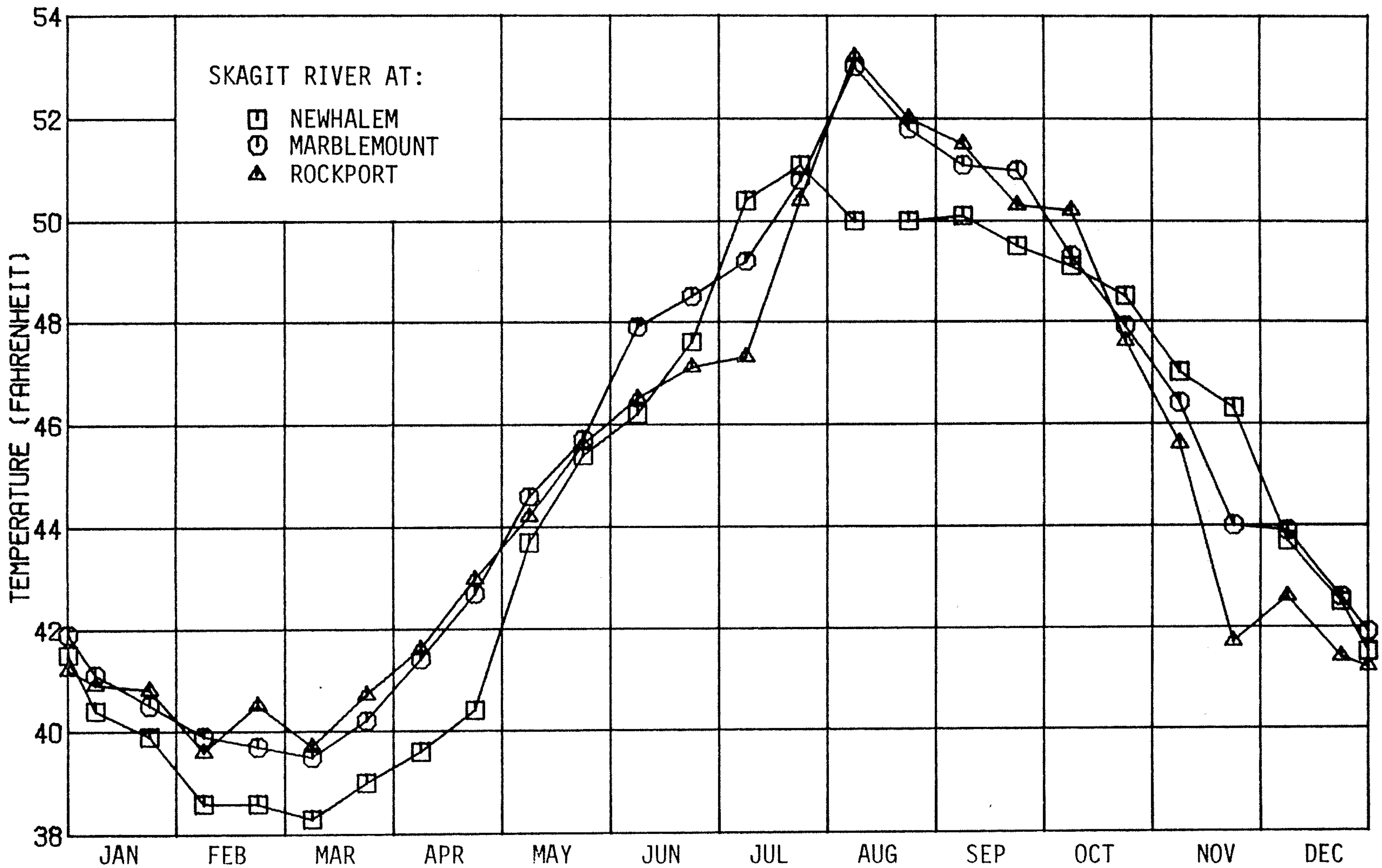

Fig. 2.28 **Semi-monthly mean water temperatures for sites on the Skagit River at** Newhalem, Marblemount, and Rockport. Values are means of the years 1974-1977 (SCL).

radiation progressively warmed the downstream temperatures until October. From October to early January, stored heat was released from the reservoirs and the temperatures became progressively cooler downstream.

These analyses indicate that the general effects of the Skagit Project on the downstream temperature regime have been to elevate the fall and early winter temperatures; reduce the late winter, early spring, and summer temperatures; and change the temperatures only slightly during late spring. This is based on the assumption that Skagit River predam temperature conditions were similar to Sauk and Cascade river temperature conditions. Analyses by Burt (1973) indicated a colder predam regime for the Skagit at all times during the year.

The annual temperature patterns for the Skagit River above Alma Creek (USGS) from September 1974 to March 1978, and the 23-year mean temperature pattern are shown in Fig. 2.29. In general, the temperature regimes were at or below average from September 1974 to September 1976, while after mid-September they were consistently above average through October 1977. During this latter period precipitation and the resulting streamflow were below average. Water temperature was particularly high from June to September 1977, attributable in part to the general drought conditions and to the reduced withdrawal of water for generation from Ross Lake during this period. Seattle City Light implemented this program to conserve water in Ross Reservoir. From November 1977 to March 1978, water temperature remained consistently below average.

The annual temperature patterns for the Sauk and Cascade rivers compared to their long-term mean temperature are presented in Figs. 2.30 and 2.31, respectively. The relationships between annual and long-term patterns are in general similar to those described above for the Skagit River above Alma Creek.

2.2.2 Potential Effect of Copper Creek Dam

The effect of the proposed Copper Creek Dam on the temperature regime of the Skagit River will depend mostly on three factors: stratification, depth of intake, and drawdown. Because specific information regarding these factors was not available, it was difficult to quantitatively estimate the impact of the dam on the downstream temperature regime of the Skagit River. However, by establishing the probable range of these factors it became possible to estimate the probable range of the proposed dam's effects.

To estimate the probable degree of stratification in the new reservoir it was useful to compare it to Diablo Reservoir. Copper Creek Reservoir would be in the same general class as Diablo in terms of capacity and retention time, but would be shallower and longer (Table 2.4). Diablo Reservoir became stratified to some degree most of the year (Table 2.5). The degree of stratification, however, was minimal except from May through October. Even then the surface and bottom temperatures usually differed by less than 10°F at the maximum.

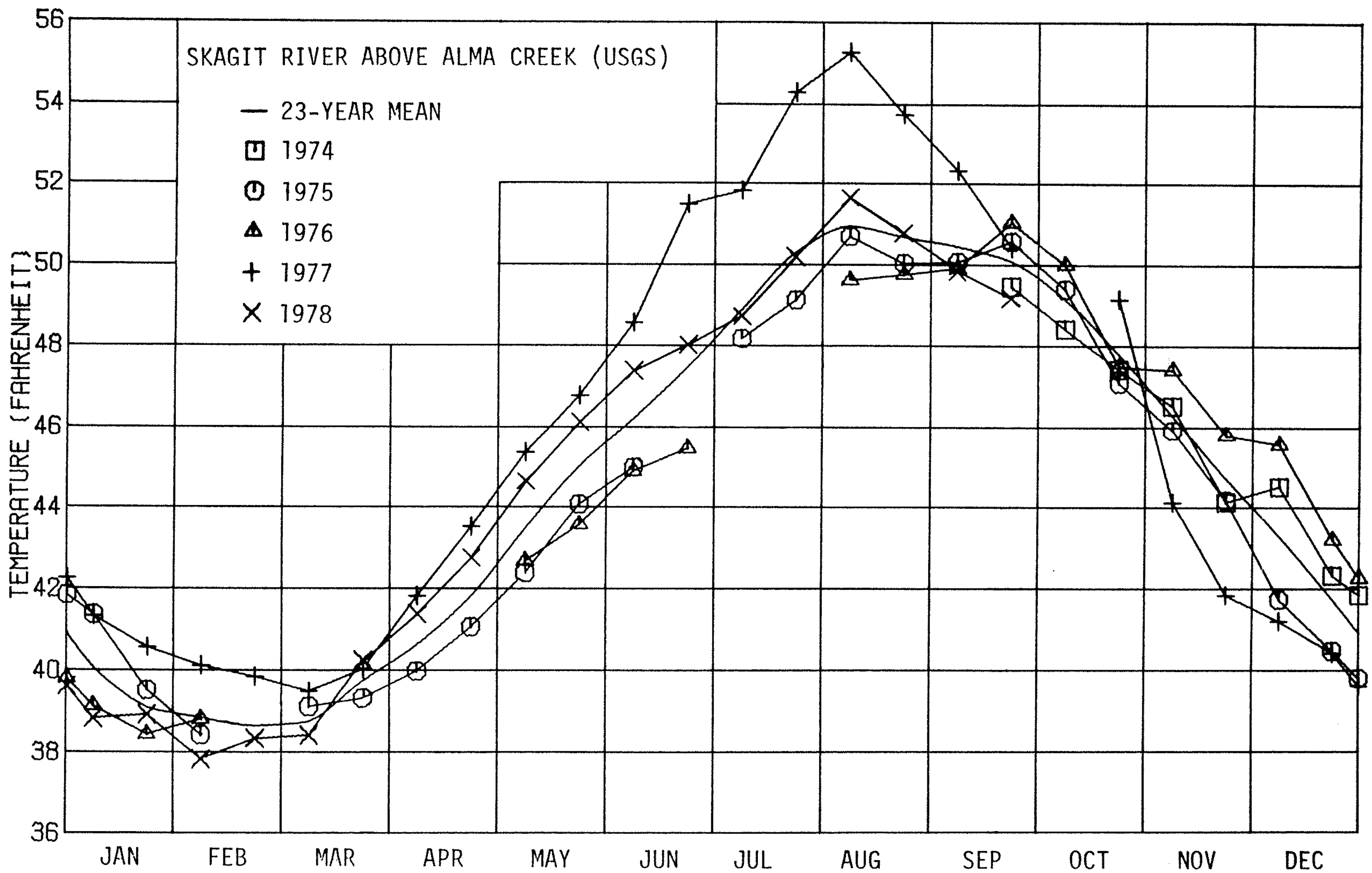

Fig. 2.29 **Semi-monthly mean water temperature (°F) for Skagit River above Alma** Creek from September 1974 to March 1978 (USGS). The 23-year mean temperature is also shown (USGS).

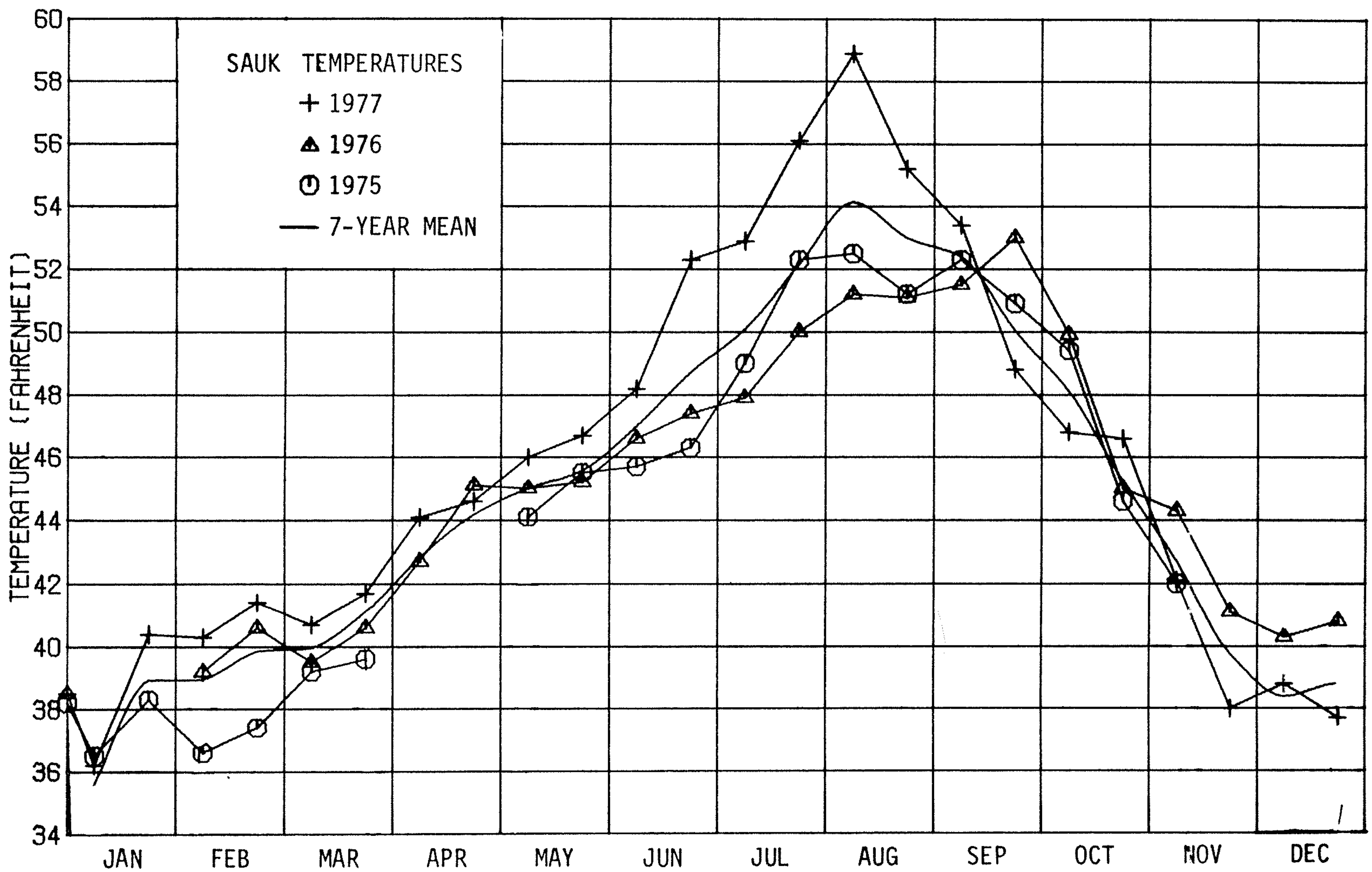

Fig. 2.30 Semi-monthly mean water temperature (°F) for Sauk River from January 1975 to December 1977 (SCL). The 7-year mean temperature is also shown (SCL).

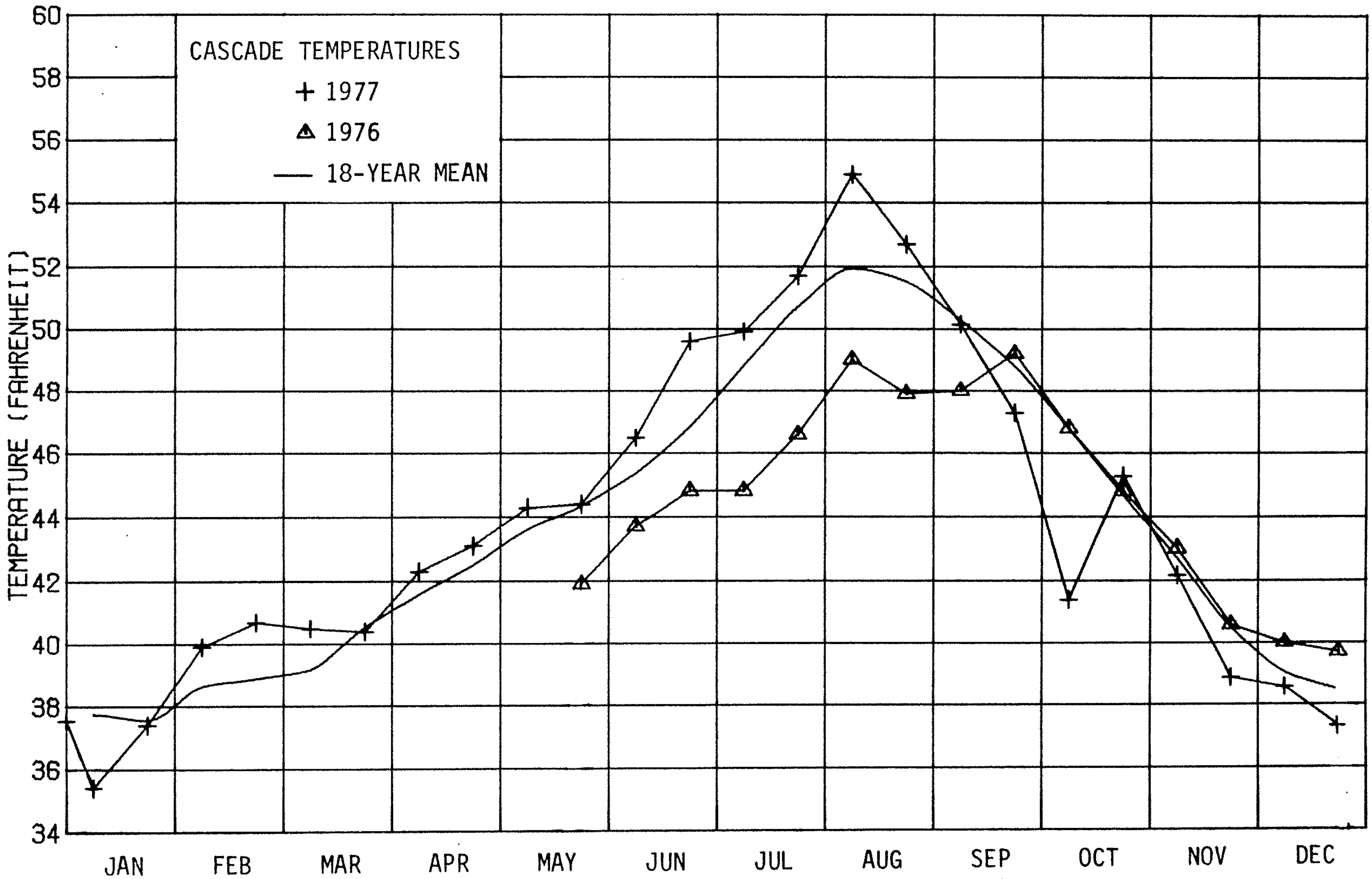

Fig. 2.31 Semi-monthly mean water temperature (°F) for Cascade River from May 1976 to December 1977 (SCL). The 18-year mean temperature is also shown (USGS).

Table 2.4 Specifications of Copper Creek (to 495-ft elevation) and Diablo reservoirs.

Reservoir	Capacity (Ac-ft)	Retention time (days)	Length (mi)	Forebay depth (ft)	Intake depth (ft)
Diablo	90,000	~ 11	4.2	300	125
Copper Creek	123,000	~ 11	10.2	~ 150	~ 110

Table 2.5 Temperature difference between surface and bottom in degrees F. for Diablo Reservoir.

Year	MONTH											
	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1971	-	-	-	.3	1.8	1.4	7.9	9.0	8.1	1.8	-	0
1972	.4	.4	.4	.7	4.0	2.2	5.2	9.4	3.4	3.6	1.4	.2
1973	.7	0	.7	4.9	10.1	-	-	9.7	-	3.4	-	.9
1974	0	0	.9	2.8	3.6	1.3	6.0	11.0	8.8	2.0	3.0	1.1
1975	-	0	.5	.7	2.2	6.4	11.7	5.1	7.0	2.9	2.2	.2
1976	-	0	0	.3	3.7	5.2	5.8	5.8	6.4	4.0	3.1	2.0
1977	1.5	.1	.2	1.9	7.6	14.0	17.4	16.4	11.7	7.6	2.4	1.3
Mean	0.7	0.1	0.5	1.7	4.7	5.1	9.0	9.5	7.6	3.6	2.4	1.0

For two reasons Copper Creek Reservoir may stratify to a lesser extent than Diablo Reservoir. First, since Copper Creek Reservoir is expected to be shallower, its bottom waters would mix more easily with the surface water. Secondly, the Copper Creek Dam is expected to be used primarily for base load generation and flow reregulation. The level of the reservoir, therefore, would be fluctuating in response to the peaking flows of the dams upstream. This peaking inflow may help to mix the reservoir water and break up stratification.

Preliminary information on Copper Creek Dam indicated that the intake would be about 110 ft below full pool elevation (495 ft). At this level the intake would draw water from below the reach of most stratification, where seasonal temperature changes are not as extreme as at the surface. This intake depth is comparable to the intake depth of 125 ft at Diablo Dam.

Drawdown is a factor because it has the effect of raising the intake depth. In addition, the heating or cooling of exposed shoreline can significantly affect surface temperatures upon subsequent flooding. However, drawdown in the proposed reservoir is not expected to exceed 15 ft and is expected to average approximately 10 ft. Again, conditions would be similar to Diablo Reservoir, where the average between the minimum and maximum elevations for 1974, 1975, and 1976 was 13.7 ft.

If the minimum values for each of the factors discussed above (limited stratification, a deep intake, and limited drawdown) are realized, then the temperature effect of Copper Creek Reservoir would probably be insignificant. The waters should be well mixed and moving through the reservoir fast enough that it would be acting very much like a free-flowing river. However, if the maximum values are realized (a high degree of stratification, shallow intake, and large drawdown) then the temperature changes could be significant.

An estimate of the temperature changes was based on the assumption that the temperature effects caused by Copper Creek Reservoir are unlikely to be more extreme than those caused by Diablo Reservoir. Figure 2.32 shows the mean monthly temperature changes from Ross tailrace to Diablo intake based on temperature profiles measured during 1971 to 1977, that is, the temperature changes as water passes through Diablo Reservoir. These were used to estimate the temperature changes that would potentially occur as water passes through Copper Creek Reservoir. Figure 2.33 shows the mean monthly temperatures at Gorge intake which were used to approximate mean monthly temperatures of water flowing into Copper Creek Reservoir. By applying the Diablo Reservoir temperature changes to the Gorge intake temperatures, the mean temperatures for Copper Creek Dam intake were estimated (Fig. 2.33).

This analysis indicated the maximum extent that Copper Creek Reservoir could potentially shift the downstream Skagit River temperature regime. The estimates are maximum partly because intake water to Copper Creek Reservoir from Gorge Reservoir would be closer to natural flow temperatures than intake to Diablo Reservoir from Ross Reservoir. Mean

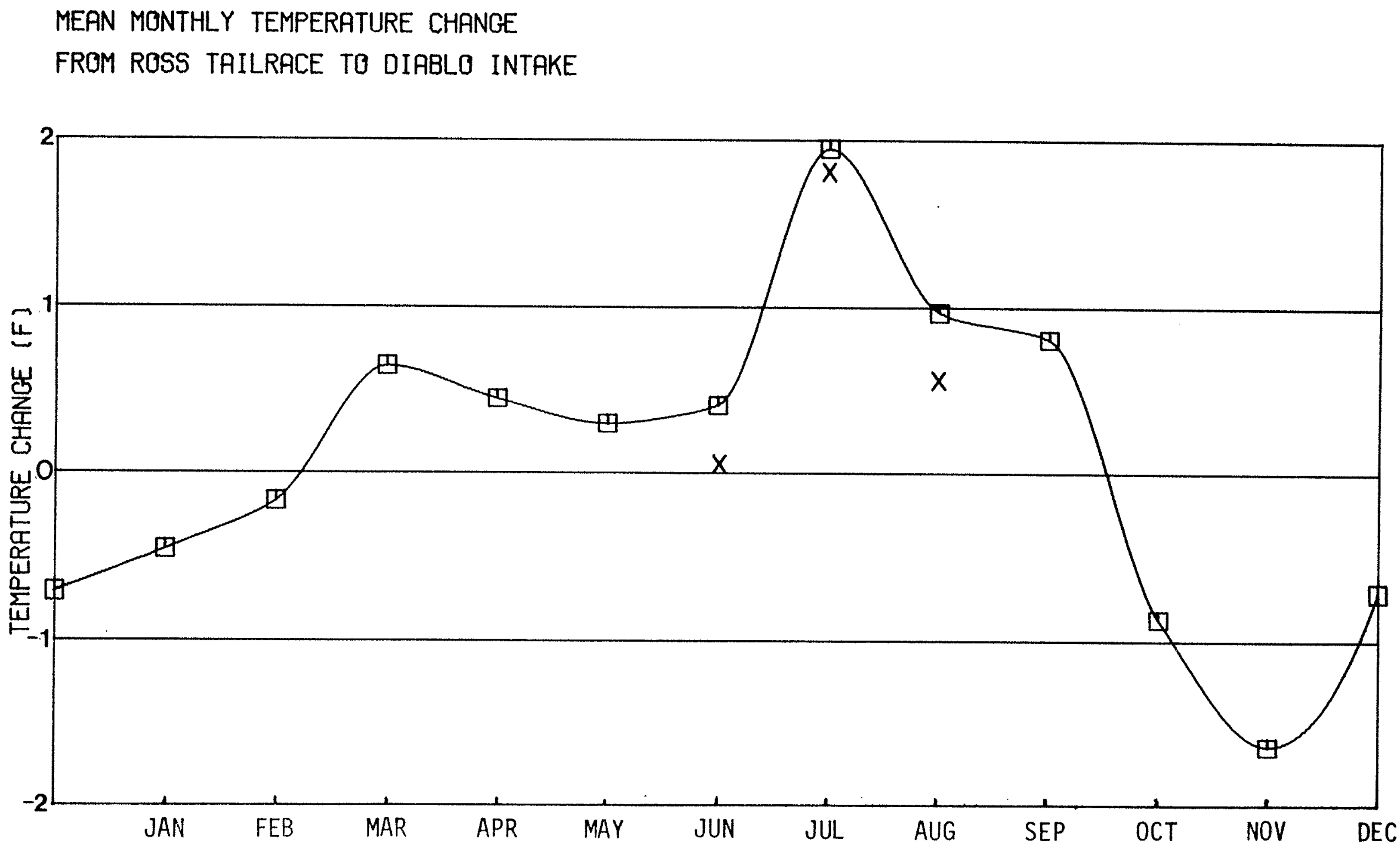

Fig. 2.32 Mean monthly temperature change from Ross tailrace to Diablo intake. Compiled from SCL data 1971-1977. Because Ross power generation was reduced in the summer of 1977, the mean for 1971-1976, i.e., excluding 1977, is indicated with an X.

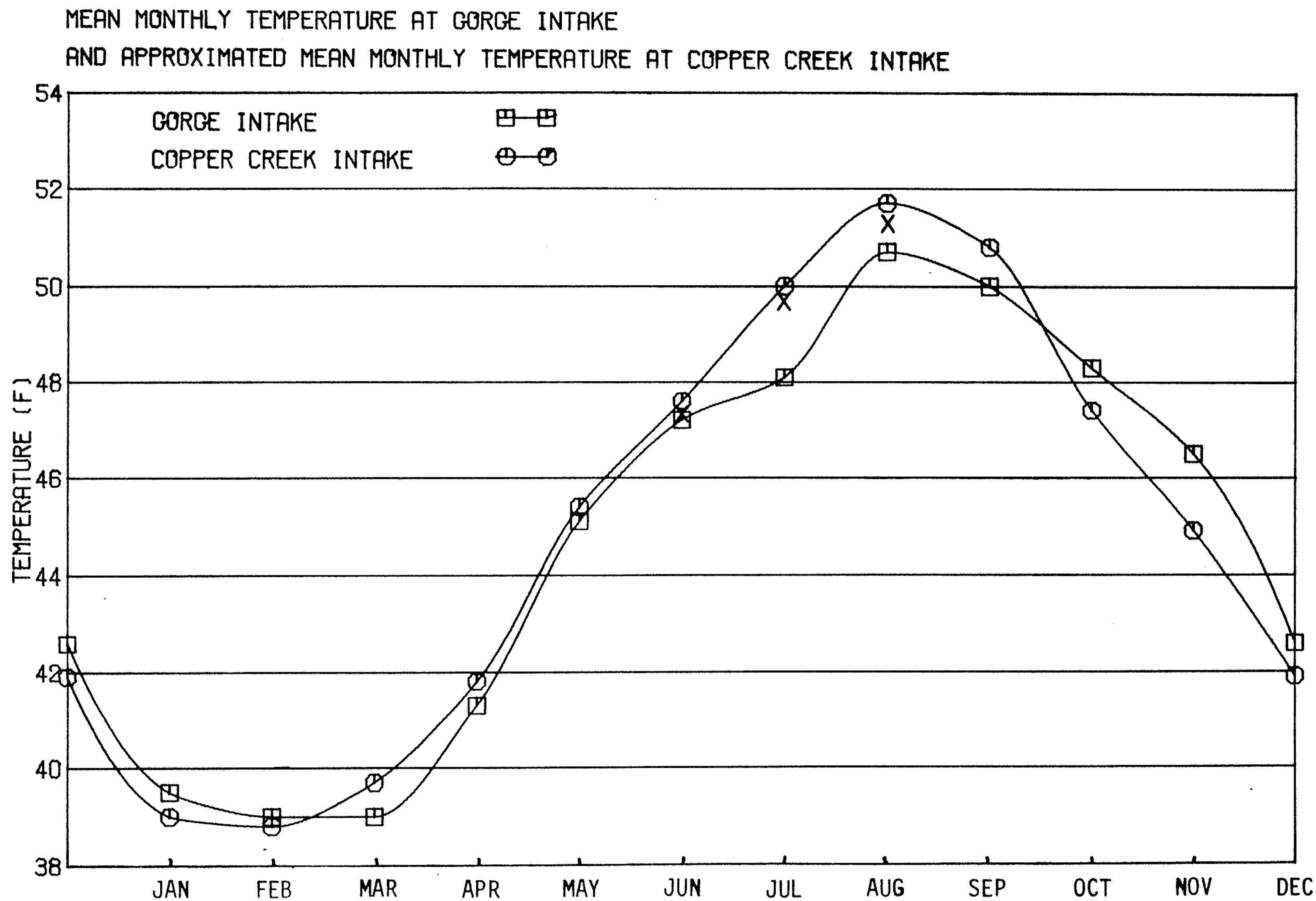

Fig. 2.33 Mean monthly temperature at Gorge intake and approximated mean monthly temperature at Copper Creek intake. Compiled from SCL data 1971-1977. X indicates the approximated mean for Copper Creek intake based on 1971-1976 temperature data. This period excludes the summer of 1977 when Ross power generation was reduced.

temperatures would be elevated between March and September and depressed between October and February. It is interesting to note that this shift would be toward the Sauk-Cascade temperature regimes (Fig. 2.25) which we have speculated may approximate the predam Skagit River regime. The shift could possibly be beneficial to the system since it may partially reverse temperature effects caused by Ross Reservoir.

In conclusion, it can be speculated that Copper Creek Dam will have a maximum potential effect of warming summer temperatures by as much as 2°F and cooling winter temperatures by as much as 1.5°F. This would mean a slight shift in the temperature regime toward predicted predam temperatures. The minimum possible effect is that the dam will not significantly change the temperature regime.

2.3 Profile and Gradient

In the 37.7 river miles between Gorge Powerhouse and the mouth of the Baker River, the Skagit River decreased in elevation from about 493 to 162 ft above mean sea level (Fig. 2.34) for a mean drop of 8.8 ft/mi. Two breaks occur in the profile of this river section, one at RM 86, just upstream of Copper Creek, and another at RM 69, just upstream of the Sauk River. The mean gradient between RM 86 and Gorge Powerhouse (RM 94.2) was 15.1 ft/mi between RM 86 and RM 69 was 8.8 ft/mi, and between the mouth of the Baker River (RM 56.5) and RM 69 was 4.7 ft/mi. The mean gradient of the Skagit River between the mouth of the Baker (RM 56.5) and Puget Sound (RM 0) was 2.9 ft/mi.

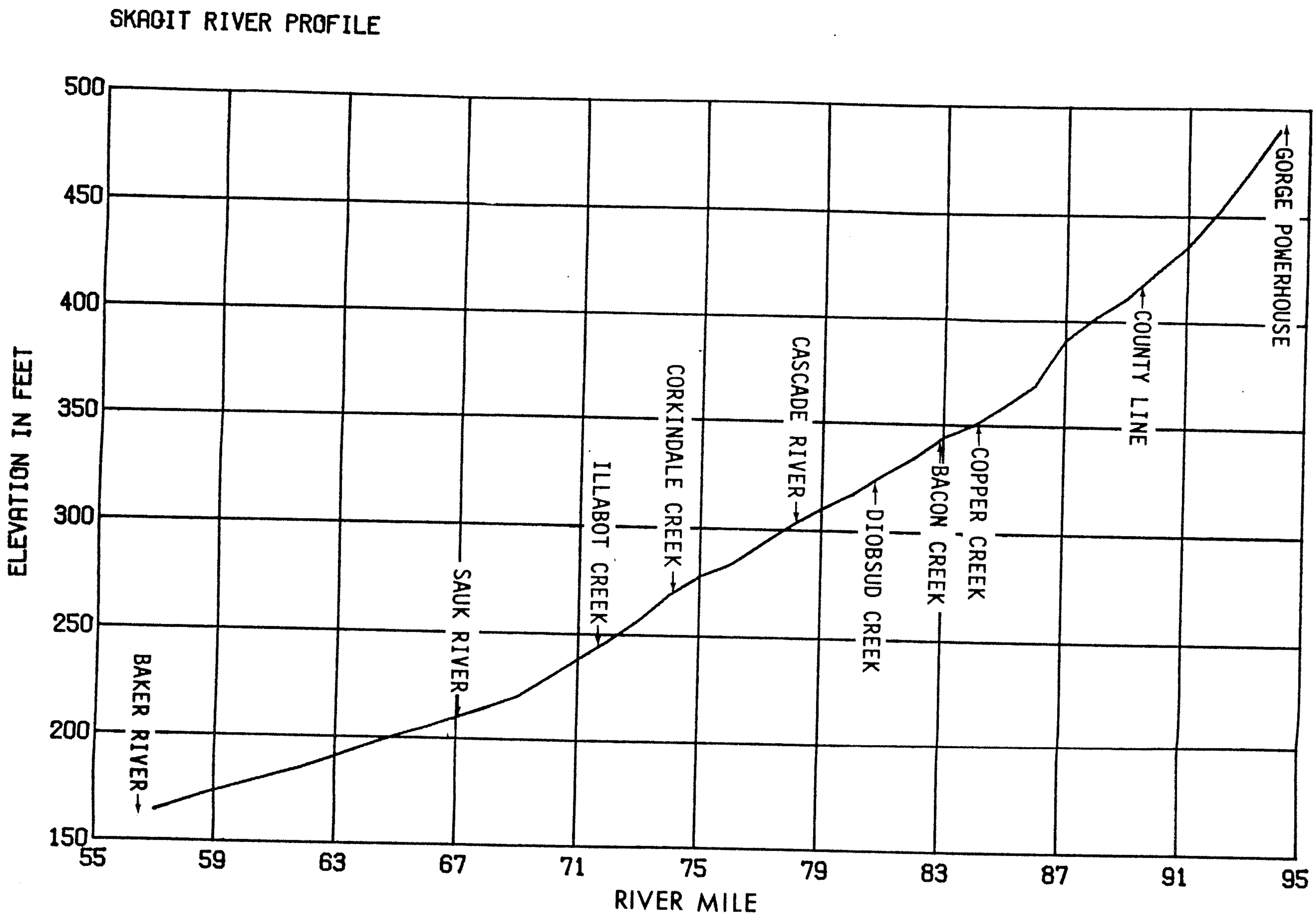

Fig. 2.34 Skagit River profile illustrating the change in elevation from Gorge Powerhouse to the Baker River.

3.0 PERIPHYTON AND BENTHIC INSECTS

3.1 Introduction

Flow fluctuations during power generation result in periodic exposure of the benthos and periphyton in shoreline areas of the Skagit River. Studies initiated in 1976 to determine the effect of this exposure on the standing crop of benthic insects and periphyton were continued during 1977. Benthic insects and periphyton in the unregulated Sauk and Cascade rivers were also examined for comparison with the Skagit. Due to unusual drought conditions during 1977, Skagit River flows were maintained at a relatively constant level during much of the year. It was possible to compare benthic insect standing crop at the same station under both fluctuating (1976) and non-fluctuating (1977) flow regimes. In addition to the field studies, the effects of flow fluctuations on aquatic insects were examined in an artificial stream.

Reductions in benthic standing crop due to fluctuating flow regimes below dams have been reported by several investigators (Powell 1958, Pearson et al. 1968, Radford and Hartland-Rowe 1971, Fisher and Lavoy 1972, Kroger 1973, Trotzky and Gregory 1974). Powell (1958) reported that insect biomass per unit area was up to 32 times greater above a hydroelectric dam producing a fluctuating flow pattern than below, and insect populations increased farther from the dam. Fisher and Lavoy (1972), as well as MacPhee and Brusven (1973), found that standing crop and diversity of benthos were markedly reduced in areas that were exposed frequently by flow fluctuations. Water level fluctuations can also destroy periphyton through desiccation during exposure and reduce primary production (Neel 1963, Kroger 1973, Brusven et al. 1974).

The objectives of the field studies were to compare the standing crop of benthic insects and periphyton in the Skagit River with standing crop in the Sauk and Cascade rivers. In making these comparisons an effort was also made to determine the effects of periodic exposure due to flow fluctuation on the standing crop of benthic insects and periphyton in the Skagit River. The objectives of the experimental studies in an artificial stream were threefold: 1) to test the ability of selected insect species to avoid becoming stranded during flow reductions; 2) to test the ability of selected species to survive desiccation on a dewatered substrate; and 3) to compare density and composition of insect communities subject to conditions of fluctuating and nonfluctuating flow regimes.

3.2 Study Area

3.2.1 Sampling Sites

No data were available on benthic and periphyton standing crop in the Skagit prior to regulation of the river by hydroelectric development. Thus, it was necessary to compare standing crop under the present regulated flow regime with standing crop in the unregulated Sauk and Cascade rivers in order to determine effects of flow fluctuations. The Sauk was frequently turbid, while the Skagit and Cascade were relatively clear year-round. The Cascade, although considerably smaller than the other rivers, was selected as a control stream because of its lack of turbidity.

Benthic insects were sampled at one station each on the Skagit, Sauk, and Cascade rivers during 1976, and at two stations on both the Skagit and Sauk during 1977. The upper stations were established on the Skagit and Sauk rivers above the original stations in 1977 to ensure representativeness within and between rivers and to establish a station on the Skagit above the proposed Copper Creek Dam site. Benthic insect sampling was discontinued in the Cascade River during 1977. Additional effort was placed on the Sauk Upper Station, which was not highly turbid and was more comparable in width and discharge to the Skagit River stations. Periphyton was sampled at the Skagit Lower, Sauk Lower, and Cascade stations during 1976 and 1977, and at the Skagit Upper Station in 1977.

Sampling station locations are shown in Fig. 3.1. The Skagit Upper Station near river mile (RM) 84 and the Skagit Lower Station, above the town of Marblemount, near RM 79 were 10 and 15 river miles, respectively, below Gorge Powerhouse. The Sauk Upper Station was established at RM 13, 6 mi above the Sauk Lower Station, and the Cascade River Station was at RM 0.9.

Physical characteristics, other than discharge and drainage area, were similar at all stations (Table 3.1). The substrate was composed primarily of cobble, 3 to 10 inches in diameter, mixed with sand and small gravel. Mean current velocity near the bottom in shoreline sampling areas ranged from 1.4 to 2.0 ft/sec among stations. Mean annual discharge, shown in Table 3.1, was roughly 1,000-2,000 cfs higher at the Skagit River stations than at the Sauk stations. Mean annual discharge was considerably lower at the Cascade Station than at any of the other stations.

The mean, maximum, and minimum discharge figures in Table 3.1 pertain to the entire period of record (hourly recording) of the U.S. Geological Survey (USGS) gaging station nearest the benthic sampling station. The period of record is different for each gaging station due to differences in the year of original installation or intermittent operation. The Sauk and Cascade gages have been operated continuously for 50 years, and the Skagit at Alma Creek gage has operated for 28 years. The USGS gage at Marblemount was operated intermittently from 1943 to 1951, deactivated for 25 years, and reactivated in 1976. The minimum recorded discharge at the Skagit Upper Station is larger than at the Skagit Lower Station because the Skagit at Alma Creek gage, near the upper station, was not operational when the 620 cfs flow occurred at the lower station.

3.2.2 Artificial Stream Site

The artificial stream system was located at Ladder Creek, near the town of Newhalem, Washington. A head tank and pipe system, formerly part of the town's water supply system, were available at this site to supply a large volume of water to the artificial stream channels. The site was

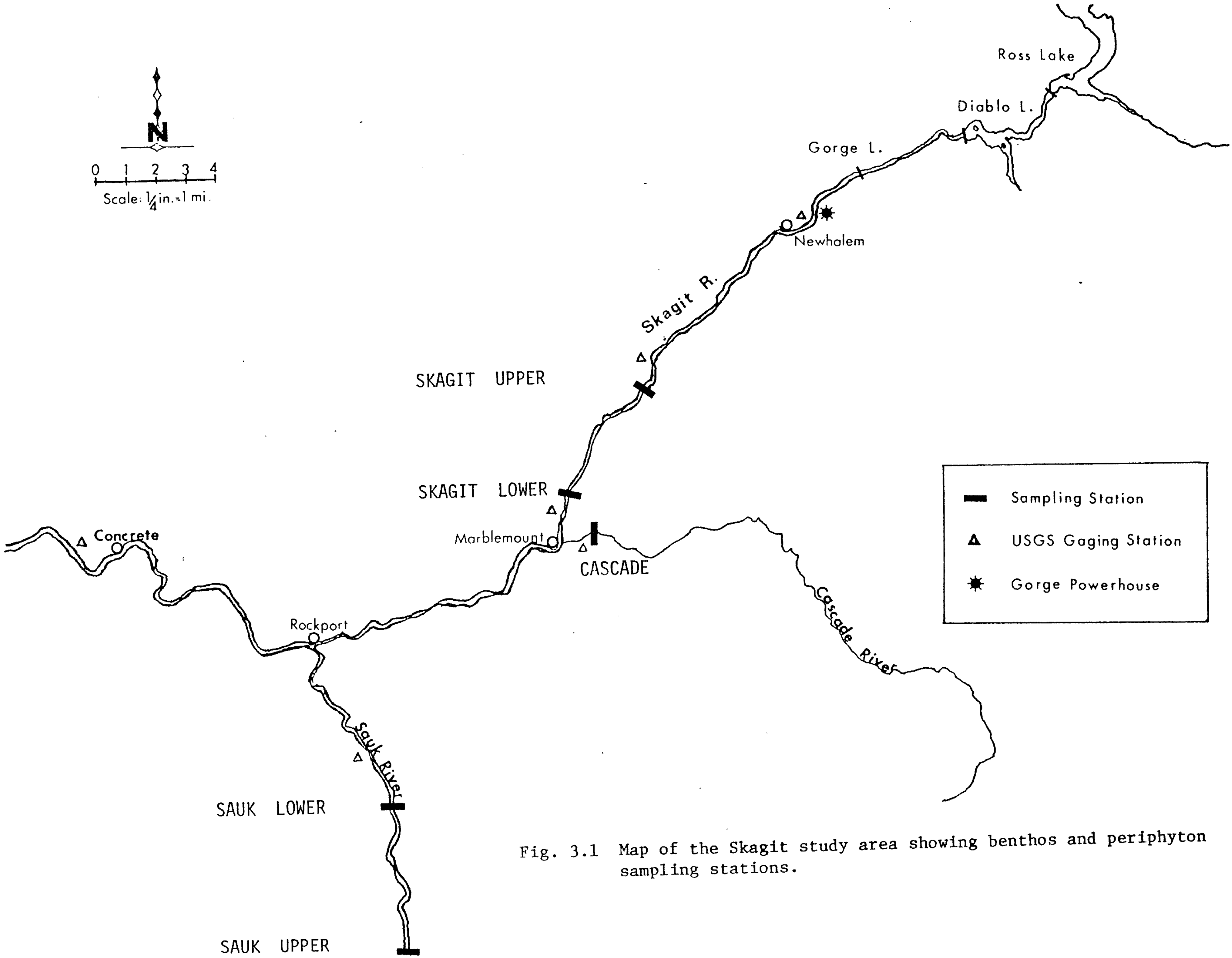

Fig. 3.1 Map of the Skagit study area showing benthos and periphyton sampling stations.

Table 3.1 Physical characteristics at sampling stations. Discharge values for the Sauk Upper Station are estimates based on drainage area. Bottom velocities pertain to shoreline areas only.

Station	Discharge (cfs)			Drainage area(mi^2)	Mean bottom velocity (ft/sec)	Substrate
	Mean Annual	Maximum Recorded	Minimum Recorded			
Skagit Upper	5,688	38,500	990	1,274	1.6	Cobble
Skagit Lower	6,580	59,300	620	1,381	1.4	Cobble
Sauk Upper	4,251	79,104	549	688	1.8	Cobble
Sauk Lower	4,428	82,400	572	714	2.0	Cobble
Cascade	1,040	18,700	118	172	1.4	Cobble

also accessible only through a locked gate. The area was heavily shaded, allowing little direct sunlight to penetrate, and air temperatures were sometimes 18°F cooler at the artificial stream site than on the shoreline of the Skagit. Insect mortality rates on exposed substrate subject to the cool air temperatures at the stream site were probably lower than would have been the case under the warmer temperature regime typical of open shoreline areas of the Skagit during summer months. The temperature of Ladder Creek water flowing through the artificial stream channels ranged from 45°F to 56°F over the period of operation of the artificial stream during 1977.

3.3 Materials and Methods

3.3.1 Physical Parameters

Hourly gage height records from the USGS streamflow gaging station nearest to each sampling station were used to determine flow patterns. The USGS gage for Skagit River at Marblemount was located approximately 0.7 mi below the Skagit Lower Station while the USGS gage for Skagit River at Alma Creek was located 1.5 mi above the upper sampling station. The USGS gage on the lower Sauk was used to determine the discharge pattern at both Sauk stations. The gage was 1.6 mi below the lower station and 7.6 mi below the upper station. The USGS gage on the Cascade River near Marblemount was within 300 yards of the Cascade Station. No major tributary streams entered the rivers between a gaging station and a sampling station, and the flow pattern at the gage was considered similar to the actual flow pattern at the sampling site.

The percentage exposure time of the substrate at each periphyton and benthic sample location was computed by determining the amount of time that the water's edge was below the sample site, leaving the site exposed to desiccation. First, permanent transects perpendicular to water flow were established at all sampling stations, and samples were collected only along these transects. A stake was located on the transect near the high waterline. Next, plots were constructed with distance (from the stake on the transect to the water's edge) on one axis and gage height (during the hour when distance was measured) on the other. The distance from stake to water's edge was measured periodically over a wide range of flows and plotted against the appropriate gage height values. A curve was drawn through these points, describing the inverse relationship between gage height and distance to the water's edge at a particular transect.

Given a gage height, one could estimate the location of the water's edge, in terms of the distance from the stake at the high water line, by using the distance and gage height curve. The gage height, or flow, that would have resulted in a water's edge at a particular point on the transect, e.g., 25 ft from the stake, could also be determined using the curve.

When samples were collected, the location of each separate sample site was determined by measuring the distance from the stake to the sample site. Separate measurements were made for each location where replicate samples were collected. By consulting the distance versus gage height curve for the transect, the gage height that would result in a water's edge at the sample location was determined. This gage height value was compared with the USGS records of hourly gage readings for the preceding two or six weeks. The number of hours that the actual gage height was below this value was equivalent to the number of hours that the sample location was exposed.

Due to infrequent malfunctioning of the streamflow gages, there were some gaps in the USGS gage height records during exposure calculation periods. If data were not available from one of the Skagit River gages, the complete discharge records from the other gage were used to calculate exposure time. When either the Sauk or Cascade gages were inoperative, it was necessary to assume that flow patterns prior to sampling were similar in these two unregulated rivers. During both 1976 and 1977 the flow patterns in the Sauk and Cascade were nearly identical, differing only in magnitude (Fig. 2.5 and 2.6). Fortunately, whenever one of the gages was not functioning, the discharge records from the other operative gage always indicated that the water level at sampling time was lower than it had been during the preceding 2 or 6 weeks. Thus, only unexposed sites were sampled on these occasions. It was assumed that the water level had declined in a similar manner in the other river, and that samples were also collected only in unexposed areas.

The estimation of standing crop above and below Copper Creek (Sec. 11.1.1) required calculation of the wetted area between zero and 1.5 ft deep and total wetted area in several sections of the Skagit River. Sample transect depth data collected during spawning studies (Sec. 6.0) were used. The procedure used to calculate wetted area was the same as the procedure to calculate spawnable area (Sec. 6.3.4), except that only the depth data, and not velocity data, were used. The wetted areas were calculated at low, medium, and high flows as defined in Table 6.10.

Turbidity was measured at or above benthic sampling stations from June 1976 through the first week of November 1977. Three to five measurements were made at each station in a month, using a Hach portable engineer's laboratory. All stations were sampled on the same day.

3.3.2 Periphyton

Artificial substrates were used to collect samples of stream periphyton from October 1976 through March 1977. The artificial substrate sampler was constructed of two 0.6- x 15- x 5-cm plexiglass plates attached in a horizontal position to a small wood block. The wooden block was bolted to a 15- x 40- x 60-cm concrete block. Four samplers, each with two replicate plexiglass plates, were placed along transects perpendicular to waterflow in each of the three rivers. During riverflow fluctuations, the plexiglass plates on the samplers were exposed and submerged periodically. Those samplers in shallow water were exposed more frequently than those in deeper areas. The colonized plexiglass plates were removed every 6 weeks and replaced with clean plates. Colonized plates were frozen and transported to the laboratory where the periphyton was scraped from the upper surface.

In spite of the heavy concrete base, the artificial substrate samplers were susceptible to washout during high flows and had to be replaced several times. A technique for direct removal of periphyton from streambed rocks was devised which avoided the problems associated with the artificial substrate samplers. This alternate method was used to collect samples from May to November 1977.

The technique involved removal of all periphyton from a 16-cm^2 area on the upper surface of natural streambed rocks. A rubber template with a 4- x 4-cm square cut in the center was held against the rock while the area inside the square was thoroughly scrubbed with a small nylon brush. The detached algae was then washed into a collecting bottle. Samples were concentrated on a 0.45-μ membrane filter and frozen for transportation to the laboratory. On each sample date, two replicate samples of five rocks each were collected at four different depths (6, 10, 14, and 18 inches) along the sampling transects at the Skagit Upper and Lower, Sauk Lower, and Cascade stations.

Samples were dried in a desiccator under refrigeration, and chlorophyll a content was determined using the method for the determination of chlorophyll a in the presence of phaeophytin a (American Public Health Association (APHA) 1971). The percentage of time that each artificial substrate sampler or sample location was exposed to desiccation during the 6 weeks prior to sampling was also determined.

3.3.3 Benthic Insects

Benthic insects were sampled bimonthly from May to November 1976, during February 1977, and bimonthly from May to November 1977. Samples were collected along a permanent transect perpendicular to waterflow at each station. It was not possible to sample the river at depths greater than 18 inches and sampling was confined to the shallower shoreline area of the transect on one side of the river. A 0.25-m^2 quadrat sampler (351-μ mesh), designed by Malick (1977), was used to sample benthos. This sampler was a larger, heavier version of the standard Surber (1937) sampler. Large rocks were removed from the substrate and individually cleaned, and the remaining substrate was thoroughly stirred three times with a rake to a substrate depth of 6 inches. Samples were preserved in the field with 70 percent ethanol containing rose bengal dye (100 mg/liter). Current velocity was measured as close to the bottom as possible at each sample location with a Gurley No. 625 Pygmy-type current meter.

The number of replicates collected and the water depth at sample locations were different in 1976 and 1977. During 1976, two replicates were collected at locations 6, 12, and 18 inches below the surface of the water at the Sauk Lower and Casacade sampling stations and at the Skagit Lower Station in May only. From July through November 1976, two replicates were collected at depths of 6, 10, 14, and 18 inches at the

Skagit Lower Station. During 1977, four replicate samples were collected at each of four locations, 6, 10, 14, and 18 inches below the water surface, along the transects at all stations.

Benthic insects were handpicked from detritus and inorganic material, identified to order, and counted. Biomass was determined by multiplying the volume of the insects by 1.05, the value for specific gravity of stream invertebrates used by Hynes (1961). The percentage of time that the substrate was exposed during the 2 weeks prior to sampling was calculated for each replicate sample location.

The selection of a 2-week exposure calculation period was based on the time necessary for complete recolonization of the stream bottom by benthos. Recolonization rates for barren substrates varied from 2 weeks (Waters 1964) to 4 weeks (Mason et al. 1967) and over 4 weeks (Coleman and Hynes 1970). Potential problems were foreseen under particular flow patterns using an exposure calculation time greater than the recolonization time. For example, if it took only 2 weeks to recolonize the stream bottom, and a 4-week exposure calculation time were used, misleading results would be obtained if the streambed were exposed continuously or frequently during the first 2 weeks, severely reducing insect abundance, and then submerged continuously for the next 2 weeks. In this situation, the benthos would have time to recolonize the affected areas before sampling, resulting in a normal seasonal standing crop but a high exposure level. These results would give the false impression that high exposure had no effect on insect abundance.

Using an exposure calculation period less than the recolonization time could also be misleading, e.g., a 2-week exposure calculation period when the recolonization time is 4 weeks. High exposure of the streambed for 2 weeks followed by a 2-week period of no exposure would probably result in a standing crop much lower than the normal seasonal value, since the insects would have had only 2 weeks to recolonize the streambed, and need 4 weeks for complete recolonization. In this case, standing crop at sampling time would be lower than normal, while exposure calculated over the last 2 weeks would also have been low. The investigator would probably assume that some factor other than exposure reduced insect abundance.

It was concluded that the period of exposure calculation should be as long as the time necessary for complete recolonization to avoid the problems mentioned above. Since the precise time for recolonization of denuded areas in the Skagit was not known, it was necessary to use a value from the literature. Actual determination of the recolonization time by removal of insects from an area of the streambed and sampling at intervals until insect abundance returned to the original level would have been impractical. Frequent flow fluctuations during 1976 would have periodically removed insects from the area, preventing complete recolonization. Two weeks appeared to be a reasonable estimate of recolonization time, and an equally long 2-week exposure calculation period was used.

3.3.4 Experimental Studies

3.3.4.1 Artificial Stream. Four artificial stream channels were constructed at the Ladder Creek site in 1976. Each of the channels was 2.4 m long, 46 cm wide, and 43 cm deep. Up to four 36- x 41-cm trays containing gravel substrate were placed in the bottom of each channel. The trays were filled with a sand and gravel mixture almost to the top. A layer of 5-cm gravel was added to the surface of the trays used in the stranding avoidance experiments, while 5- to 15-cm rocks were used in the trays in the flow fluctuation experiments. The trays sloped from one side of the channel to the other (24 percent slope), simulating a sloping river shoreline. A screen (333-μ mesh) at the upstream end of the channel prevented insects and debris larger than 333 μ from entering, a drift net (333-μ mesh) at the downstream end collected drifting insects, and a screen on the top trapped emerging adults.

Water depth and velocity in each channel were controlled by manipulation of an inflow valve and sluice gate at the end of the channel. Average velocity in the channels remained relatively constant as the depth was changed, and ranged from 0.41 to 0.51 ft/sec at the valve and gate settings used.

3.3.4.2 Flow Fluctuation Experiments. The effects of two different types of flow pattern on density and composition of benthic insects in an artificial stream channel were examined during 1977. Preparation of channels was similar for all experiments. Rocks colonized by algae were collected in the Skagit and placed in the substrate trays in the two channels. Six bottom samples were collected with a 0.25-m^2 quadrat sampler at the Skagit Lower Site, and the uncounted insects and detritus from three samples were distributed as evenly as possible over the four substrate trays in each channel. Water was maintained at a constant level in both channels for 1 week to allow the insect community to stabilize. Prior to initiating experimental flows, the substrate tray from the downstream end of each channel was removed, and the aquatic insects were collected to determine if equal numbers were present in both channels. The trays with substrate material were then returned to their original location in the channel.

After the 1-week stabilization period, the experimental channel was either: 1) dewatered for 18 hr a day for 7 days; or 2) dewatered for 48 continuous hours. Two replicate experiments were conducted using the first flow pattern, while only one experiment was conducted with the second pattern. The water level was always raised and lowered at a rate of 0.7 ft/hr. Organisms drifting out of the experimental channel during increasing or decreasing flow were collected in a drift net. During the flow manipulations in the experimental channel, drift was also collected in the control channel for comparison. At the conclusion of the experiments the three undisturbed trays in each channel were removed and the insects were collected for analysis.

3.3.4.3 Stranding Avoidance. Three species of aquatic insects were tested to determine their ability to avoid becoming stranded during flow reductions in an artificial stream channel. At the start of an experiment, water level was adjusted so that the entire substrate surface was submerged. After 50 insects of a single species were released in the upper half of the upstream tray, the water level was lowered at a rate of 0.7 ft/hr. The upper half of the sloping substrate tray was completely exposed and only the lower half was submerged after 30 min of dewatering. Insect movement during dewatering was observed visually, and the number of insects that remained in or on the exposed substrate after 24 hr was compared with the number that moved to the lower, submerged half of the substrate tray. The number of insects that avoided stranding by drifting was also recorded.

Three species of insects commonly found in the Skagit and Sauk rivers were tested during 1977: *Ephemerella tibialis* (Ephemeroptera), *Acroneuria pacifica* (Plecoptera), and *Dicosmoecus* sp. (Trichoptera). Insects were collected in the Skagit River and transported in a cooler to the artificial stream site where they were allowed to acclimate for 24 hr in screened containers in the channels. The range in body length of insect larvae tested was 6-8 mm for *E. tibialis*, and 10-15 mm for *A. pacifica*. The case lengths of the *Dicosmoecus* sp. larvae ranged from 17 to 26 mm. Two replicate stranding avoidance tests were conducted with each of the three species, using 50 individuals in each test.

3.3.4.4 Desiccation Survival. The three species of aquatic insect larvae tested for ability to avoid stranding were also examined to determine their ability to survive desiccation in the event of stranding. A total of 40 to 50 insect larvae was placed in petri dishes or plastic containers with a 1-cm layer of either dry or damp sand on the bottom. A control was used to estimate mortality caused by handling. Control insects were subjected to the same handling procedure as the others, but were placed in a screened cage in flowing water. Percent mortality of experimental and control insects was determined at 24 hr.

3.4 Results and Discussion

3.4.1 Physical Parameters

3.4.1.1 Flow Pattern. The flow pattern in the Skagit River below Gorge Powerhouse during 1976 was influenced primarily by demand for power in the City of Seattle. Increased release of water through generating facilities as demand increased in the morning usually resulted in rising water levels. Water level generally remained high during the period of peak demand in the day, and then receded at night as demand declined. Weekend flows tended to remain at a low level for 48 hr. The use of the generating facilities on the Skagit River in this manner for hydroelectric peaking resulted in daily fluctuations in water level which alternately exposed and submerged the shoreline areas of the river.

There was a pronounced difference between the degree of fluctuation in the regulated Skagit and the naturally fluctuating Sauk and Cascade rivers in 1976. The mean difference between daily maximum and minimum water levels during the period June to December 1976 was 1.01 ft at the

Marblemount gaging station near the Skagit sampling site, while it was only 0.29 ft at the Sauk gaging station (Table 3.2). Mean daily fluctuation between high and low water levels was always greater in the Skagit at Marblemount than in either the Sauk or Cascade during those months for which discharge data were available. Because of the dampening effect of tributary inflow, variation in water level in the Skagit at Marblemount was considerbly less than at Newhalem, where the mean daily fluctuation from June to December 1976 was 1.76 ft.

The pattern of flow fluctuations in the Sauk (Fig. 2.15) and Cascade (Fig. 2.19) was the result of natural factors such as precipitation and snowmelt which sometimes caused rapid increases in flow. However, peak flows usually subsided over a period of days or weeks in contrast to the Skagit, where water level fluctuated an average of 1.89 ft at Newhalem and 1.01 ft at Marblemount every 24 hr during 1976. Daily variations in water level of 2 ft or more occurred several times during June through August 1976 in the Skagit at Marblemount (Fig. 2.11), and daily variations of this magnitude occurred frequently in the Skagit at Newhalem during 1976 (Fig. 2.9). During late January 1976, the water level in the Sauk rose 3.4 ft in a single day, the maximum daily variation for the year. However, the water level dropped slowly, and required approximately 10 days to return to its previous level.

Except for a 2-week period in late January, daily fluctuations in water level of 2 to 3 ft were recorded frequently from January to late April 1977 at Newhalem as a result of hydroelectric peaking (Fig. 2.10). Flow was nearly stable from late April to mid-November. Due to low water levels in the reservoirs, no daily hydroelectric peaking was occurring during this time period, and discharge from Gorge Powerhouse was maintained at a nearly constant level. Peaking was resumed in mid-November and continued through the end of 1977.

The pattern of flow fluctuations in 1977 at Marblemount (Fig. 2.12) resembled the pattern at Newhalem. Daily ranges of flow fluctuations from late April to mid-November were slightly more variable than at Newhalem. Inflow from tributary streams was responsible for this increased fluctuation downstream from Newhalem, particuarly during the spring runoff in June. The mean daily range in water level at Marblemount from May to October 1977 was 0.20 ft and was only 0.15 ft at Newhalem (Table 3.3). During periods of hydroelectric peaking, tributary inflow generally dampened the fluctuations downstream. Mean daily range in water level was lower at Marblemount than at Newhalem from January to April and in November and December due to tributary inflow. The higher flows due to rainfall or snowmelt during these periods were definitely accentuated at Marblemount by tributary inflow.

The pattern of flow fluctuation was almost identical in the Sauk (Fig. 2.16) and Cascade (Fig. 2.20) rivers during 1977. Only the magnitude of the fluctuations was different due to the different sizes of the rivers. Flow patterns at the Sauk and Marblemount gaging stations, as well as the magnitude of the mean daily range in gage height (Table 3.3), were also quite similar from late April to mid-November. The variation in

Table 3.2 Mean daily range in water level (ft) during each month in 1976 at the Skagit at Newhalem and Marblemount, the Sauk, and the Cascade gaging stations (USGS).

	Station			
Month	Skagit at Newhalem	Skagit at Marblemount	Sauk	Cascade
January	2.86	--	0.54	--
February	1.92	--	0.17	--
March	1.19	--	0.19	--
April	1.81	--	0.18	--
May	2.64	--	0.35	--
June	1.34	0.91	0.31	--
July	1.86	1.40	0.40	--
August	2.24	1.40	0.28	0.30
September	1.54	0.72	0.18	0.09
October	1.41	0.69	0.18	0.14
November	2.00	1.09	0.36	0.24
December	1.90	0.84	0.33	0.20
Annual mean	1.89	--	0.30	--
May-October mean	1.84	--	0.28	--

Table 3.3 Mean daily range in water level (ft) during each month in 1977 at the Skagit at Newhalem and Marblemount, the Sauk, and the Cascade gaging stations (USGS).

Month	STATION			
	Skagit at Newhalem	Skagit at Marblemount	Sauk	Cascade
January	1.08	0.75	0.40	0.23
February	2.23	1.14	0.13	0.16
March	1.79	0.93	0.17	0.07
April	1.20	0.65	0.31	0.23
May	0.14	0.18	0.24	0.16
June	0.28	0.33	0.46	0.38
July	0.04	0.12	0.16	0.18
August	0.28	0.27	0.16	0.28
September	0.09	0.14	0.27	0.24
October	0.04	0.13	0.20	0.18
November	1.11	0.87	0.93	0.54
December	1.22	0.68	0.75	0.28
Annual Mean	0.79	0.51	0.35	0.24
May-October Mean	0.15	0.20	0.25	0.24

water level at both the Sauk and Marblemount stations during the summer was the result of natural factors such as precipitation and snowmelt, resulting in similar patterns.

During the periods of hydroelectric peaking in 1977, mean daily range in water level was considerably higher at the Skagit stations than at the Sauk or Cascade stations (Table 3.3). However, from May through October, daily fluctuation was slightly less at the Skagit stations than at the two unregulated sites. These unusual flow conditions made it possible to compare insect standing crop in the Skagit under fluctuating (1976) and relatively stable (late April to mid-November 1977) flow conditions. Flow conditions were nearly the same at Marblemount, near the Skagit Lower Station and at the Sauk sampling stations from May to October.

3.4.1.2 Exposure Time. It is necessary to know the exposure history of the river bottom locations where samples were collected during any type of benthic study to avoid erroneous interpretation of results. This is true for unregulated coastal streams of Pacific Northwest, where water levels may fluctuate widely on a weekly or monthly basis, as well as for regulated streams subject to peaking flows. Sampling a highly exposed zone of the river bottom shortly after it had been submerged during high flow would probably yield samples containing few benthic organisms. An investigator with no knowledge of the flow or exposure history of the area sampled would probably conclude that the river was extremely unproductive, although benthic macroinvertebrate density in unexposed areas in the deeper regions might be high. If samples had been collected before or after the high flow, in the unexposed zone, the observed abundance would have been higher.

Calculation of exposure time during a specified period prior to sampling is a useful method for summarizing the exposure history of a particular area of the river bottom. Its primary use is in comparing standing crops in zones of the same stream that were subjected to different degrees of exposure, as was done by Fisher and LaVoy (1972) below a hydroelectric dam on the Connecticut River. The correlation between exposure time and density of benthic organisms is better under conditions of periodic, daily exposure resulting from hydroelectric peaking flows than under a natural flow regime where bottom areas may be exposed for a week and then submerged for a week.

The exposure history of all sample locations was taken into account when making comparisons among stations and seasons. It would not have been valid to compare a station where most of the samples were collected in highly exposed areas due to high water at sampling time with another station where samples were collected in unexposed areas. Therefore, only results from unexposed sampling locations were used in computing the mean density for a station on a given sampling date, with a few exceptions. If no unexposed locations were sampled on a sample date, only the data from the location with the lowest degree of exposure were used. If the mean of the replicates at a location with some exposure would not lower the overall mean for the station--i.e., the mean of the exposed replicates was higher than the mean of the other unexposed replicates--they were also used to compute the station mean. These exceptions were noted in the tables containing exposure data.

Most of the artificial substrate periphyton samples were highly exposed during the winter of 1976-1977 (Table 3.4). Since the locations of the samplers were fixed, some of them were exposed 100 percent of the time. The high level of exposure and lack of data from unexposed samplers at the Skagit Lower and Cascade stations made it difficult to compare rivers in 1976.

The flows were relatively stable during the period when the periphyton was removed directly from streambed rocks. As a result, there was relatively little exposure of the sampling sites (Table 3.5). None of the sites at the Skagit Upper Station was exposed prior to sampling from May to November 1977. The 6 inch sites in May and June 1977 were exposed early in the 6-week exposure calculation period, and the periphyton apparently had enough time to return to a high level before sampling. The other sites at the Sauk Lower and Cascade stations marked with an asterisk (*) were also exposed early in the 6-week period, allowing the periphyton to recolonize before sampling.

There was no exposure of benthic insect sampling locations during the 2-week exposure calculation period at the Sauk Lower and Cascade stations in 1976 (Table 3.6). The amount of exposure at sites at the Skagit Lower Station was high during May, September, and November 1976, and no samples were collected in unexposed areas in May or November. During 1977, there was little exposure at any of the stations other than at the Skagit Upper Station in February. All 16 replicate samples were used to calculate the station means during 1977, with the exception of the Skagit Upper Station in February. Since periphyton and benthos were always sampled at the same depths and usually on the same dates in 1977, the 6-week exposure figures in Table 3.5 also represent the amount of exposure for benthic insect sample locations during the 6 weeks prior to sampling.

The distances from the permanent marker near the high-water line to each periphyton and benthic sample location are shown in Table 3.7. At a particular site, these distances indicate the locations where the two to four replicate samples were collected.

3.4.1.3 Turbidity. Turbidity levels were much lower at all stations during August and September 1976 (Table 3.8) than during the same months in 1977 (Table 3.9). The Skagit and Cascade were considerably less turbid than the Sauk during July and August 1977. The drainage areas of the three rivers contain numerous glaciers, and the increased turbidity in 1977 was caused primarily by glacial flour in the water. Glacial melting was more extensive in 1977 than in 1976 because of low precipitation during the winter and generally warmer air temperatures during the summer of 1977. The amount of suspended sediment in the Skagit was reduced by settling in the reservoirs.

The difference in turbidity levels between the Upper and Lower Sauk stations was caused by suspended sediment of glacial origin contributed by

Table 3.4 Percentage of time that the artificial substrate periphyton samplers were exposed to desiccation during the six-week period prior to sampling. Samplers were located on a cross-river transect, and depth increased with the sampler number.

Station	Date	Sampler Number 1	2	3	4
Skagit Lower	10/14/76	72	41	40	20*
	11/29/76	87	81	56	26*
	1/12/77	24	13	5*	2*
	2/24/77	44	25	9	0
Sauk Lower	10/15/76	81	9	0	0
	11/30/76	91	72	0	0
	1/12/76	92	54	0	0
	3/21/77	87	7*	0	0
Cascade	10/15/76	40	22	0	0
	11/30/76	95	90	80	39*
	1/12/77	93	83	61	14*
	3/21/77	100	100	81	38*

*Results from these exposed samplers were used in calculating the mean for the sampling station.

Table 3.5 Percentage of time that the streambed at periphyton sampling locations was exposed to desiccation during the six-week period prior to sampling.

Station	Sampling Date	Depth of Water at Sample Site (inches)			
		6	10	14	18
Skagit Upper	5/11/77	0	0	0	0
	6/16/77	0	0	0	0
	7/26/77	0	0	0	0
	9/14/77	0	0	0	0
	11/ 9/77	0	0	0	0
Skagit Lower	5/ 6/77	8*	0	0	0
	6/16/77	10*	0	0	0
	7/26/77	0	0	0	0
	9/14/77	0	0	0	0
	11/ 9/77	0	0	0	0
Sauk Lower	5/ 5/77	38	0	0	0
	6/17/77	63*	0	0	0
	7/27/77	0	0	0	0
	9/13/77	0	0	0	0
	11/ 8/77	43*	0	0	0
Cascade	5/10/77	63	25	9*	0
	6/17/77	52	36	0	0
	7/25/77	0	0	0	0
	9/14/77	0	0	0	0
	11/10/77	74*	62*	44*	8*

*Results from these exposed sample locations were used in calculating the mean for the sampling station.

Table 3.6 Percentage of time that the streambed at benthic sampling locations was exposed to desiccation during the two-week period prior to sampling.

Station	Sampling Date	Depth of Water at Sample Site (inches)				
		6	10	12	14	18
Skagit Upper	2/24/77	72	64	--	50	16*
	5/11/77	0	0	--	0	0
	7/26/77	0	0	--	0	0
	9/14/77	0	0	--	0	0
	11/9/77	0	0	--	0	0
Skagit Lower	5/20/76	35		21		16*
	7/28/76	1*	1*	--	0	0
	9/14/76	40	33	--	6	0
	11/12/76	96	86	--	69	22*
	2/24/77	0	0	--	0	0
	5/6/77	0	0	--	0	0
	7/26/77	0	0	--	0	0
	9/14/77	0	0	--	0	0
	11/9/77	0	0	--	0	0
Sauk Upper	2/17/77	0	0	--	0	0
	5/ 5/77	17*	12*	--	11*	10*
	7/27/77	0	0	--	0	0
	9/13/77	0	0	--	0	0
	11/8/77	0	0	--	0	0
Sauk Lower	5/21/76	0	--	0	--	0
	7/14/76	0	--	0	--	0
	9/15/76	0	--	0	--	0
	11/12/76	0	--	0	--	0
	2/17/77	16*	0	--	0	0
	5/ 5/77	10*	0	--	0	0
	7/27/77	0	0	--	0	0
	9/13/77	0	0	--	0	0
	11/ 8/77	0	0	--	0	0
Cascade	5/21/76	0	--	0	--	0
	7/14/76	0	--	0	--	0
	9/15/76	0	--	0	--	0
	11/12/76	0	--	0	--	0

*Results from these exposed sample locations were used in calculating the mean for the sampling station.

Table 3.7 Distance (ft) from the permanent marker near the high water line to benthic insect and periphyton sample sites along the transects at sampling stations.

Station	Sampling Date	Depth of Water at Sample Site (inches)				
		6	10	12	14	18
Skagit Upper	2/24/77*	0	18	--	31	45
	5/11/77	57	64	--	69	75
	6/16/77**	58	65	--	68	73
	7/24/77	67	70	--	76	81
	9/14/77	70	76	--	87	93
	11/ 9/77	68	74	--	80	89
Skagit Lower	5/20/76*	0	--	23	--	30
	7/28/76*	0	22	--	66	108
	9/14/76*	23	30	--	67	96
	11/12/76*	30	50	--	69	89
	2/24/77*	81	93	--	107	127
	5/ 6/77	81	93	--	107	127
	6/16/77**	77	101	--	114	123
	7/26/77	111	122	--	130	140
	9/14/77	121	127	--	140	146
	11/ 9/77	117	125	--	132	143
Sauk Upper	2/17/77*	52	61	--	72	81
	5/ 5/77*	11	16	--	21	28
	7/27/77*	31	38	--	51	57
	9/13/77*	51	56	--	64	70
	11/ 8/77*	44	64	--	74	90
Sauk Lower	5/21/76*	101	--	110	--	121
	7/14/76*	97	--	108	--	114
	9/15/76*	76	--	84	--	90
	11/12/76*	84	--	88	--	96
	2/17/77*	95	102	--	109	114
	5/ 5/77	90	96	--	99	103
	6/17/77**	83	89	--	95	97
	7/26/77	100	103	--	111	116
	9/14/77	103	105	--	116	127
	11/ 8/77	95	101	--	107	113
Cascade	5/21/76*	75	--	88	--	109
	7/14/76*	54	--	72	--	86
	9/15/76*	30	--	35	--	41
	11/12/76*	45	--	50	--	62
	5/10/77**	70	73	--	77	80
	6/17/77**	60	69	--	73	75
	7/25/77**	74	77	--	80	82
	9/16/77**	83	84	--	86	89
	11/10/77**	74	76	--	79	82

*Only benthic insects sampled on these dates.
**Only periphyton sampled on these dates.

Table 3.8 Mean monthly turbidity (J.T.U.) at stations on the Skagit, Cascade, and Sauk rivers during 1976.

	Station			
Month	Skagit at Newhalem	Skagit at Marblemount	Cascade	Sauk Lower
June	1.7	3.3	8.3	7.7
July	4.0	5.6	13.0	31.0
August	4.7	4.3	3.7	13.0
September	0.3	0	0.5	15.0
October	0	0	1.0	5.0
November	2.6	2.8	2.0	8.4
December	6.3	9.3	11.3	11.5
Mean	2.8	3.6	5.4	12.7
June-November mean	2.1	2.5	4.4	14.1

Table 3.9 Mean monthly turbidity (J.T.U.) at stations on the Skagit, Cascade, and Sauk rivers during 1977.

MONTH	STATION				
	Skagit at Newhalem	Skagit at Marblemount	Cascade	Sauk Upper	Sauk Lower
January	4.2	4.4	6.4	--	5.8
February	5.0	6.7	10.0	--	6.7
March	3.8	3.7	4.3	--	4.3
April	5.3	6.3	7.6	--	15.0
May	3.3	3.4	3.2	--	5.2
June	6.3	5.3	6.7	--	19.3
July	2.0	4.7	2.8	20.0	43.8
August	10.0	7.3	9.0	39.5	197.5
September	5.3	5.3	30.0	8.3	30.5
October	4.8	4.2	4.6	8.8	24.0
November	5.0	2.0	3.0	6.0	9.0
Mean	4.9	4.8	8.1	18.1	34.4
June-November Mean	5.6	4.9	10.1	--	60.7

the Suiattle River. Water from the Suiattle entered the Sauk immediately above the upper sampling station on the opposite side of the river and did not become mixed with Sauk River water until it had flowed past the sampling transect. As a result, comparatively clear upper Sauk River water flowed over the shoreline area of the transect where samples were collected, while frequently turbid Suiattle River water flowed over the unsampled half of the transect.

3.4.2 Periphyton

3.4.2.1 Flow Fluctuation Effects. Under natural flow conditions, most periphyton production in large streams is probably limited primarily to a zone along the shoreline where environmental conditions are suitable for growth and attachment. The width of the zone depends upon the slope of the shore. This zone moves laterally as the average daily flows change through the year. In the Sauk, maximum flows occurring during the winter and summer were followed by periods of low flow. Periphyton present in shallow areas during the high flow periods was exposed and destroyed by desiccation as the flow decreased. However, the average daily flow decreased gradually and should have allowed periphyton to become established in areas farther from the waterline where water depth or velocity did not permit growth under higher flow, resulting in a net movement of the periphyton zone toward midchannel. As average daily flows rise in the spring and fall, the periphyton zone would be expected to move laterally toward the river margins as previously dry areas become wetted, and velocity becomes too high in midstream.

Daily flow fluctuations caused by hydroelectric peaking limit the potential area available for colonization by periphyton by reducing the width of the periphyton zone. Frequent exposure during low flows prevents the establishment of periphyton near the river margins and only areas that are permanently submerged or infrequently exposed to desiccation for short periods of time may be suitable for colonization. Scouring of the bottom during high flows due to peaking and spilling may reduce the periphyton standing crop in the midchannel areas where current velocity is usually greatest.

Stream profiles at the Skagit River transect are shown in Fig. 3.2 along with periphyton sampler locations and maximum and minimum water levels during the first three 6-week colonization periods. Low flows exposed the deepest sampler, at 125 ft from the high-water mark, to desiccation during all three colonization periods, and precluded the collection of data on chlorophyll a values under conditions of zero exposure. Since the plexiglass plates were 7.5 inches above the riverbed, it was possible for the plates to be exposed during a low flow while the concrete base of the sampler remained submerged. The sampler nearest the high-water line was exposed at flows below 5,800 cfs.

To determine the effects of exposure on periphyton standing crop, the mean chlorophyll content of the two replicate samples from each periphyton sample was plotted against percent exposure. Results from each colonization period are shown separately in Figs. 3.3-3.6.

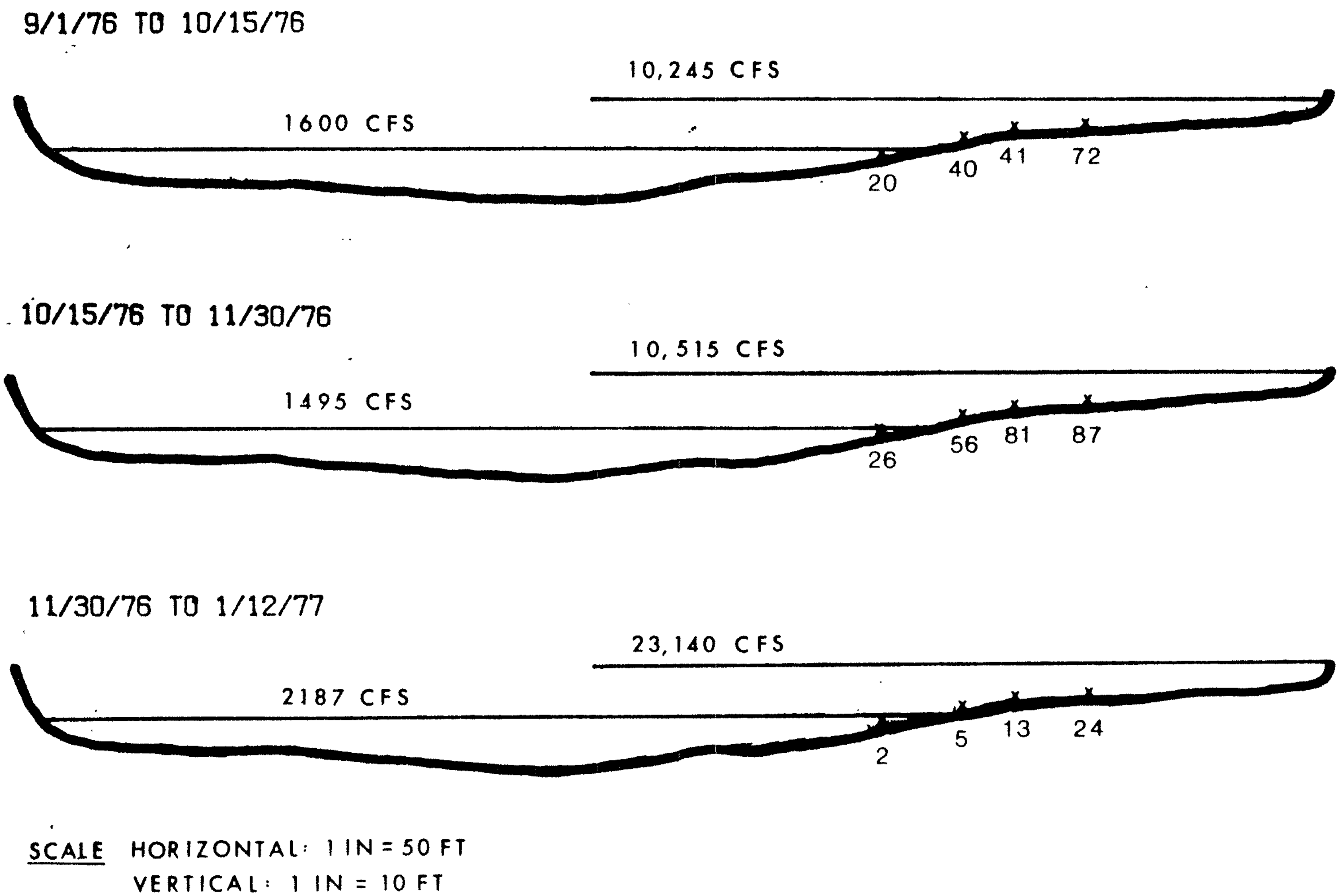

Fig. 3.2 Stream profiles at the Skagit Lower station showing maximum and minimum water levels during the six-week colonization periods. The percentage of time that each periphyton sampler was exposed to desiccation during the six weeks prior to sampling is given below the sampler location, which is indicated by an X.

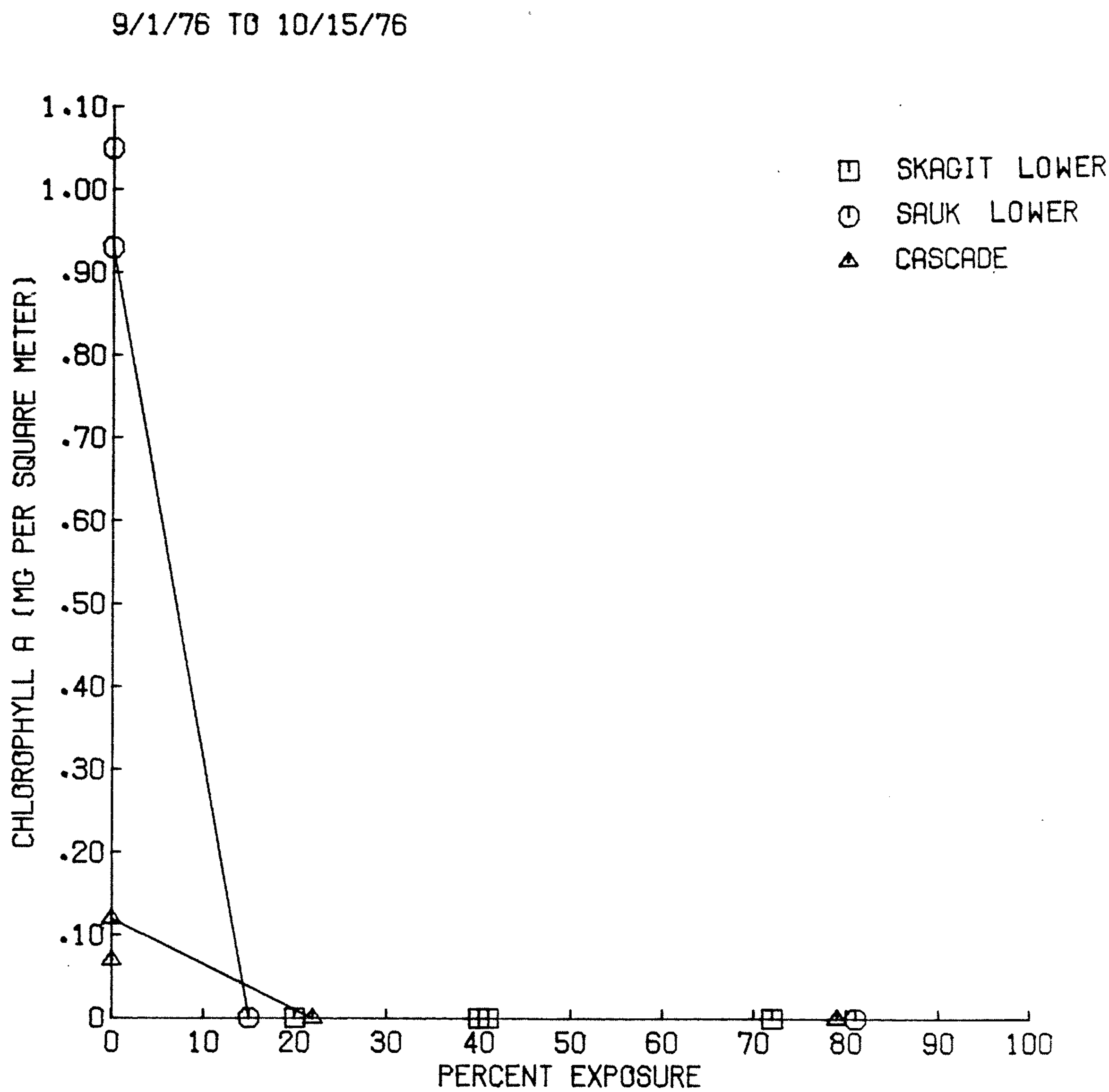

Fig. 3.3 Chlorophyll a content of periphyton samples collected at the Skagit Lower, Sauk Lower, and Cascade stations in October 1976.

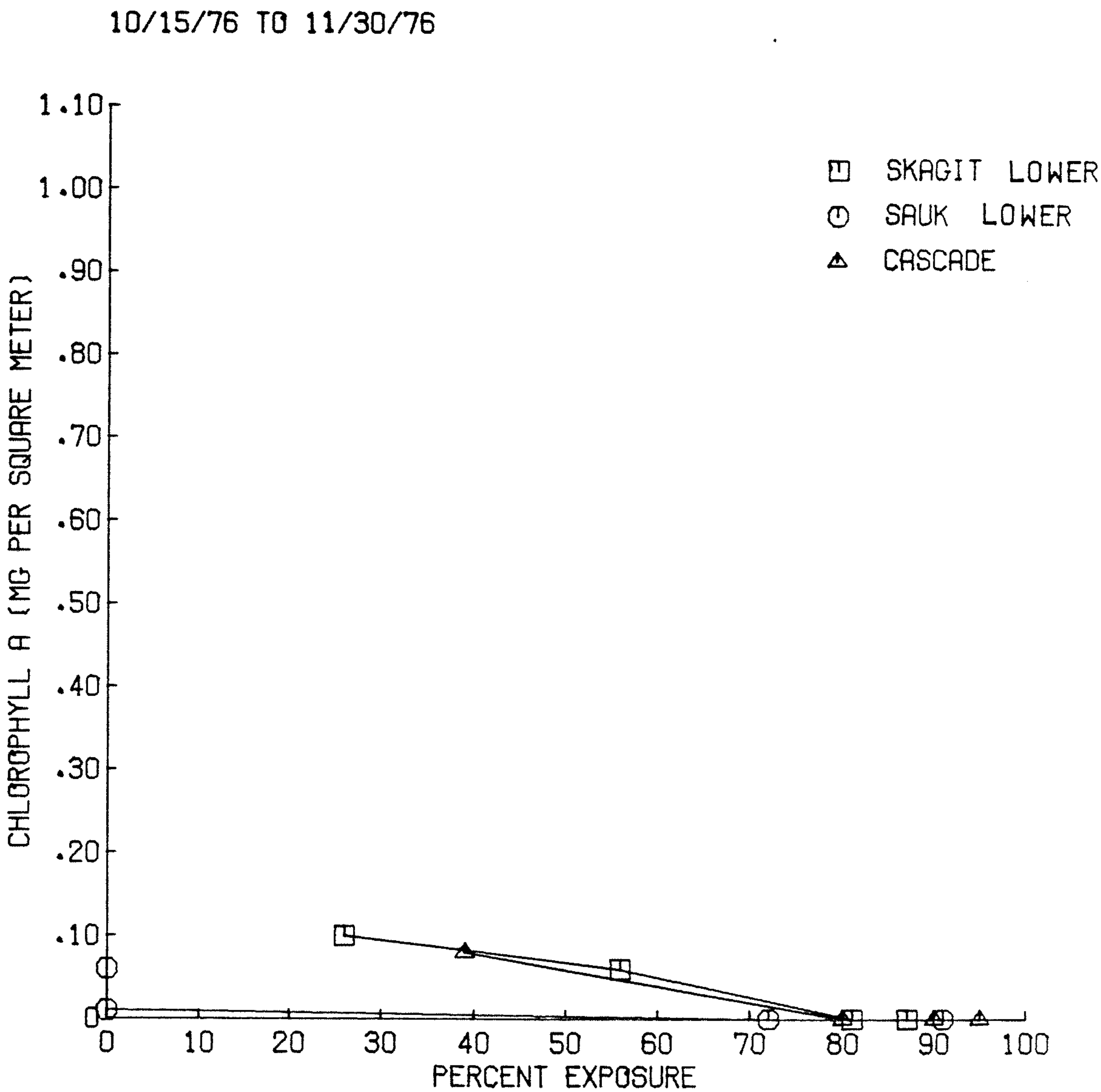

Fig. 3.4 Chlorophyll a content of periphyton samples collected at the Skagit Lower, Sauk Lower, and Cascade stations in November 1976.

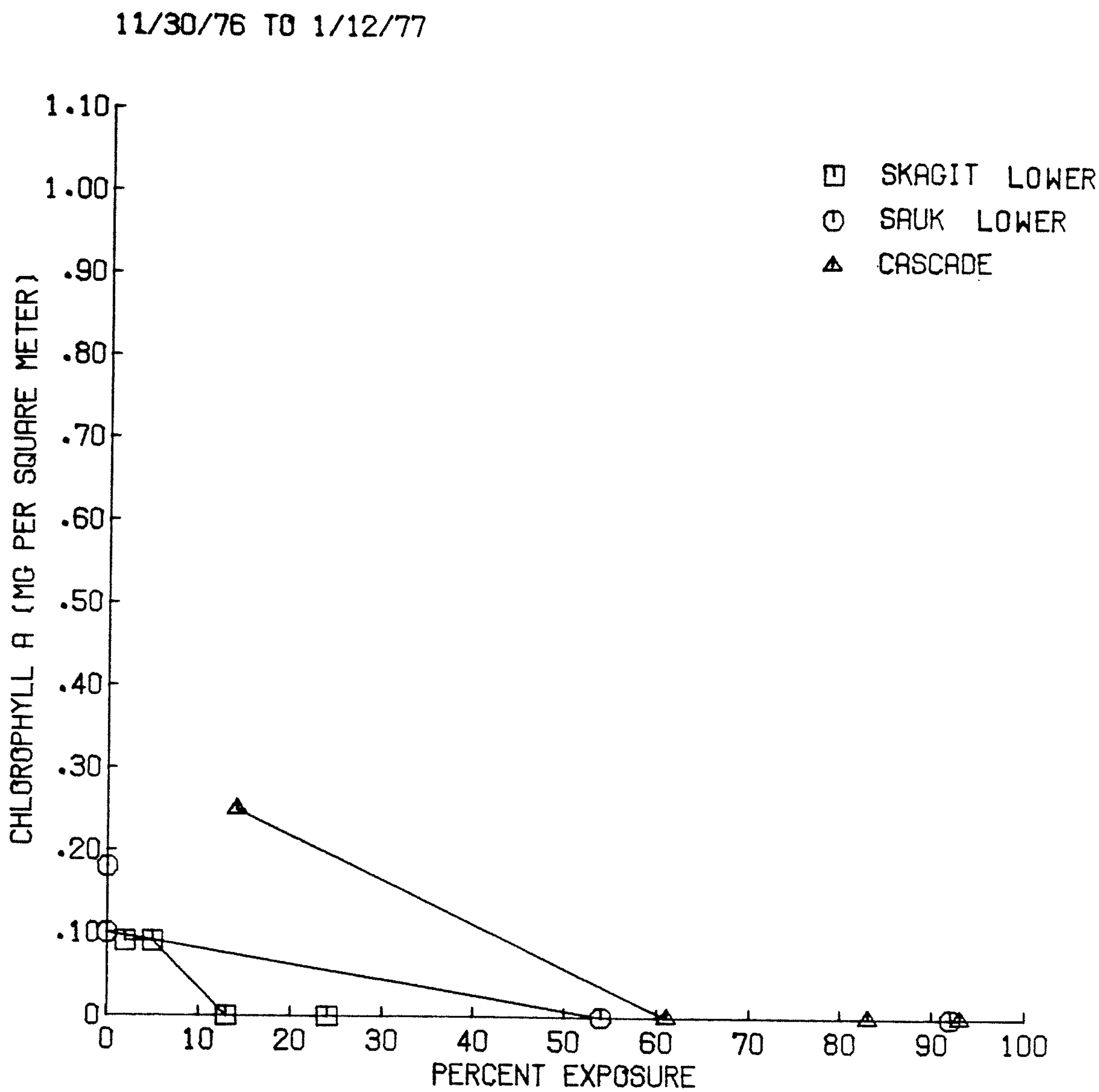

Fig. 3.5 Chlorophyll a content of periphyton samples collected at the Skagit Lower, Sauk Lower, and Cascade stations in January 1977.

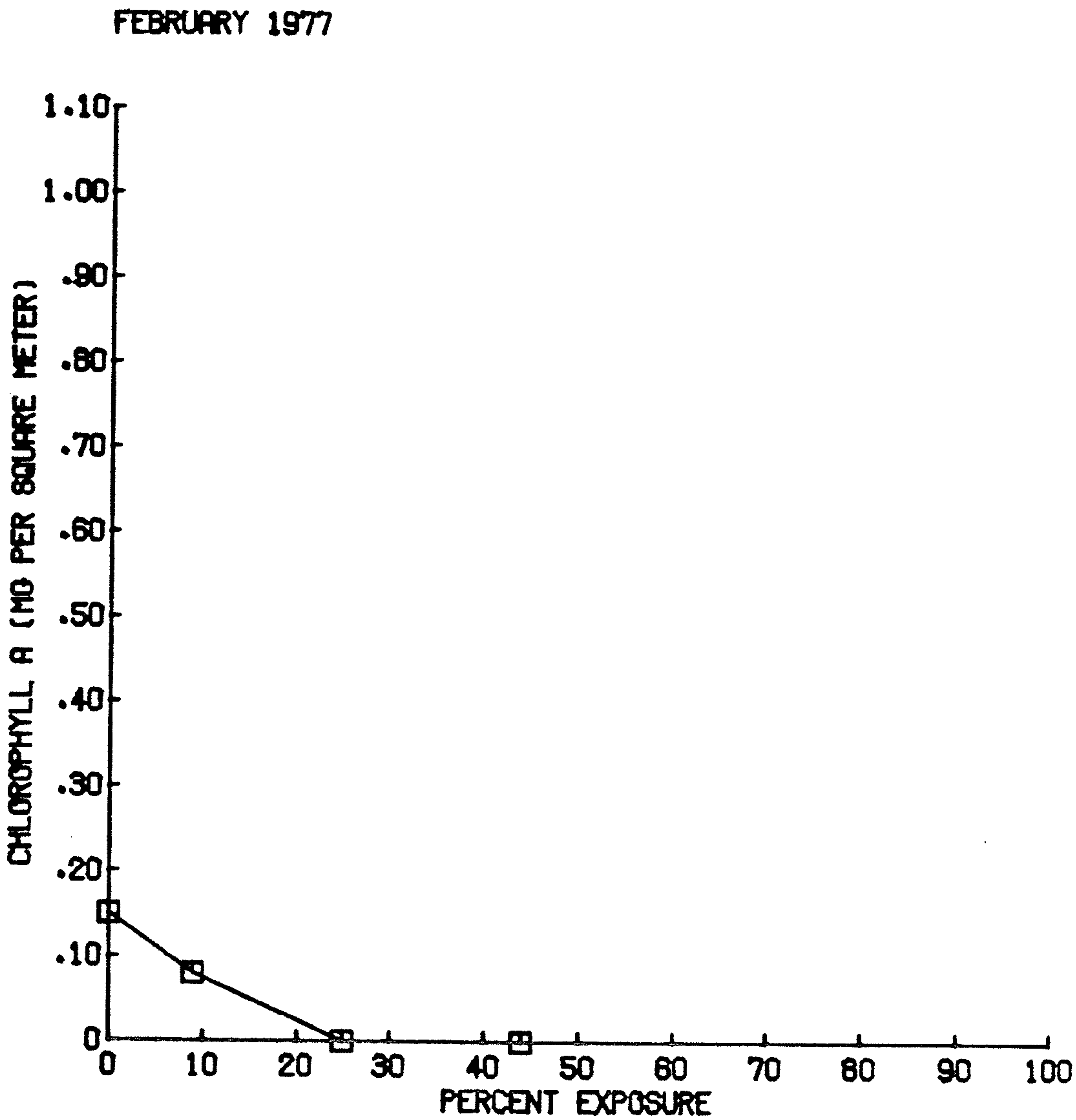

Fig. 3.6 Chlorophyll a content of periphyton samples collected at the Skagit Lower Station in February 1977.

In general there was a trend of increasing chlorophyll a with decreasing exposure to desiccation. This trend is particularly evident in the results from the Skagit River during November 1976 (Fig. 3.4) and February 1977 (Fig. 3.6). It appears that the daily fluctuations, accompanied by daily exposure, reduced periphyton abundance in these areas of the river margins, and that the amount of periphyton present was related to the degree of exposure.

3.4.2.2 Seasonal Variation. It was difficult to compare stations during the period of October 1976 to March 1977 because of the lack of data from unexposed artificial substrate samples in the Skagit and Cascade rivers. The two deepest samplers at the Sauk Station were unexposed during all sampling periods (Table 3.4) and only data from these samplers were graphed, while data from some exposed samplers at the Skagit and Cascade stations were used in Figs. 3.7 and 3.8.

Periphyton standing crop on artificial substrates at the Sauk Station was highest in October and decreased to a lower level during the remaining colonization periods (Fig. 3.7). During October 1976, unexposed substrates at the Cascade Station (Fig. 3.8) had much less periphyton than the Sauk substrates, and chlorophyll a remained low through March. Chlorophyll a on highly exposed Skagit River substrates was low through February. Results in February from unexposed Skagit samplers were similar to results from unexposed Sauk River samplers in March.

During the period when the periphyton was removed from streambed rocks, flow patterns were roughly similar, and exposure was low at all sampling stations (Table 3.5). Valid comparisons were possible among stations, but it was not valid to compare standing crop in October or November 1976 with standing crop in these months in 1977 because different sampling methods were used.

The pattern of seasonal variation in periphyton standing crop was similar at the Sauk Lower (Fig. 3.7) and Cascade (Fig. 3.8) stations during 1977. Standing crop was almost the same at both stations from January through June; higher at the Cascade Station during the summer, and again similar in November. Maximum standing crop was present during the summer at both stations.

Periphyton standing crop at the Skagit Lower Station (Fig. 3.7) rose rapidly from May to June, when it reached the maximum value for the year. Standing crop in May and June was much higher than at the other three sites during this time period, but dropped to the same general level as the Sauk and Cascade during the summer. Unlike the Sauk and Cascade, periphyton standing crop at the Skagit Lower Station remained relatively high into November.

Periphyton standing crop at the Skagit Upper Station (Fig. 3.8) increased steadily from May to November. During spring and early summer, chlorophyll a levels were comparable to levels in the Sauk and Cascade. However, standing crop continued to increase into the fall, as standing crop in the two unregulated streams fell sharply.

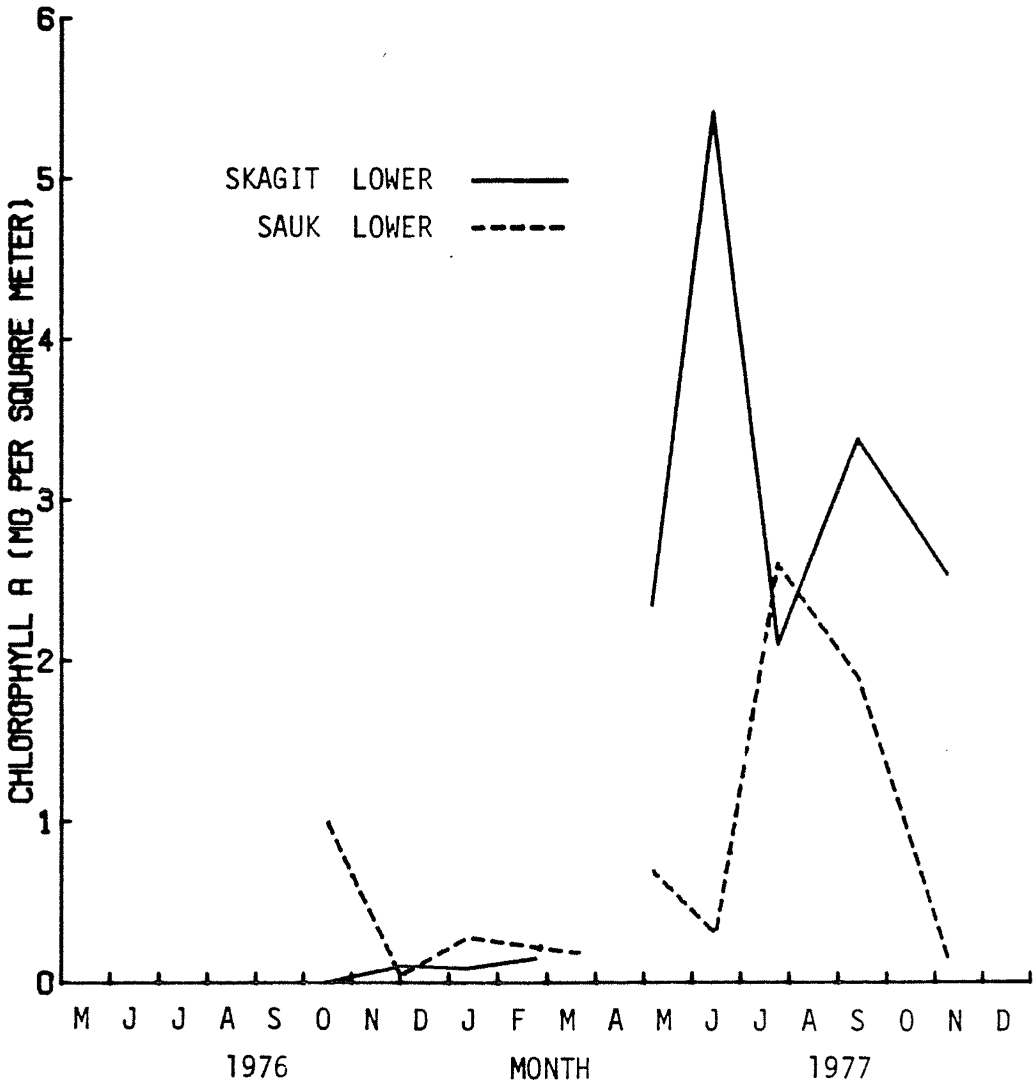

Fig. 3.7 Periphyton standing crop, as indicated by chlorophyll a content, at the Skagit Lower and Sauk Lower stations. Two different sampling methods were employed, and results using each method were plotted separately.

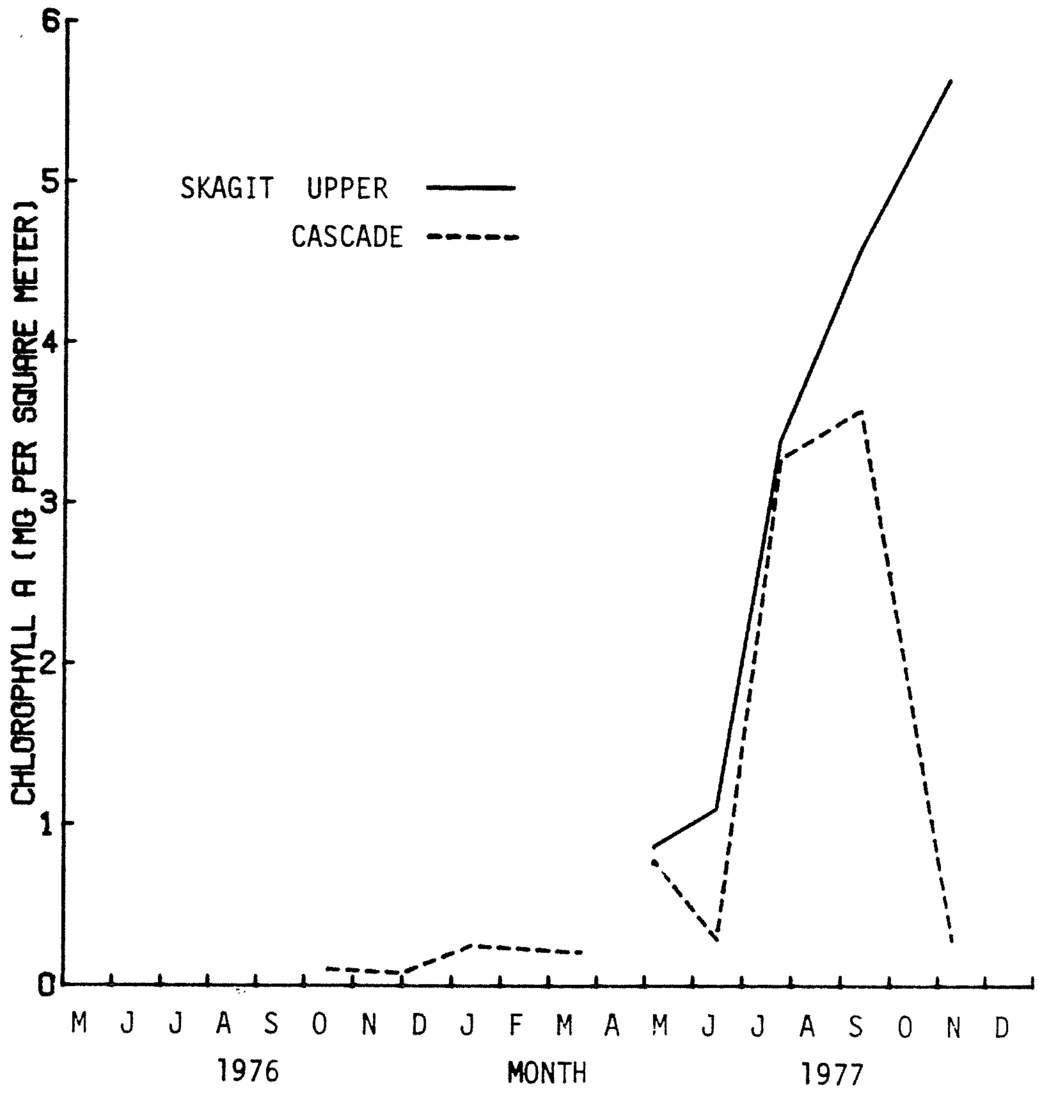

Fig. 3.8 Periphyton standing crop as indicated by chlorophyll _a_ content of samples collected at the Skagit Upper and Cascade stations. Two different sampling methods were employed in the Cascade River, and results using each method were plotted separately.

The relatively stable flow in the Skagit contributed to the high periphyton standing crop at the two Skagit River stations during the May through November period. Only minor fluctuations occurred during this time span, and the periphyton was able to grow without being affected by desiccation during flow reductions. The variations in flow consisted of slight increases in water level for a few days, which would not have exposed any periphyton, but may have removed some biomass through scouring and high current velocity.

High flows occurring 1 week before sampling were probably responsible for the reduction in standing crop observed at the Skagit Lower and Sauk stations in November 1977. On November 1, the water level rose almost 6 ft in the Sauk River. Increases in water level of over 4 ft and over 5 ft were recorded at the Skagit at Marblemount and Alma Creek gages, respectively, on the same date. Water level only varied 2.5 ft at Newhalem on November 1.

The observed reduction in periphyton standing crop at the Skagit Lower and Sauk stations was not due to sampling in previously exposed areas during the higher water in November. Although the November samples were collected in areas closer to the high-water line (Table 3.7), there was considerable overlap in the sections of the transects sampled in September and November at all stations except the Cascade. More importantly, most locations sampled in November had been unexposed for extremely long periods. All sampling locations at the Skagit Lower Station had not been exposed during 1977 and all locations at the upper station had been submerged since at least July. At the Sauk Lower Station, the shallowest location had been exposed for several days in September and October, but the other three locations had been submerged continuously during 1977.

Since most of the areas sampled in the Sauk and Skagit in November had not been exposed prior to sampling, the reduction was attributed to scouring during the high flows. The reduction in Cascade standing crop may have been due to either exposure or scouring. The standing crop at the Skagit Upper Station was higher in November than in September, and was apparently not reduced during the high water. The amount of suspended sediment in the upper part of the river below Gorge Powerhouse may have been lower, resulting in reduced scouring at the Skagit Upper Station.

The large amount of suspended sediment in the Sauk River during the summer undoubtedly limited the amount of light reaching the benthic zone and reduced periphyton growth. Standing crop in the Cascade River was higher than in the Sauk during July and September, probably because of the lower turbidity levels in the Cascade.

The ranges of chlorophyll a values at the Skagit Lower, Sauk Lower, and Cascade stations were compared with the ranges in several other rivers (Table 3.10). Ranges for each type of substrate used in this study are given separately, and values are from unexposed substrates only. The artificial substrates were used during fall and winter, when periphyton

Table 3.10 Range of chlorophyll *a* values in the Skagit, Sauk, and several other North American streams.

Stream	Substrate	Chlorophyll *a* (mg/m^2)
Logan River, Utah (McConnell and Sigler, 1959)	Streambed rocks	140 - 1420
Laboratory Stream, Ore. (McIntire and Phinney, 1965)	Streambed rocks	140 - 2010
Valley Creek, Minn. (Waters, 1961)	Concrete cylinders	9.2 - 21.1
Carnation Creek, B.C. (Stockner and Shortreed, 1976)	Plexiglass plates	0.9 - 2.1
Skagit River, Wash. (October 1976 - February 1977)	Plexiglass plates	0.09 - 0.15
Skagit River, Wash. (May 1977 - November 1977)	Streambed rocks	0.41 - 8.28
Sauk River, Wash. (October 1976 - March 1977)	Plexiglass plates	0.01 - 1.05
Sauk River, Wash. (May 1977 - November 1977)	Streambed rocks	0.07 - 3.92
Cascade River, Wash. (October 1976 - March 1977)	Plexiglass plates	0.07 - 0.25
Cascade River, Wash. (May 1977 - November 1977)	Streambed rocks	0.20 - 4.35

growth is probably at its lowest level, due to reduced light. The natural substrates were used during the seasons of peak periphyton growth.

Results using plexiglass artificial substrates in the Skagit, Sauk, and Cascade rivers are comparable to the range of values in Carnation Creek, British Columbia (Stockner and Shortreed 1976). Stockner and Shortreed (1976) considered the level of chlorophyll in Carnation Creek to be extremely low, and attributed this low level to extremely low nutrient concentrations and poor light conditions under the forest canopy. There was no forest canopy at the Skagit, Sauk, or Cascade stations, and turbidity was low during 1976 and early 1977. Therefore, one would expect the chlorophyll levels to be higher at these stations. The low values may have resulted from the use of artificial substrates.

The smooth plexiglass plates may not have been suitable for the attachment and growth of some species of algae. Considerable growth of filamentous algae was observed on streambed rocks in the Skagit and Cascade rivers in areas where periphyton samplers were placed, and on the concrete bases of the samplers, but comparable growth did not occur on the plexiglass plates. The length of time that the substrates were available for colonization may not have been long enough. The plexiglass slides were held several inches off the bottom in this study and in the Carnation Creek study (Stockner and Shortreed 1976). The higher velocities above the bottom may have inhibited colonization or may have removed periphyton by scouring.

The level of chlorophyll a on the streambed rocks was much greater than on the plexiglass plates. This difference may be due to differences in substrate or seasonal effects. The maximum value at the Skagit station, collected from natural substrates, approached the minimum value in Valley Creek, Minnesota (Waters 1961). Values from the three rivers examined, even from streambed rocks, were much lower than the minimum value observed in the Logan River, Utah (McConnell and Sigler 1959).

3.4.3 Benthic Insects

3.4.3.1 Flow Fluctuation Effects. Flow fluctuations can have a detrimental effect on benthic insects by dewatering the substrate and also by altering environmetal conditions in submerged areas of the riverbed. During flow reductions, aquatic insects that are not able to move rapidly enough toward midstream or do not drift downstream are left stranded on the dewatered substrate, where mortality through desiccation or freezing may result. Natural seasonal fluctuations in water level also cause dewatering of shoreline substrate. However, the change in water level occurs gradually, allowing most insects to avoid stranding.

Changes in velocity during flow fluctuations can also affect the benthic community. Many species of aquatic insects have specific current velocity requirements, and velocity over a particular area of the bottom may exceed the range of tolerance during high daily flows, eliminating some species from affected bottom areas. Deeper areas that are never dewatered can also be affected if velocities during high flows are severe enough to cause shifting of the substrate or scouring.

Stream profiles at the Skagit River Lower Station showing maximum and minimum water levels during the 2 weeks prior to benthic sampling in 1976 are presented in Figs. 3.9 and 3.10. During the July 1976 sampling period (Fig. 3.9), a small length of the transect was exposed and submerged, and the duration of the dewatering was very short. This flow pattern resulted in high benthic insect densities near the riverbank. The length of the transect exposed and submerged was much greater in May, September, and November, and the duration of exposure near the bank was higher. Consequently, insect densities were low in shallow areas of the transect. The width of the transect was 374 ft, and between 86 and 112 ft of the sampled side of the transect were exposed at minimum flow during the September and November sampling periods. Only 41 ft were exposed during the 2 weeks prior to the July sample.

The relationships between percent exposure and benthic insect density and biomass are shown for May, July, September and November 1976 Skagit River samples in Figs. 3.11-3.14. Benthic insect density and biomass were much lower in areas of the Skagit subject to high exposure than in areas subjected to low exposure.

A relationship in which density and biomass increase as exposure decreases, was evident. During May (Fig. 3.11) density and biomass increased sharply as the exposure decreased. This pattern was also observed during September (Fig. 3.13). During July (Fig. 3.12), all sample locations were subject to extremely low exposure (0-1 percent) because minimum flows were high during July. November density and biomass were low at all sample locations at the Skagit Lower Station transect (Fig. 3.14) and were associated with high exposure at all locations.

It appears that the benthic insect fauna in shoreline areas of the Skagit was reduced as a result of periodic exposure in 1976, and the degree of reduction was related to exposure time. The pattern of increasing benthic invertebrate density with decreasing exposure was identical to the pattern found below other hydroelectric dams by Fisher and LaVoy (1972) and MacPhee and Brusven (1973).

The diurnally fluctuating water levels during hydroelectric peaking in the Skagit have prevented the establishment of the productive shoreline benthic community that is present in unregulated streams. Several investigators have found that the shallow areas of streams near the shore are more productive than areas near midstream. Needham and Usinger (1956) found that the density of most aquatic insect genera was several times greater in shallow, slower moving water (0.7-3.0 ft/sec) of an unregulated stream than in the deeper, faster moving water (up to 5.3 ft/sec) at midstream. Kennedy (1967) reported that the majority of benthic organisms in Convict Creek, California, preferred depths between 3 and 6 inches and current velocities between 1.0 and 1.2 ft/sec. As depth increased beyond 6 inches, the number of organisms decreased. The frequent flow fluctuations in the Skagit during periods of hydroelectric peaking reduced

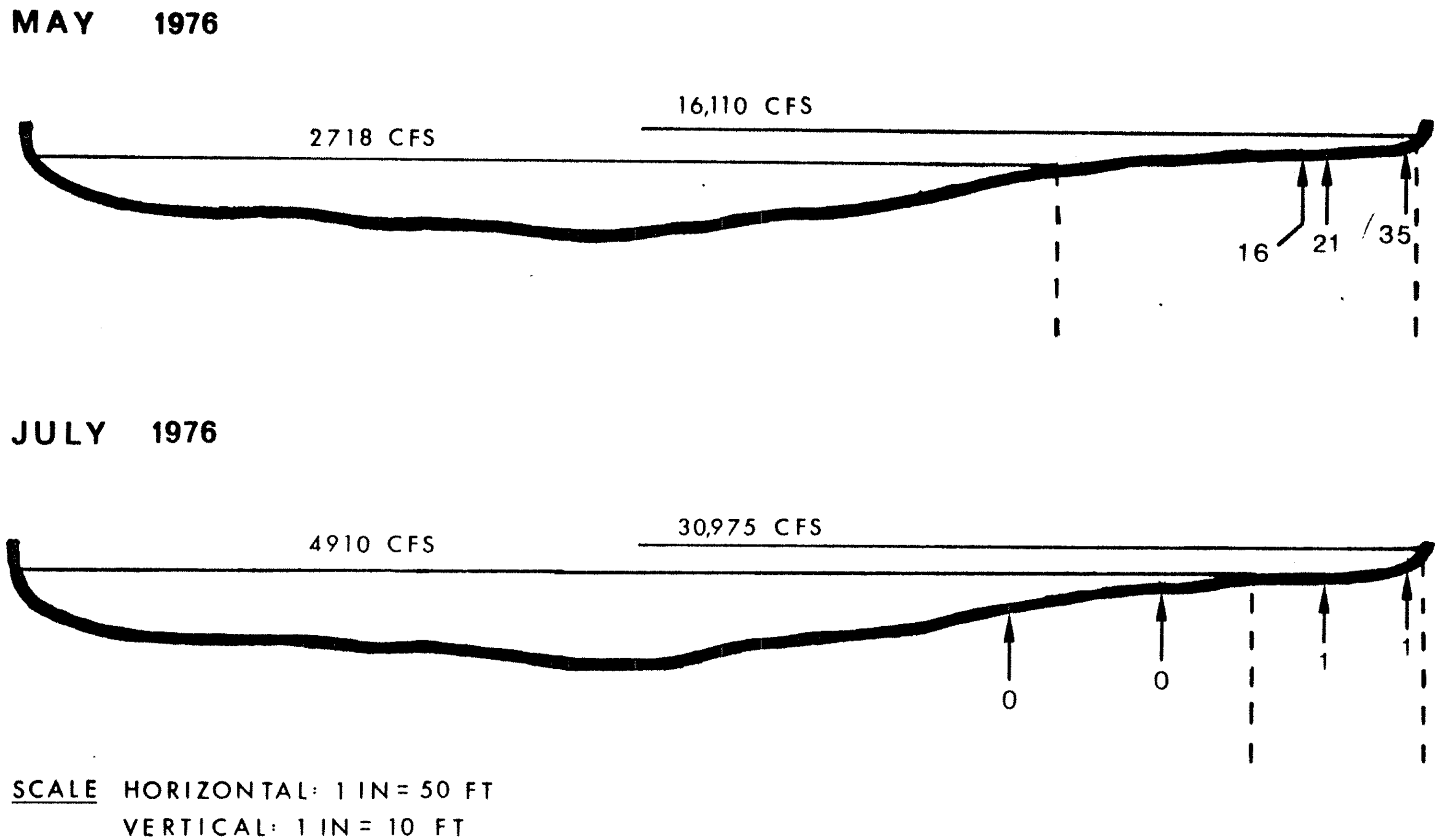

Fig. 3.9 Stream profiles at the Skagit Lower Station showing maximum and minimum water levels during the two weeks prior to benthic insect sampling in May and July 1976. The area between the dashed lines is the area of the riverbed that was periodically exposed and submerged. The locations where replicate benthic samples were collected and percent exposure time are indicated by arrows.

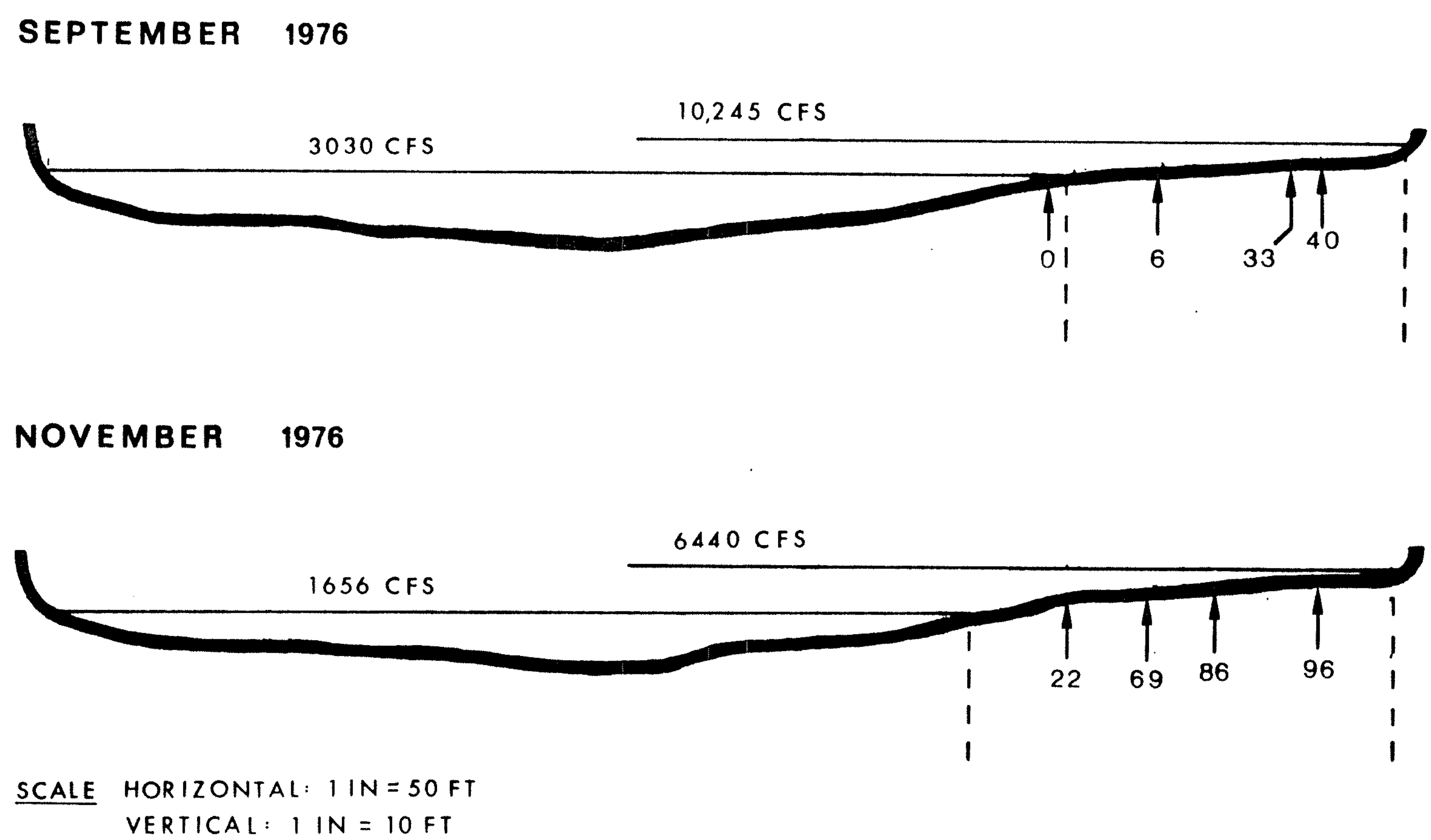

Fig. 3.10 Stream profiles at the Skagit Lower Station showing maximum and minimum water levels during the two weeks prior to benthic insect sampling in September and November 1976. The area between the dashed lines is the area of the riverbed that was periodically exposed and submerged. The locations where replicate benthic samples were collected and percent exposure time are indicated by arrows.

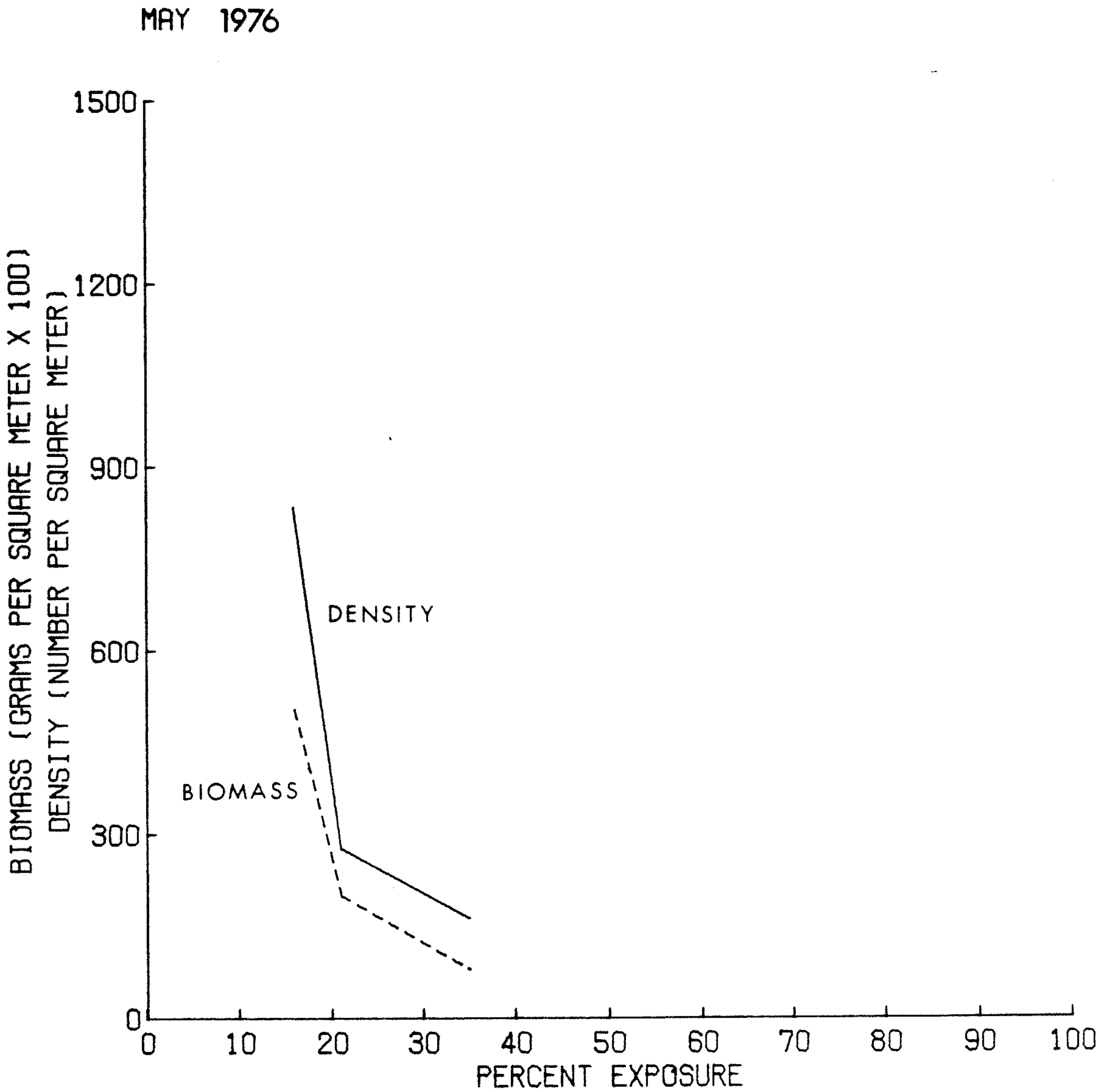

Fig. 3.11 Density and biomass of benthic insects at the Skagit Lower Station in May 1976.

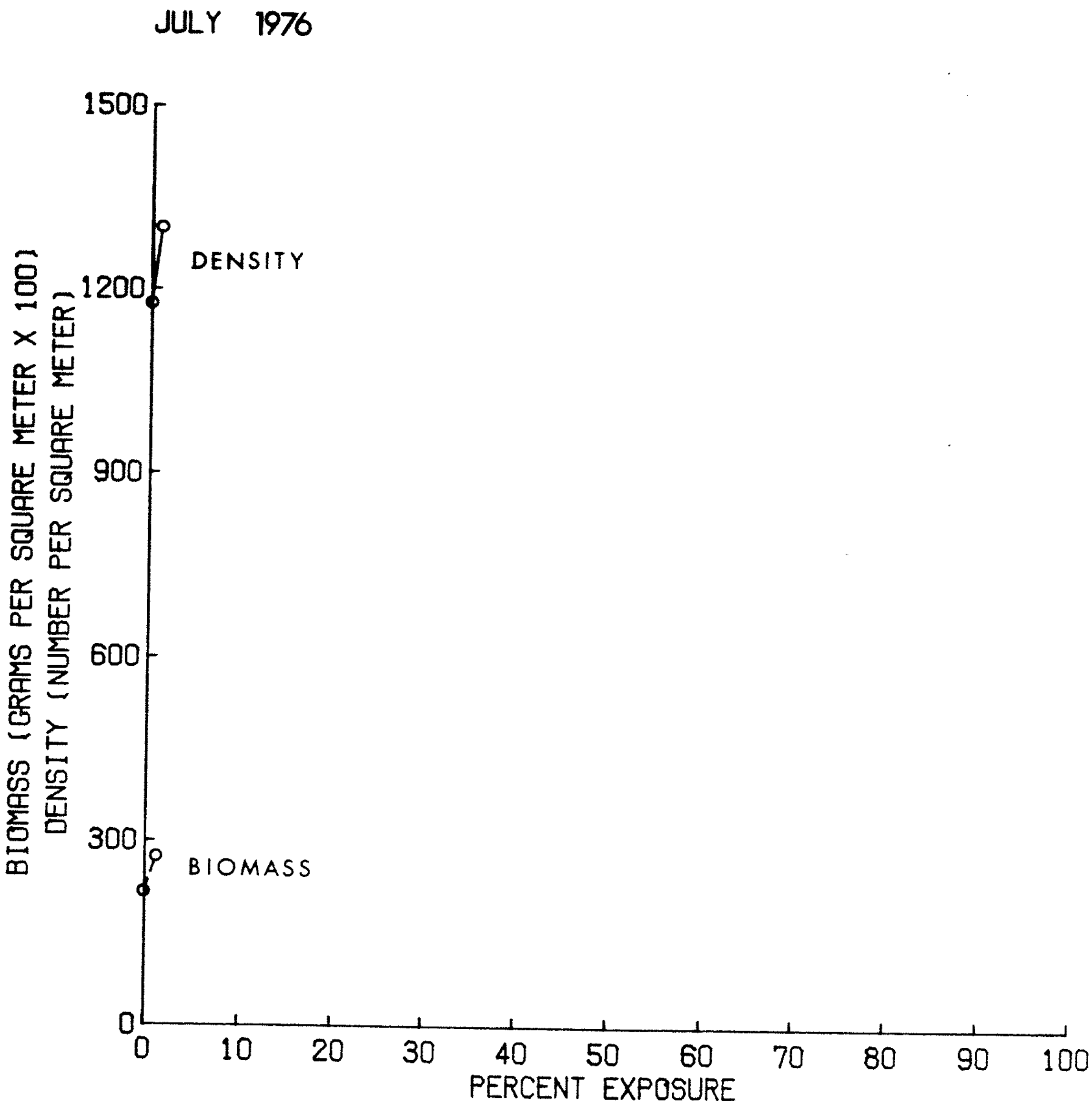

Fig. 3.12 Density and biomass of benthic insects at the Skagit Lower Station in July 1976.

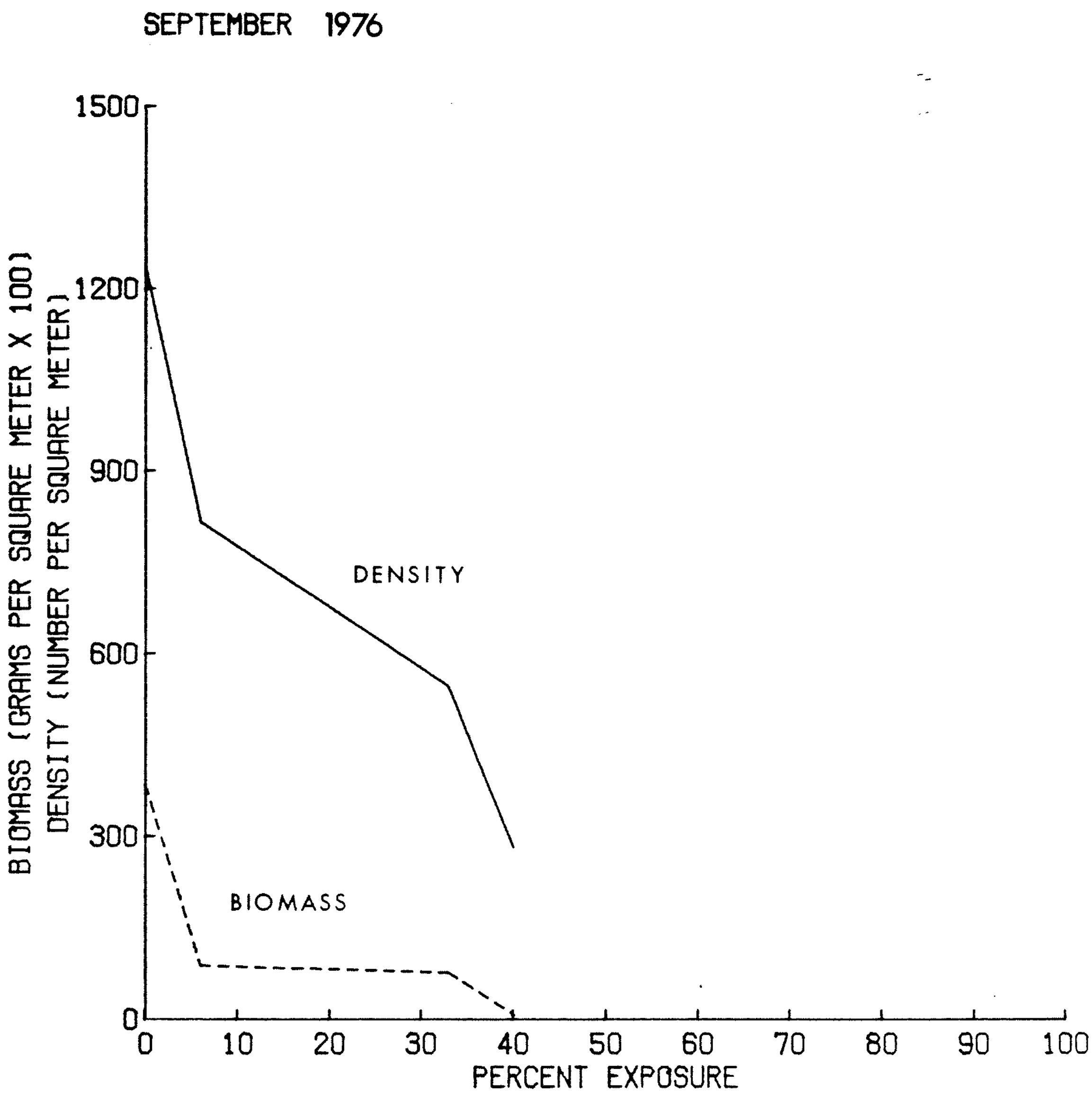

Fig. 3.13 Density and biomass of benthic insects at the Skagit Lower Station in September 1976.

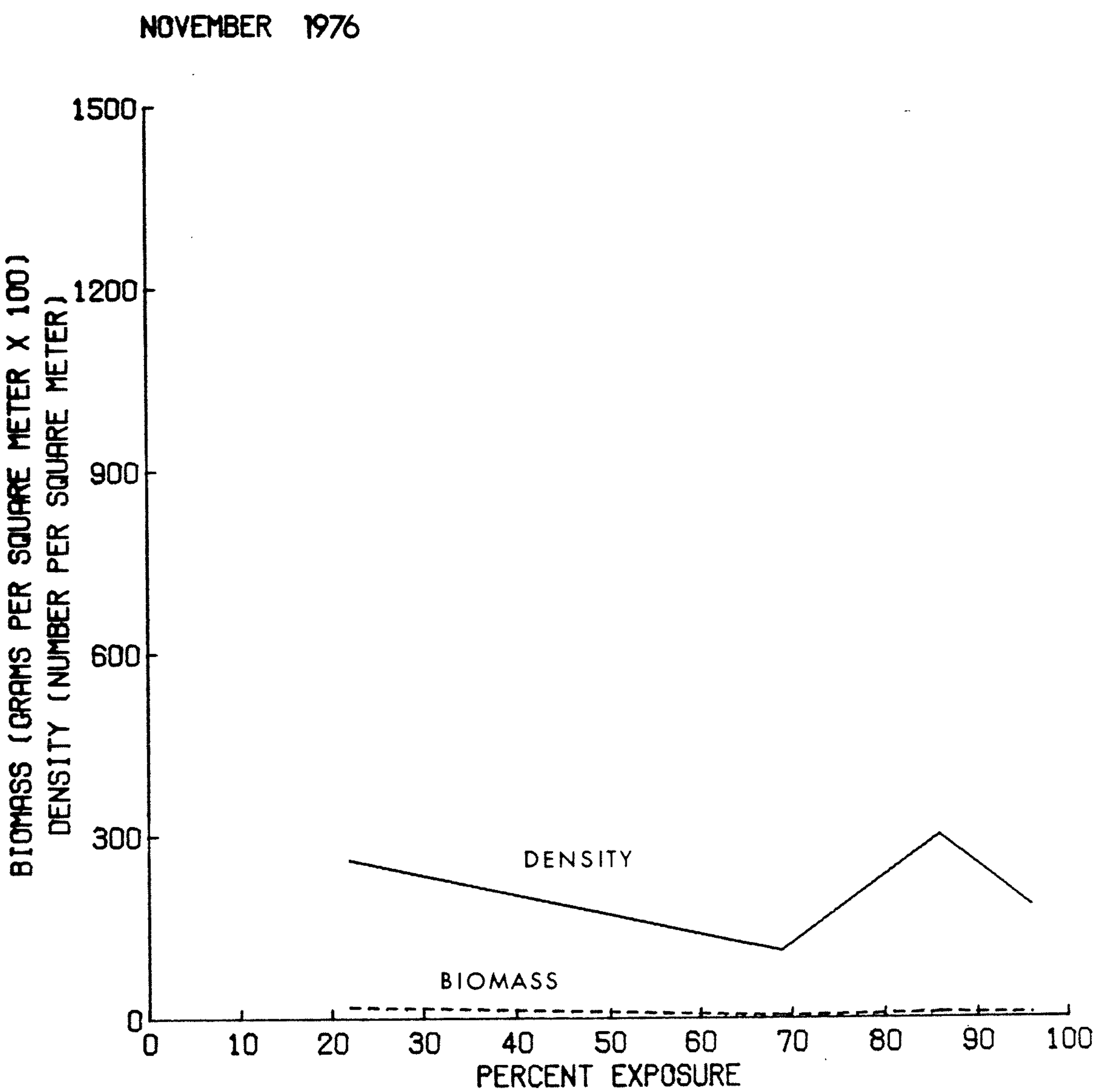

Fig. 3.14 Density and biomass of benthic insects at the Skagit Lower Station in November 1976.

benthic standing crop in these potentially highly productive shoreline zones, leaving only the relatively less productive midstream areas unexposed. Although these areas near midstream remained permanently submerged, detrimental effects were still possible due to fluctuating current velocity.

Insect density and biomass in the deeper areas of the Skagit near midstream were relatively high during late spring and early summer of 1976, but these insects may have frequently been unavailable to the fish. During periods of high water in the Skagit, salmonid fry may be forced into the frequently exposed areas that contain fewer food organisms by high current velocities in the deeper, relatively food-rich areas. However, insect drift originating in the unexposed areas of the river may provide sufficient food for these fish if there is sufficient mixing action across the width of the stream and the drift rate is high.

3.4.3.2 Seasonal Variation. The pattern of seasonal abundance of benthic insects is shown in Figs. 3.15 and 3.16. The mean of all replicates at all unexposed sample locations, or at the site with the least exposure, on sampling dates at each station is shown in these figures. The number of replicates used to calculate the station mean was therefore variable, and the exact number can be determined by referring to Table 3.6.

During 1976, the pattern of seasonal abundance differed among stations. Insect density generally increased from May through November at both the Sauk Lower (Fig. 3.15) and Cascade (Fig. 3.16) stations. All sample locations at these two stations were unexposed during the 2 weeks prior to sampling. The standing crop at the Skagit Lower Station (Fig. 3.15) was similar to the density at the Sauk and Cascade rivers in May of 1976. Mean density at unexposed locations in the Skagit was similar to density in the Sauk in July. Both the Sauk and Cascade rivers had higher standing crops than the unexposed sample locations in the Skagit during September. Sauk and Cascade standing crops continued to increase into November while Skagit River standing crop decreased. However, the sample location used to compute the station mean was exposed 22 percent prior to sampling, and a valid comparison cannot be made between the Skagit and the other rivers in November.

During 1977, benthic insect standing crop was greater in the Skagit than in the Sauk. At the Skagit Lower Station, density was relatively high during February, declined somewhat in May, and then increased through the summer until in reached a maximum value of 11,330 insects/m^2 in September (Fig. 3.15). Insect density declined in November, but was still considerably higher than in the unregulated Sauk River.

Density at the Skagit Upper Station increased steadily from February to November (Fig. 3.16). The two Skagit River stations were sampled on different days in February when flow conditions were different. As a result, the samples from the upper station were collected in shoreline areas that had been exposed at least 16 percent of the time during the 2 weeks prior to sampling, while samples were taken only in unexposed

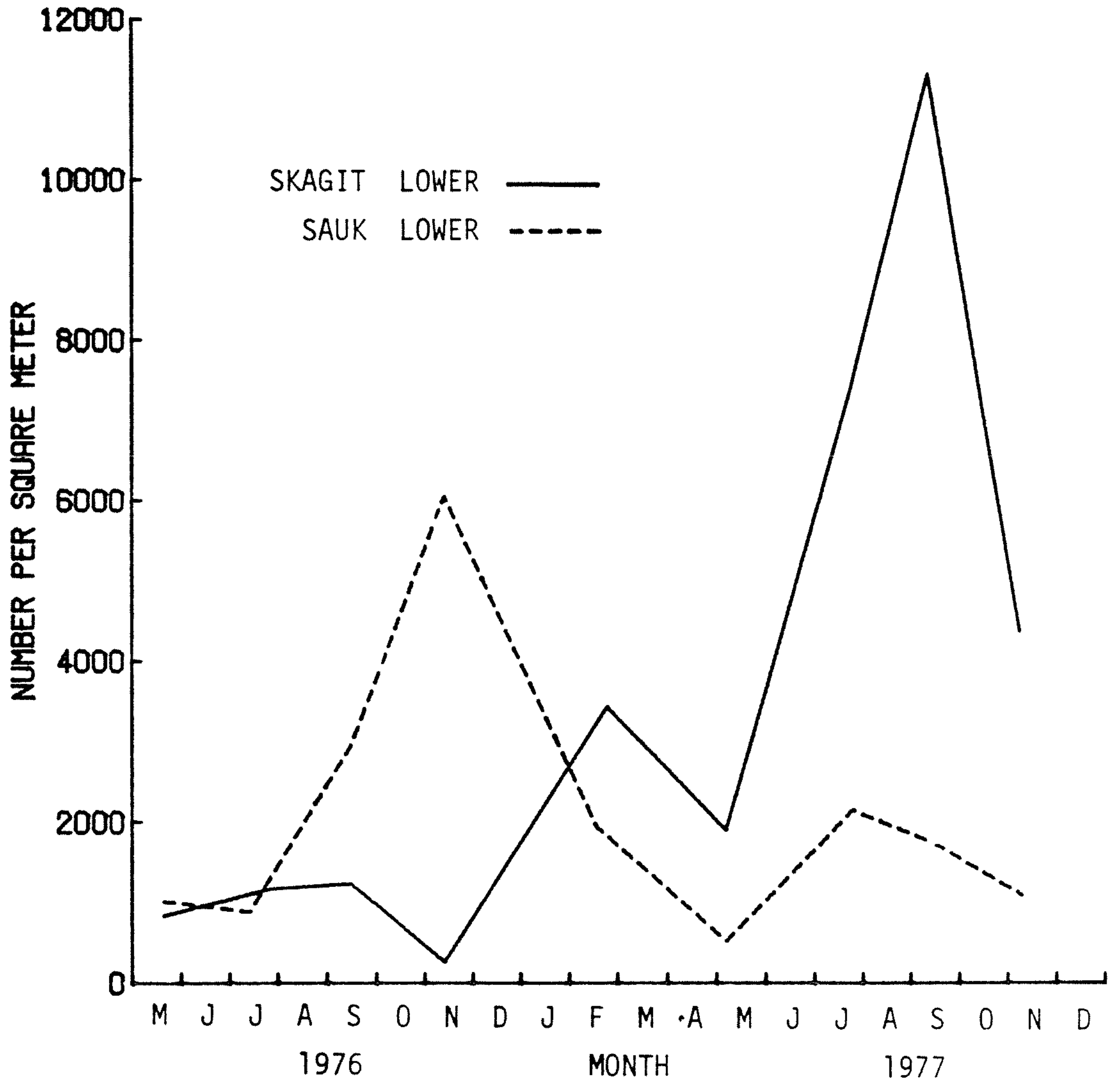

Fig. 3.15 Benthic insect standing crop at the Skagit Lower and Sauk Lower sampling stations.

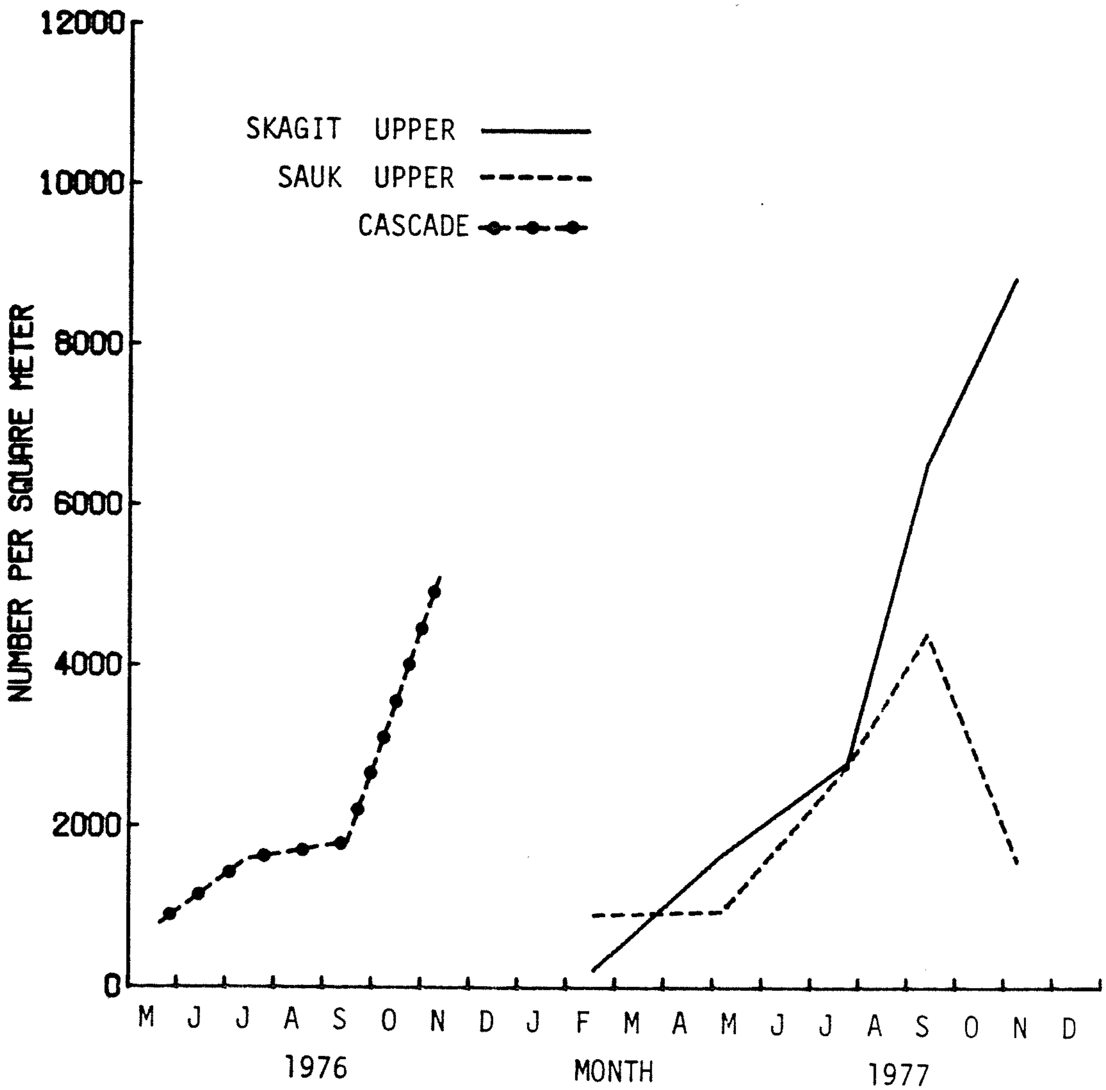

Fig. 3.16 Benthic insect standing crop at the Skagit Upper, Sauk Upper, and Cascade sampling stations.

areas at the lower station. The difference in exposure time accounts for the disparity in density at the two Skagit stations in February. If samples could have been collected in unexposed zones at the upper station, the density values would have been more comparable.

Density at the Sauk Lower Station varied between a low of 519 insects/m^2 in May to a high of 2,149/m^2 in July (Fig. 3.15). Density at the Sauk Upper Station increased steadily through September 1977, when it reached a maximum value of 4,406 insects/m^2 (Fig. 3.16). Density at both of these stations declined in November.

The high water on November 1, 1977, was probably responsible for the reduced benthic insect density observed during the November sampling period. Although samples were taken in areas slightly closer to the high-water line in November than in September, the sampling locations had not been exposed for extremely long periods, as was explained in Section 3.4.2.2. Benthic insect standing crop at the Skagit Upper Station, as well as periphyton standing crop, were not reduced when compared with the other stations in November. The amount of suspended inorganic material may have been lower at the Skagit Upper Station, resulting in lower loss of insects from scouring.

Standing crop at the Sauk Lower Station was lower during September and November of 1977 than during the same months in 1976. This difference between years may have been due to increased amounts of settled silt and sand in the riverbed in 1977. The accumulation of inorganic sediment in the interstices of the streambed gravel can reduce benthic macroinvertebrate abundance (Cordone and Kelley 1961, Nuttal 1972, Brusven and Prather 1974). Turbidity was extremely high at the lower station in August (Table 3.9), and a large amount of the suspended sediment must have settled out, possibly degrading the benthic macroinvertebrate habitat. Turbidity levels were lower at the Sauk Upper Station, and benthic insect abundance was higher at this station than at the lower station during September 1977.

In contrast to 1976 observations, insect density in 1977 was highest at stations subjected to regulated flow rather than unregulated flow. Density at the Skagit Lower Station was always higher than at the unregulated Sauk River stations. Density at the Skagit Upper Station was greater than at the Sauk stations during summer and fall months. Benthic insect abundance at the Skagit Lower Station during July and September 1977 was 6 to 9 times greater than at unexposed sample locations in July and September of 1976.

Near stable flow conditions in the Skagit were probably responsible for the increased standing crop in the summer of 1977. From late April to mid-November, the benthic community in shoreline areas was subjected to flow fluctuations that were no greater than the fluctuations at the unregulated Sauk Lower Station. The degree of fluctuation was even less at the Skagit Upper Station, since it was closer to the Gorge Powerhouse. Under the relatively stable flow regime, losses of insects from stranding during flow reductions were reduced. Changes in bottom velocity during the flow fluctuations were also reduced, and environmental conditions were nearly constant during this time period. Increased seasonal flow constancy due to regulation has had a beneficial effect on benthic standing crop in other rivers, although species diversity was reduced in some cases (Ward 1976a). Apparently increased flow constancy from late April to mid-November resulted in enhanced standing crop in the Skagit when compared to 1976 results.

Seasonal variation of benthic insects at the Skagit Lower and Sauk Lower stations in 1977 was compared with that in two other North American streams (Fig. 3.17). A Surber sampler with 1.024-mm mesh was used for sampling the Provo (Gaufin 1959) and the Kananaskis (Radford and Hartland-Rowe 1971) rivers, which would not have captured the earlier instars of some nymphs and many of the mature chironomids. No information was given on depths sampled, but the Surber sampler cannot be used in water over 12 inches deep, and is probably suitable only for depths of about 8 inches or less.

The Skagit, Sauk, and Provo rivers had roughly similar patterns of seasonal abundance. Abundance declined from February to May and then increased during the summer. Abundance declined during the fall in the Skagit and Sauk during 1977, probably due to high water in November. There were no similar periods of extremely high water prior to the November 1976 sampling date, and abundance at the Sauk Station increased through the summer and fall, reaching a peak in November.

Density in the Skagit was much higher than in the Provo River during most of the year. Although underestimated, Provo River density was consistently greater than Sauk density. The unregulated Provo River was considered an exceptionally rich stream in terms of food grade (Gaufin 1959). Density in the fluctuating, regulated, Kananaskis River was lower than in any of the other rivers. A rich and varied fauna (no quantitative data) was present in the river prior to operation of the dam. Density in smaller tributary stream sampled for comparison with the Kananaskis was usually higher (Radford and Hartland-Rowe 1971).

3.4.3.3 Composition. The composition of the benthic insect community was influenced by exposure during flow fluctuaton. Composition at each of the Skagit sites and in the Sauk and Cascade rivers is shown for each sampling date in 1976 in Tables 3.11-3.14. In general, Diptera (flies) formed a larger portion of the community in the highly exposed areas of the Skagit, while the percentage of Ephemeroptera (mayflies) was lower in these areas. Mayflies were particularly susceptible to stranding and were intolerant to exposure while chironomids (Diptera) and Trichoptera (caddieflies) appeared to be relatively tolerant (Brusven et al. 1974). It appears that most of the mayflies were eliminated from areas of the Skagit with high exposure, while the more tolerant chironomids were able to remain.

The percent composition at the Sauk and Cascade sample locations (all with no exposure) was most similar to composition at Skagit locations that were not exposed. Mayflies were always more abundant than dipterans in

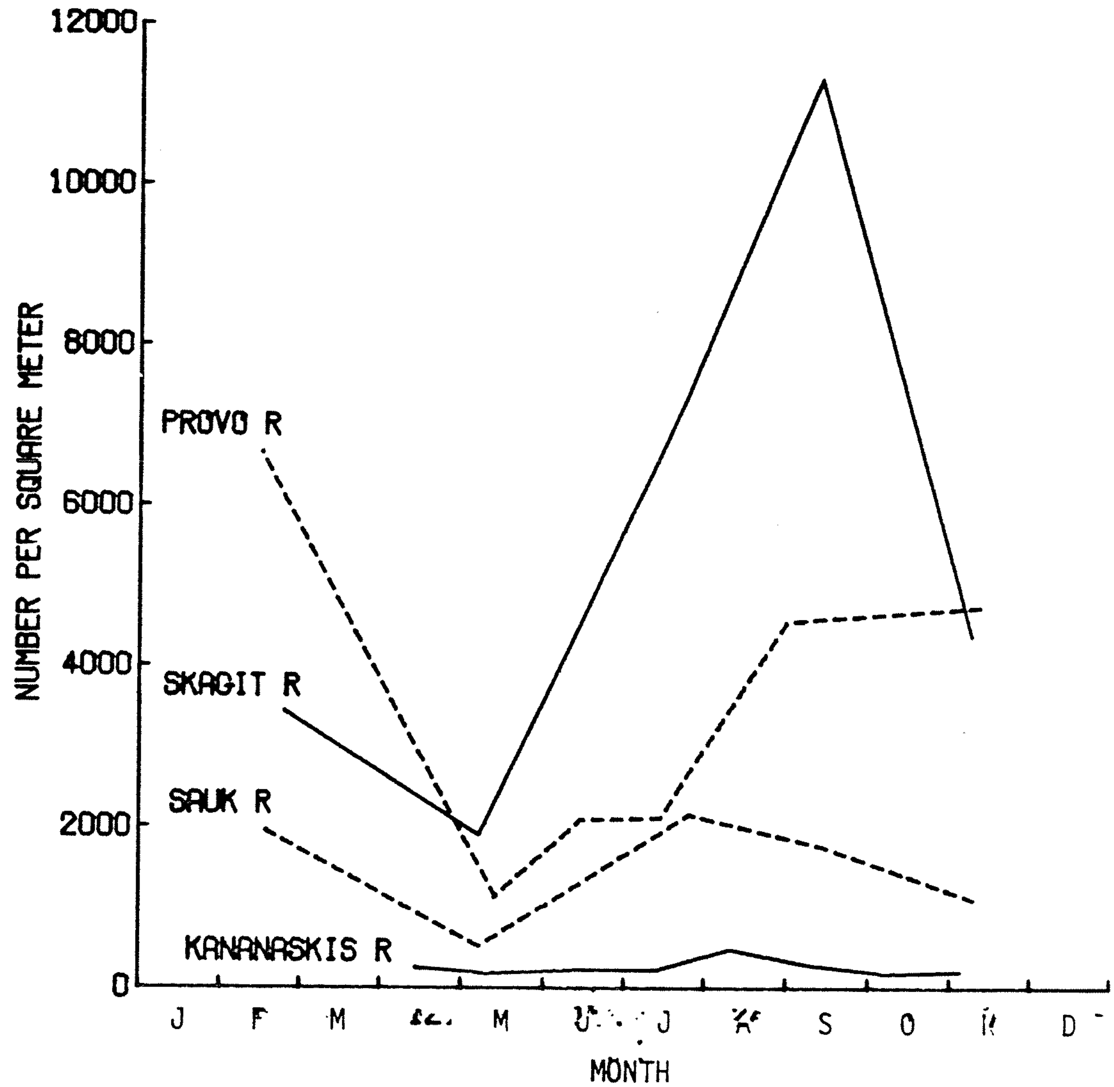

Fig. 3.17 Seasonal variation in benthic macroinvertebrate density in the Skagit, Sauk, and two other rivers in western North America. The Provo River, Utah (Gaufin, 1959), and the Sauk are unregulated streams. The Skagit River and the Kananaskis River, Alberta (Radford and Hartland-Rowe, 1971), are regulated streams.

Table 3.11 Percent composition of benthic insects at sampling stations during May 1976. Composition is presented separately for each sample location at the Skagit Lower Station. Percent exposure during the two weeks prior to sampling is also given for each location at the Skagit Station.

	STATION				
	Skagit Lower			Sauk	
Order	35%	21%	16%	Lower	Cascade
Ephemeroptera	43	54	72	53	83
Plecoptera	24	22	18	16	11
Trichoptera	8	4	1	3	2
Diptera	25	20	9	28	4
Coleoptera	0	0	<1	0	0

Table 3.12 Percent composition of benthic insects at sampling stations during July 1976. Composition is presented separately for each sample location at the Skagit Lower Station. Percent exposure during the two weeks prior to sampling is also given for each location at the Skagit Station.

	STATION			
	Skagit Lower		Sauk	
Order	1%	0%	Lower	Cascade
Ephemeroptera	16	32	47	83
Plecoptera	13	11	19	8
Trichoptera	14	9	3	1
Diptera	57	48	31	8
Coleoptera	<1	<1	<1	<1

Table 3.13 Percent composition of benthic insects at sampling stations during September 1976. Composition is presented separately for each sample location at the Skagit Lower Station. Percent exposure during the two weeks prior to sampling is also given for each location at the Skagit Station.

	STATION					
	Skagit Lower				Sauk	
Order	40%	33%	6%	0%	Lower	Cascade
Ephemeroptera	0	3	4	37	43	52
Plecoptera	7	18	25	12	8	15
Trichoptera	1	5	3	7	12	7
Diptera	92	74	67	44	37	26
Coleoptera	0	0	1	0	0	0

Table 3.14 Percent composition of benthic insects at sampling stations during November 1976. Composition is presented separately for each sample location at the Skagit Lower Station. Percent exposure during the two weeks prior to sampling is also given for each location at the Skagit Station.

	STATION					
	Skagit Lower				Sauk	
Order	96%	86%	69%	22%	Lower	Cascade
Ephemeroptera	4	4	14	32	54	55
Plecoptera	5	1	5	13	24	31
Trichoptera	3	1	4	4	10	6
Diptera	88	94	77	51	12	8
Coleoptera	0	0	0	<1	0	<1

the Sauk and Cascade rivers, while dipterans were usually several times more abundant than mayflies at the exposed Skagit River sampling locations.

An annual pattern of alternating dominance of Ephemeroptera and Diptera (mainly Chironomidae) was observed at the Skagit Upper and Lower stations, which had almost identical compositions in 1977 (Figs. 3.18 and 3.19). This pattern was evident, but less pronounced at the Sauk Lower Station (Fig. 3.20) and Cascade Station (Fig. 3.21). Ephemeropterans dominated the insect communities at the Skagit and Sauk sites during February and May 1977. During July, the numbers of Diptera collected increased as most of the chironomids became large enough to be retained by the sampling net. Many of the mayfly nymphs that were present in February and May emerged, and the Diptera now comprised the largest proportion of the insect community. The dominance shifted again to the Ephemeroptera in the late summer and fall after many of the dipterans had emerged and the progeny of the mayflies that emerged in the spring were retained by the sampler.

Seasonal variation was less obvious at the Sauk Upper Station (Fig. 3.22). The Diptera reached a peak in July at this station, but never formed more than 17 percent of the total insect community. The community was composed primarily of Ephemeroptera (62-78 percent) throughout the year. The proportion of Plecoptera (stoneflies) was greater at the Sauk Upper Station during February and May than at the other stations.

3.4.4 Experimental Studies

3.4.4.1 Flow Fluctuation Experiments. The effects of the experimental flow fluctuations were determined by comparing postfluctuation density and composition in the experimental and control channels (Table 3.15). Since environmental conditions, except for flow pattern, were identical in both channels, any differences in postfluctuation density and composition should have been due to the different flow regimes. Density in the control channel at the conclusion of the experiments was always slightly less than prefluctuation density because of normal losses from drift, emergence, natural mortality, and other factors during the experiment.

Approximately equal numbers of insects were present in both channels at the start of the experiments. Prefluctuation density in the experimental and control channels was compared using a paired t-test after logarithmic transformation of the data. Density data collected prior to four flow fluctuation experiments conducted in 1976 and 1977 were used. No significant difference between channels was detected.

Postfluctuation benthic insect density was lower in the experimental channel than in the control channel in both types of flow fluctuation experiment (Table 3.15). After 7 days of periodic exposure, benthic insect density in the fluctuating experimental channel was only one-third of that in the nonfluctuating control channel. When the number of insects

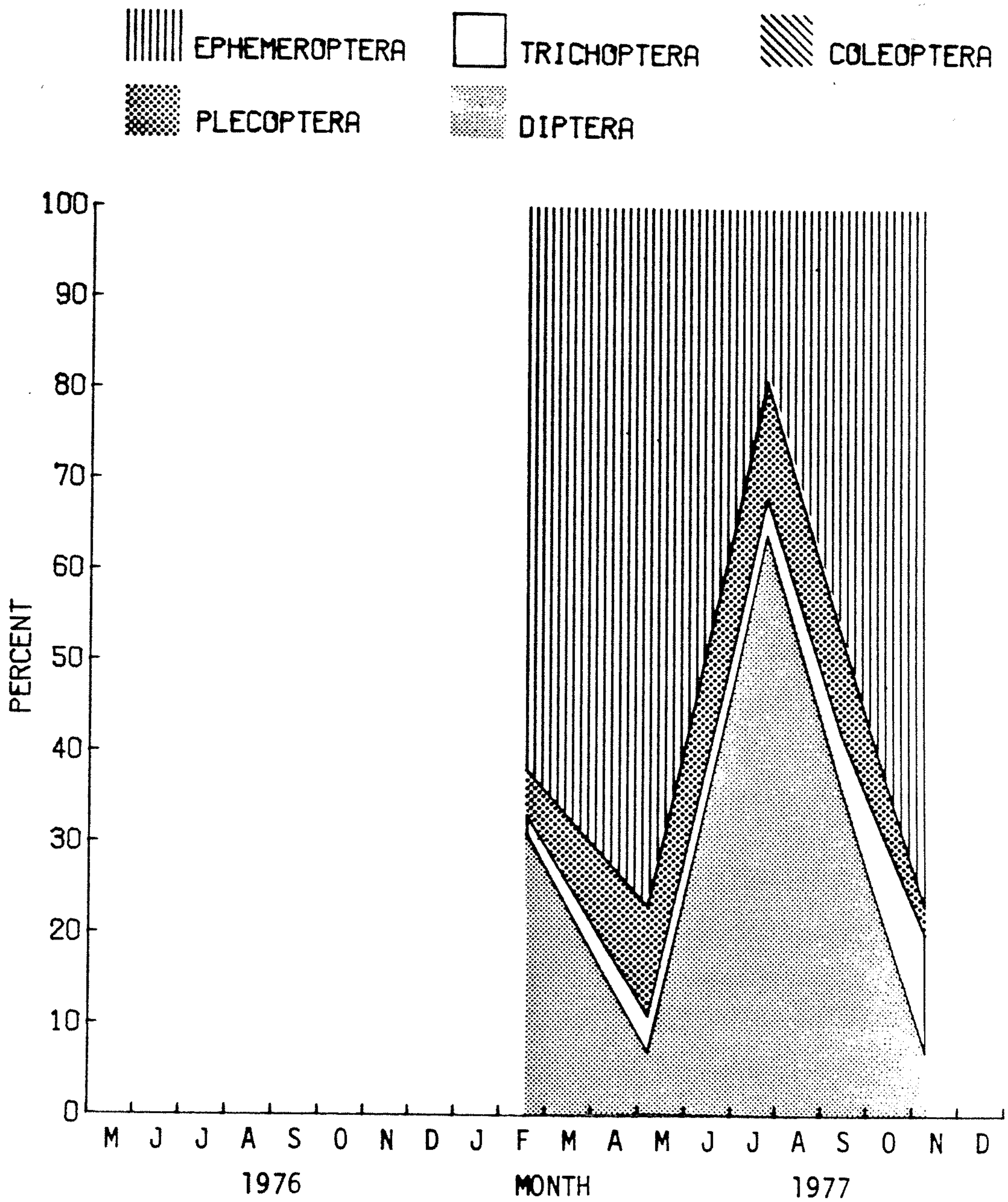

Fig. 3.18 Percent composition of benthic insects collected at the Skagit Upper Station.

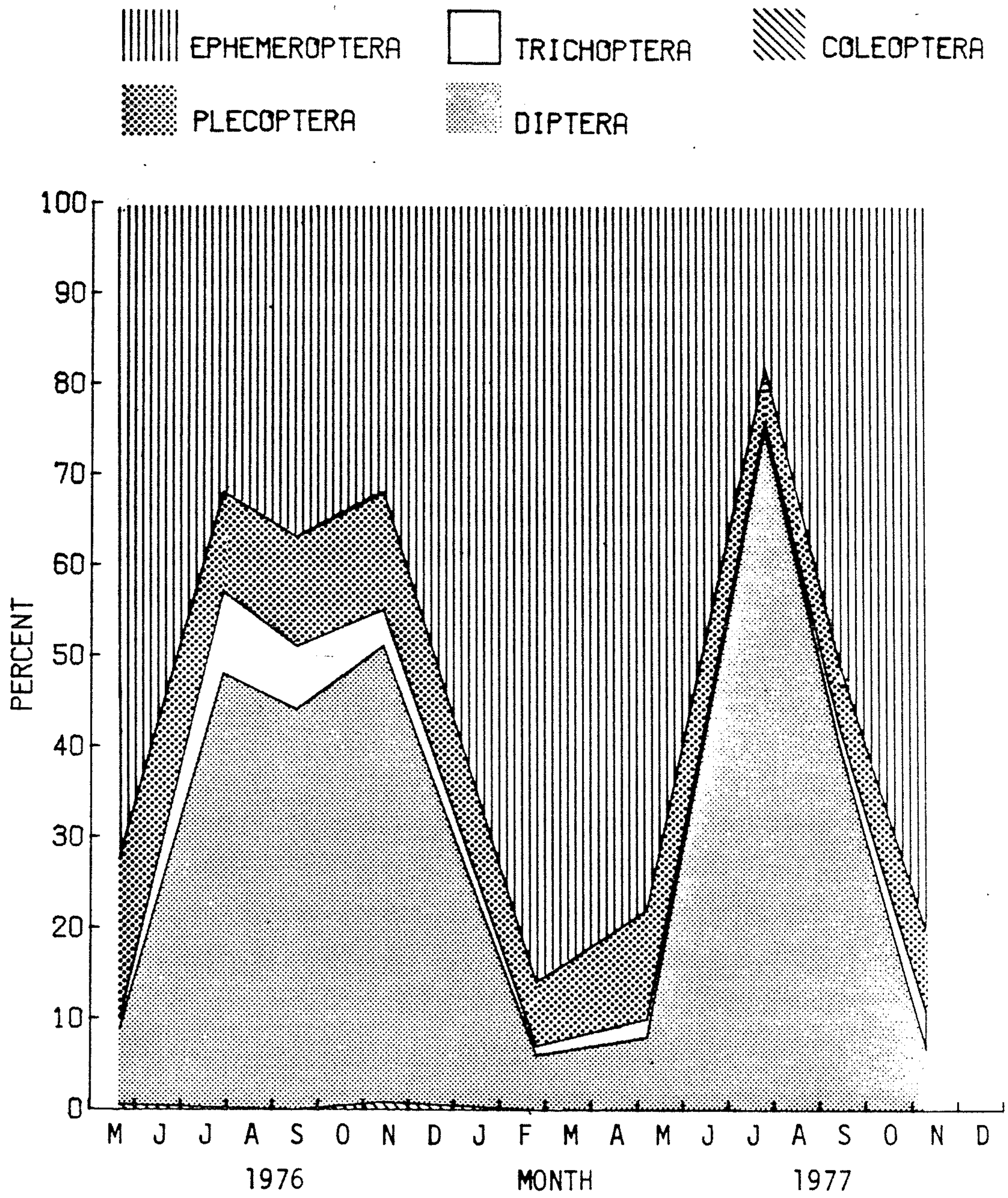

Fig. 3.19 Percent composition of benthic insects collected at the Skagit Lower Station.

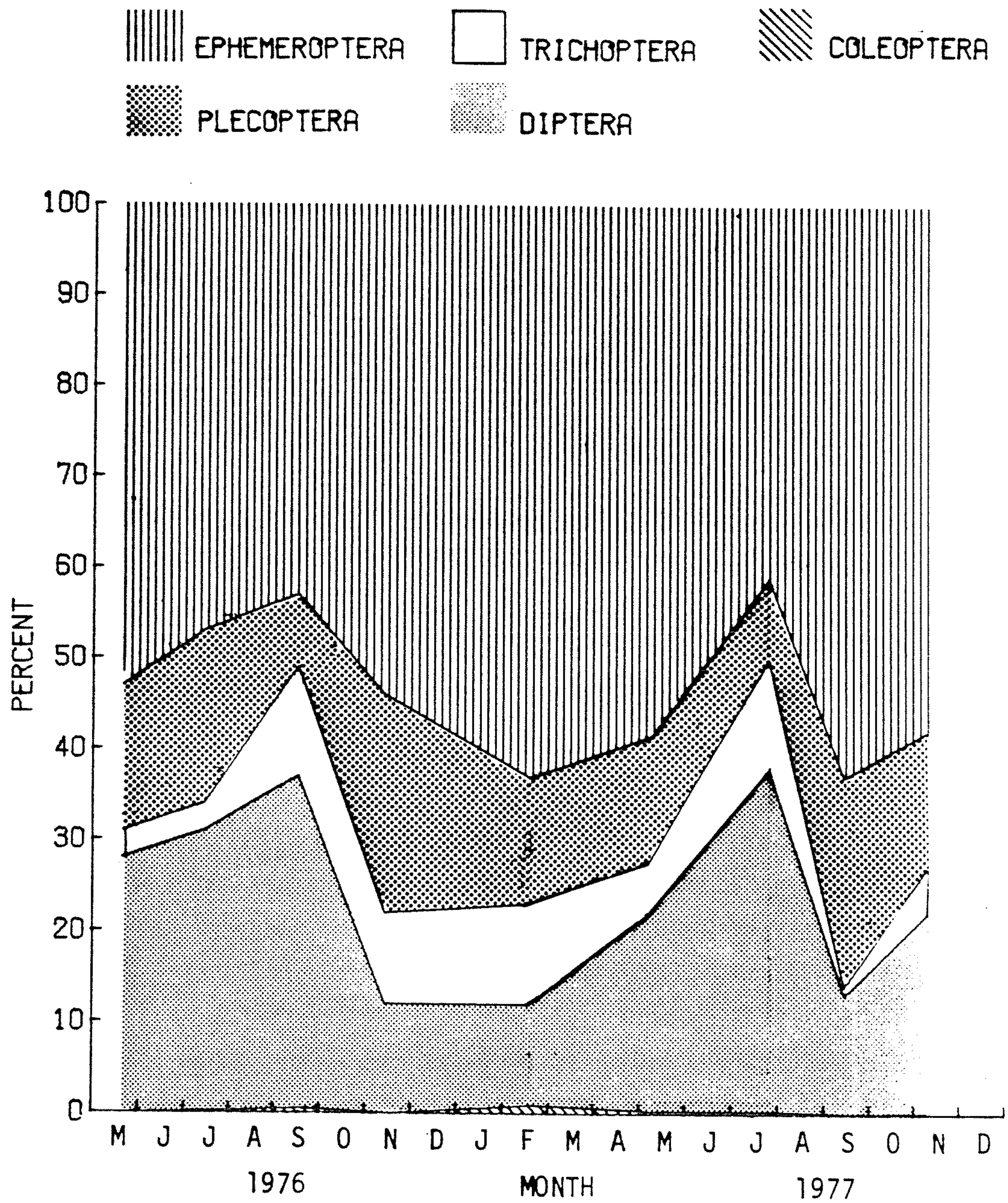

Fig. 3.20 Percent composition of benthic insects collected at the Sauk Lower Station.

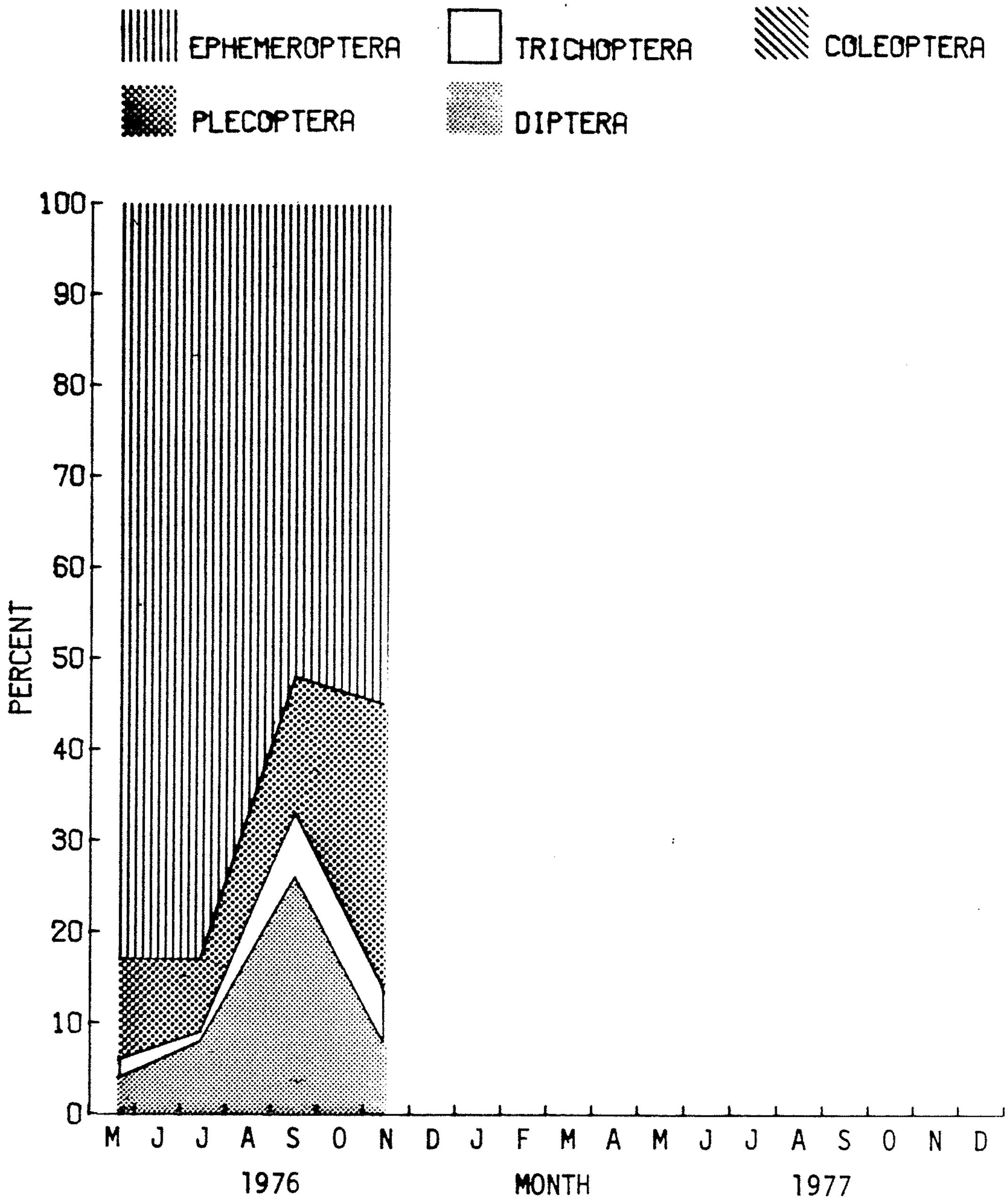

Fig. 3.21 Percent composition of benthic insects collected at the Cascade River Station.

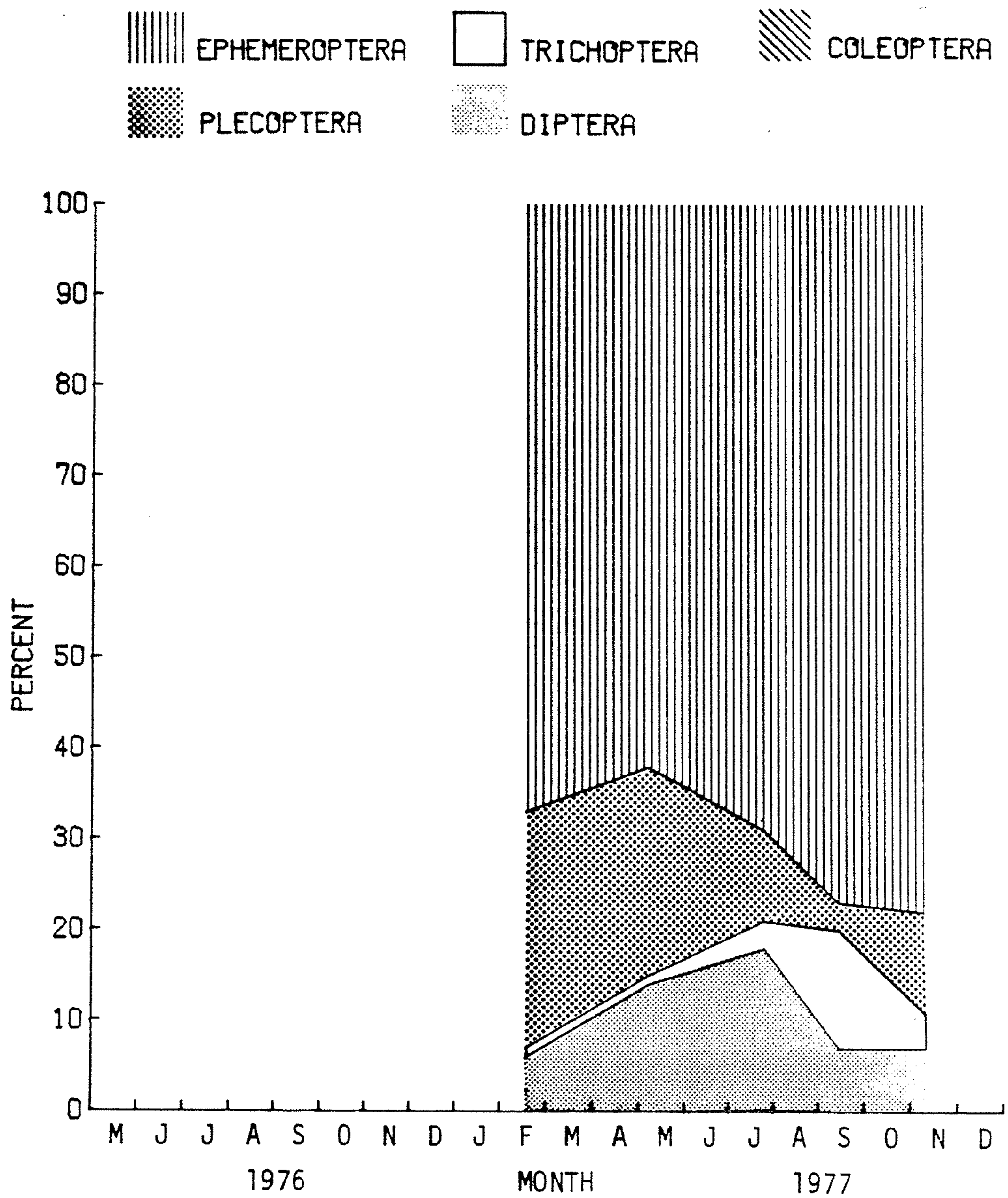

Fig. 3.22 Percent composition of benthic insects collected at the Sauk Upper Station.

Table 3.15 Mean number of insects per substrate tray in experimental and control artificial stream channels before and after experimental flow fluctuation.

Experimental Flow Pattern	Pre-fluctuation	Post-fluctuation	
		Experimental	Control
Periodic exposure for one week	251	64	194
48-hr continuous exposure	536	378	482

per substrate tray was compared between channels in a paired t-test, the difference between channels was statistically significant at the .01 level. Following 48 hr of continuous exposure, the density in the experimental channel was 22 percent lower than in the control channel. However, this difference was not statistically significant.

These data indicate that periodic exposure over a 1-week period can significantly reduce benthic insect density. The level of exposure to desiccation in the experimental channel during the 2 weeks prior to sampling was only 30 percent. Flow reductions of similar frequency and duration in the Skagit probably reduced benthic insect density in shaded shoreline areas by a similar amount, either through mortality of stranded insects or drift losses.

The 48 hr of continuous exposure did not reduce density as much as 1 week of periodic exposure. In the Skagit, shoreline zones that were continuously submerged or exposed periodically during the week, may have been exposed continously for 48 hr on weekends. This type of experiment was intended to duplicate the weekend flow conditions in the Skagit. A loss of 22 percent of the insects from a particular area of the riverbed would be a sizeable reduction in the amount of food available to the fish. The effect would be even greater if the same area were exposed for 48 hr on several consecutive weekends.

The number of surviving insects in the experimental channel may have been overestimated by the inclusion of dead insects. Due to cool and moist conditions on the exposed substrate trays in the experimental channel, insects dying from exposure to air would not have been decomposed or desiccated after only 48 hr. After preservation in alcohol, these dead insects would have been indistinguishable from insects that were alive at the end of the experiment and would have been included in the count of insects remaining after 48 hr. Thus, the actual reduction in density was probably greater than 22 percent. The observed 22 percent density reduction was most likely due only to the loss of drifting insects during initial dewatering. During the periodic exposure experiments, any insects killed during exposure would have been washed out of the channel when the substrate was resubmerged.

Both types of experimental flow pattern changed benthic insect community composition. The percentage of Ephemeroptera and Plecoptera was lower in the experimental channel than in the control channel after 1 week of periodic exposure (Table 3.16) and after 48 hr of continuous exposure (Table 3.17). The percentage of Diptera was greater in the experimental channel than in the control under both flow patterns.

During both flow reduction and increased flow, Ephemeroptera comprised 56-57 percent of the drift, while Diptera comprised 31-36 percent (Table 3.18). In contrast, the substrate trays contained only 15 percent Ephemeroptera and 73 percent Diptera prior to fluctuation (Table 3.16). The different proportions of Ephemeroptera and Diptera in the drift and on the bottom of the channel indicate that the Ephemeroptera had a greater propensity to drift during flow fluctuations than Diptera.

Table 3.16 Percent composition of benthic insects in experimental and control artificial stream channels before and after one week of periodic exposure.

Order	Pre-fluctuation	Post-fluctuation	
		Experimental	Control
Ephemeroptera	15	5	7
Plecoptera	11	6	13
Trichoptera	1	1	<1
Diptera	73	88	80
Coleoptera	0	0	0

Table 3.17 Percent composition of benthic insects in experimental and control artificial stream channels before and after 48 hr of continuous exposure.

Order	Pre-fluctuation	Post-fluctuation	
		Experimental	Control
Ephemeroptera	11	10	13
Plecoptera	4	5	7
Trichoptera	1	<1	1
Diptera	84	85	79
Coleoptera	0	0	0

Table 3.18 Percent composition of drifting aquatic insects in the experimental artificial stream channel during dewatering and rising water and in the control channel during the same time period.

Order	Flow Pattern		
	Dewatering	Rising water	Control
Ephemeroptera	56	57	49
Plecoptera	8	12	11
Trichoptera	<1	<1	1
Diptera	36	31	39
Coleoptera	<1	0	0

Apparently the density of Ephemeroptera was reduced by drift during the fluctuations at a greater rate than dipteran density, resulting in the observed postfluctuation change in community structure.

Differences in the ability to survive exposure to air on the dewatered substrate also could have accounted for the observed changes in percent composition. Chironomids were relatively tolerant of desiccation on dewatered streambed substrates under cool temperatures, while mayflies were the most sensitive insect order (Brusven et al. 1974). The density of the Ephemeroptera would be expected to decrease at a higher rate through desiccation mortality than dipteran density.

3.4.4.2 Stranding Avoidance. Benthic insects that are unable to avoid stranding during flow reductions and are left on the exposed surface of the riverbed may be killed by desiccation or freezing. Insects may avoid stranding by: 1) drifting; 2) migrating with the receding water; 3) migrating from exposed areas to submerged areas; or by 4) burrowing into wet substrate and waiting for the water level to return. The numbers of insects that avoided stranding by the first three methods were recorded during flow reductions in the artificial stream. The interstices in the substrate in the bottom of the trays were too small to allow any deep burrowing by the species tested.

There were pronounced differences among the three species tested in ability to avoid stranding (Table 3.19). Only 65 percent of the mayfly nymphs (*Ephemerella tibialis*) were able to escape stranding, primarily by drifting downstream. Almost all of the stonefly nymphs (*Acroneuria pacifica*) escaped stranding, mainly by moving to the submerged half of the channel. A total of 96 percent of the caddis larvae (*Dicosmoecus* sp.) avoided stranding, primarily by drifting.

Both the stonefly and caddis species tested were able to move several centimeters over dewatered substrated to enter the flowing water. Once exposed, the mayfly nymphs did not move more than a centimeter on the exposed substrate.

The results of the stranding avoidance experiments indicate that mayfly nymphs (Ephemeroptera) are much more likely to become stranded during flow reductions than large stonefly (Plecoptera) nymphs and caddis (Trichoptera) larvae. A reduction in water level at a rate of more than 0.7 ft/hr, the rate used in the experiments, would probably result in a higher rate of stranding for all three species. Stranding would probably be more severe on gently sloping shoreline areas than on steep riverbanks.

3.4.4.3 Desiccation Survival. The ability to survive desiccation on dewatered substrates varied among the three species tested (Table 3.20). *Dicosmoecus* sp., a case-bearing caddis larva, was the most resistant and survived with no mortality on both dry and damp substrates. All *Acroneuria pacifica* nymphs survived on the damp substrate, but 64 percent died on the dry substrate. *Ephemerella tibialis* was the least resistant species and had a high mortality rate on both substrates.

Table 3.19 Percentage of aquatic insect larvae stranded and not stranded during experimental flow reductions. The not stranded category includes insects that avoided stranding by moving to the submerged half of the channel or drifting downstream.

Species	Stranded	Not Stranded		
		Total	Submerged	Drift
Ephemerella tibialis	35	65	23	42
Acroneuria pacifica	1	99	63	36
Dicosmoecus sp.	4	96	22	74

Table 3.20 Percent mortality of aquatic insect larvae exposed to desiccation for 24 hr on dry and damp substrates.

Species	Dry Substrate	Damp Substrate	Control	Maximum Air Temperature (°C)
Ephemerella tibialis	100	84	2	20
Acroneuria pacifica	64	0	0	20
Dicosmoecus sp.	0	0	0	14

The damp substrate was intended to simulate conditions in shaded areas of the dewatered shoreline areas, or areas dewatered at night or during rain. Conditions on the dry substrate resembled those on areas exposed to sunlight.

The caddis species, *Dicosmoecus* sp., had a sand grain case which probably enabled it to survive desiccation with no mortality. Other species with cases would also be expected to have high survival rates on dewatered substrates. Most stonefly species, including *Acroneuria pacifica*, crawl out of the water to emerge and can survive short periods out of the water as nymphs. Therefore one would expect them to be more resistant than mayfly nymphs which usually emerge directly from the surface of the water. The desiccation survival experiments, as well as the stranding avoidance experiments, indicate that the mayflies are particularly vulnerable to flow fluctuations. Flow fluctuations in the Skagit probably reduced the mayfly populations at a greater rate than stonefly and caddis populations, causing changes in community structure.

4.0 PLANKTON DRIFT

4.1 Introduction

In 1975 and 1976, examination of salmonid fry stomachs from the Skagit River showed that salmon and steelhead fry were using zooplankton released from the system of Seattle City Light (SCL) hydropower reservoirs (Sec. 8.0). Contribution of zooplankton to total numbers of food items in 1976 ranged from 26 percent in chinook fry to 0 percent in chum fry. Ross Lake zooplankton had been studied previously (SCL 1973), but little was known about zooplankton abundance in the river. Some sampling of zooplankton abundance and vertical stratification was done in 1973 and 1974 in Gorge and Diablo reservoirs. They generally had lower plankton densities than those of Ross Lake (Burgner 1977).

Low plankton standing crop values of some lakes and reservoirs have been attributed to rapid water exchange rates (Brook and Woodward 1956, Tonolli 1955, Axelson 1961, Johnson 1964, Rodhe 1964, and Cowell 1967). Brook and Woodward (1956) found in small Scottish lakes that there was no significant development of zooplankton unless the average water retention time was greater than 18 days. Johnson (1964) found that plankton production was greatly depressed if the mean flushing time of a lake was less than 15 days.

Some reservoirs have been observed to receive plankton in discharges from other reservoirs (Tonolli 1955, Cushing 1963, and Johnson 1964), some as far as 80 km upstream (Cowell 1967).

Increased abundance of stream benthos immediately below lake outlets releasing zooplankton has been reported (Briggs 1948, Cushing 1963, Armitage and Capper 1976). It has been suggested that production of filter feeding macroinvertebrates is enhanced by plankton drift and, even if not fed upon directly, plankton could be strained out by aquatic vegetation and produce nutrient rich detritus (Gibson and Galbraith 1975). Malick (1977) found low drifting detritus densities below a dam on the Cedar River but high densities of filter feeding insects. The reservoir apparently acted as a sink for large particles of detritus but contributed limnoplankton--a higher quality food--to the river downstream. Ward (1975), however, found the hypolimnion releases of hydropower reservoir in Colorado contained so little suspended material that it was actually detrimental to the filter feeding community.

Most of these investigators found a rapid decrease in zooplankton density below the lake. Turbulence, abrasion on rocks, and filtering by vegetation and macroinvertebrates are cited as probable causes of this decrease (Chandler 1937).

As for effects on fish, Gibson and Galbraith (1975) found that the salmonid biomass was much higher closer to the outlet of a lake.

Studies were initiated in April 1977, on the Skagit River and the SCL reservoirs to:

1. Discover the fate of crustacean zooplankton passing through the dams and the reservoirs.

2. Determine the availability of plankton to salmonid fry throughout the year and at different distances down the river.

4.2 Study Stations

The study stations for the plankton drift samples are shown in Fig. 4.1. The Ross Tailrace Station was upstream from the footbridge below Ross Dam. It was generally flowing and unstratified except for the period June through August 1977 when there was little inflow provided by generation at Ross Powerhouse.

The Diablo Forebay Station was at the log boom opposite the intake near the right bank. The reservoir was over 125 ft deep there. The power tunnel intake extends from 105 to 125 ft below the full pool elevation. In 1974, measurements of secchi depths showed that Diablo Reservoir was more turbid than Ross Lake during comparable periods due to seasonal inflows of glacial water from Thunder Creek. The retention time based on long-term average annual discharge was about 11 days (Burgner 1977). In 1977, Diablo Reservoir was thermally stratified from about May to October (Table 2.5) but remained well oxygenated to the bottom. The thermocline was 25 to 40 ft deep.

The Diablo Tailrace Station was below Diablo Powerhouse and above Stetattle Creek. The current was generally flowing faster than 2 ft/sec.

The Gorge Forebay Station was at the log boom behind Gorge Dam. Depth at this station was about 90 ft. The power tunnel intakes extend from 60 to 80 ft below the full pool elevation. Turbidity from Thunder Creek caused seasonally high turbidity in this reservoir as well. Retention time for this reservoir based on long-term average annual discharge was about one day (Burgner 1977) and stratification was, at most, slight in 1977.

The County Line Station was near the Whatcom-Skagit County line on the Skagit River at about river mile (RM) 89.2, about 4 mi below Gorge Powerhouse. This site was selected rather than one closer to Gorge Dam because it was safely accessible and had been used previously for salmonid fry collections for condition and food habits determinations.

The Talc Mine Station was on the Skagit River at approximately RM 84.3, in the neighborhood of the proposed Copper Creek Dam Site.

The Marblemount Station was just below the Marblemount Bridge that crosses the Skagit at about RM 78.3. It was above the mouth of the Cascade River.

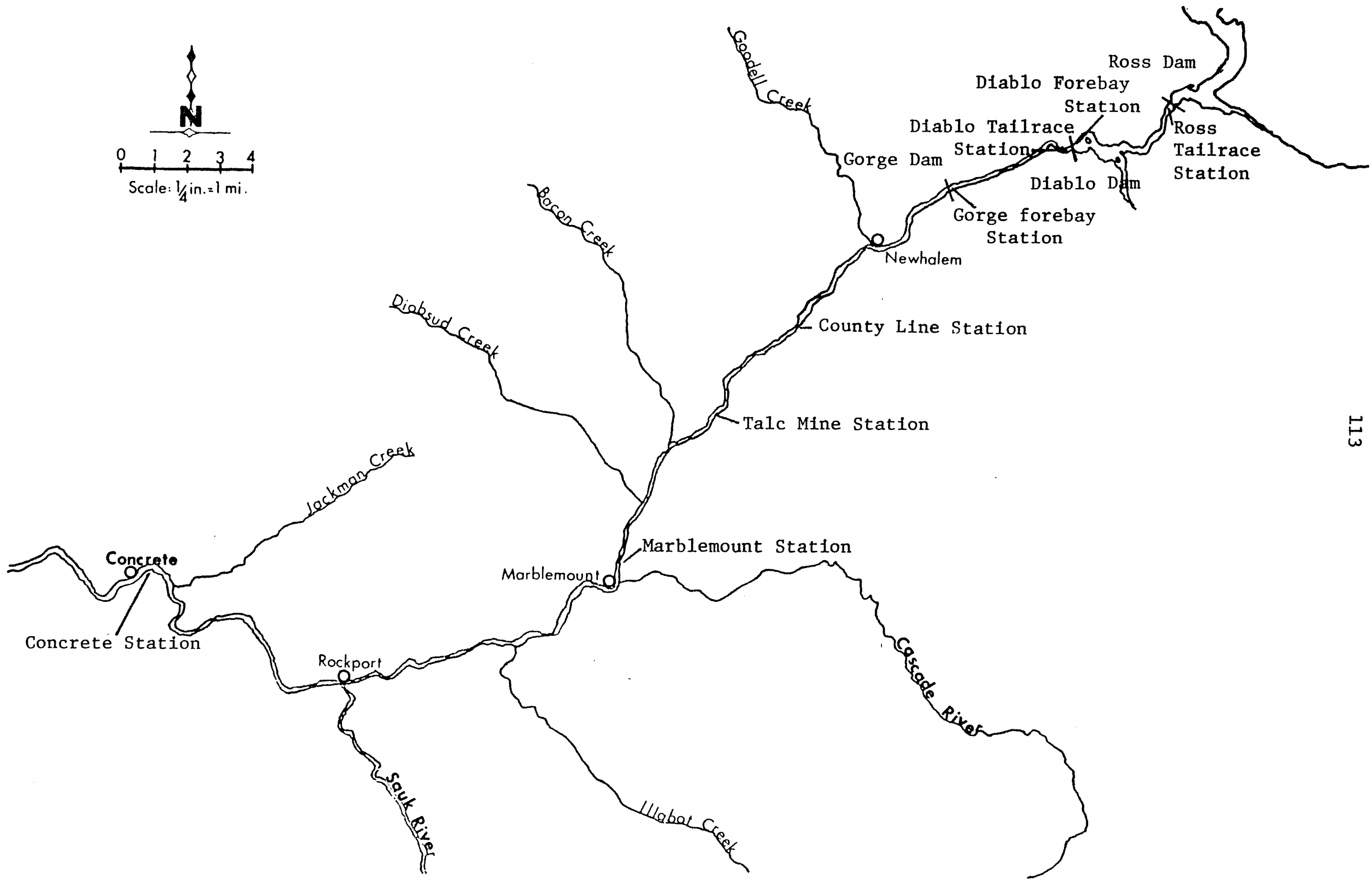

Fig. 4.1 Plankton drift sampling stations, 1977.

The Concrete Station was just above the community of Concrete and the mouth of the Baker River at about RM 56.7. Turbidity was often extremely high at this station due to inflows from the Sauk River.

4.3 Materials and Methods

The sampling apparatus was a Homelite centrifugal water pump, powered by a 5-hp Briggs and Straton engine. The pump was used to draw water from the lake or river, pump it through a brass water meter, and then into a stainless steel cylinder where the water upwelled and then fell of its own weight through a 73-μ aperture plankton net which retained the sample. A volumetric sample could thus be taken at a specified depth in running or standing water. This was used aboard a SCL tug or a Wooldridge river sled boat.

At the forebay stations, a 70-ft long, 2-inch I.D. non-collapsible hose was used to obtain a sample near the level of the power tunnel intakes. A dull steel funnel pointed downward on the end of this hose. Some drifting during sampling was encouraged so that new areas would be swept by the plankton pump. At the tailrace stations, samples were taken approximately midway between surface and bottom. At the river stations, a shorter 2-inch diameter hose was used and samples were taken near the surface from a boat holding station in the current. On the end of this hose was a squat 3.5-inch long and 6-inch wide cylinder, with sides made of coarse screening with 0.4-inch apertures.

From 100 to 300 gal of water were filtered to obtain a sample, depending on the amount of sediment or organisms present. The net was then thoroughly rinsed down with water and the contents were preserved in 10 percent unbuffered formalin. Two samples were generally taken at the same time and site.

In October, a test for differences between the drift sampled in midstream and the drift inshore in rearing areas of juvenile salmonids was conducted. At the stations below Gorge Dam, sample 1 was taken in mid-channel as usual, while sample 2 was taken as far inshore as practical without including much bottom material.

Samples were examined under a binocular microscope and contents enumerated. Some samples were stained with rose bengal (≅ 100 mg/liter) to make the organic material more visible. The individuals counted as whole organisms could have less than mortal injuries such as two or three appendages missing. "Parts" were defined as more than half an organism damaged more extensively than a couple of appendages missing. It was assumed that by this method an individual organism would be counted only once and an inflated estimate of the density of organisms would be prevented. After counting, the samples were individually retained in 5 percent unbuffered formalin.

The average retention period for the reservoirs was calculated by dividing the full pool storage of the reservoirs--89,880 acre-ft for Diablo and 9,758 acre-ft for Gorge--by the daily discharge averaged over a month converted to acre-ft. Diablo and Gorge reservoir levels are not drawn down annually like Ross Reservoir (Burgner 1977), so full pool storage of the two smaller reservoirs approximates their volume throughout the year.

4.4 Results and Discussion

The results from plankton pump samples from April through December 1977 are presented by month in Tables 4.1 through 4.9, respectively, standardized to numbers of organisms/m^3 and rounded to the nearest integer. Since most samples were made by straining 300 gal and there are 264 gal/m^3, most sample counts were reduced slightly by multiplying by 264/300.

Similarity between replicates was often poor. Larger sample volumes would have been desirable in many cases. In other cases, sediment and drifting algae made it impracticable to pass larger samples through the net.

Daphnia appear to be the most fragile of the crustacean zooplankton. Often more than half of the *Daphnia* in a sample were in parts. Certainly, most of these were broken up by the sampling method. In the reservoir forebay environment, there should be few damaged before sampling. The Clarke-Bumpus net (replicate 3, Table 4.6) damaged much less than the plankton pump. However, as Ward (1975) found in hydropower releases in a Colorado river, the frail carapaces of *Daphnia* fail to persist for long in the river compared to smaller, more compact zooplankton like *Bosmina* and *Diaptomus* nauplii.

In September 1977, avoidance of the sampling gear by strongly swimming zooplankters was assessed. A Clarke-Bumpus net, a volumetric plankton sampler, was towed at the same depth that the plankton pump sampled. In both Gorge and Diablo reservoirs, the Clarke-Bumpus net (replicate 3, Table 4.6) sampled higher numbers of organisms/m^3 of *Daphnia*, and lower numbers of organisms/m^3 of *Diaptomus* parts, *Daphnia* parts, and unbroken *Bosmina* than the plankton pump. However, the numbers of organisms/m^3 yielded by the Clarke-Bumpus net cannot be considered to be without bias. Any type of plankton sampler has some selectivity (Edmondson and Winberg 1971).

It may appear from comparing zooplankton densities at Ross Tailrace (Table 4.3) to densities at Diablo Forebay (Table 4.5) that *Diaptomus*, nauplii, and *Daphnia* densities decrease during passage through Diablo Lake. However, for the period from June through September, mean daily flow at Ross Dam was only about 400 cfs (Table 4.10). Probably little zooplankton was contributed by Ross Lake during this period because of the low discharge relative to volume of Diablo Lake. Ross Tailrace became a calm and warm arm of Diablo Lake and apparently supported much higher densities of *Daphnia* and *Diaptomus* in June, July, and August than the Diablo Forebay Station. *Bosmina* counts were down at Ross Tailrace during this period, possibly because they thrive better in cooler water. When generation near a normal load was resumed at Ross Dam in October 1977,

Table 4.1 Numbers of organisms/m^3 from plankton pump samples, April 28-29, 1977.

Site	Sample replicate	Volume (gal.)	*Diaptomus*	*Diaptomus* parts	Nauplii	*Daphnia*	*Daphnia* parts	*Bosmina*	*Bosmina* parts	Chydorids	Harpac-ticoids	Cyclop-oids	Chironomid larvae	Plecoptera nymphs	Ephemeroptera nymphs
Ross T.R.	1	200	30	3	48	15	13	26	0	0	1	0	0	0	0
	2	6	0	0	88	0	132	220	0	0	0	0	0	0	0
Diablo F.B.	1	200	99	5	41	7	8	79	0	0	1	0	0	0	0
	2	200	100	5	40	0	3	33	0	0	3	3	0	0	0
Diablo T.R.	1	200	53	0	36	12	18	41	1	0	0	4	0	0	0
	2	200	40	4	37	12	18	28	1	0	0	0	1	0	0
Gorge F.B.	1	200	22	0	11	9	16	36	3	0	1	1	4	0	0
	2	24	11	0	0	33	0	33	0	0	0	0	11	0	0
County Line	1	200	13	3	33	3	16	25	0	0	0	0	0	0	0
	2	200	13	0	40	3	22	66	3	5	3	3	0	4	0
Talc Mine	1	200	5	0	4	0	1	21	0	1	0	0	5	0	0
	2	200	8	0	4	1	0	16	0	0	0	0	0	0	0
Marblemount	1	200	4	0	13	0	0	0	0	0	0	0	0	0	0
	2	200	7	3	26	0	1	11	0	0	5	0	9	0	3
Concrete	1	200	0	0	0	0	0	0	0	0	1	0	0	0	1
	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.2 Numbers of organisms/m^3 from plankton pump samples, May 23-24, 1977.

Site	Sample replicate	Volume (gal.)	*Diaptomus*	*Diaptomus* parts	Nauplii	*Daphnia*	*Daphnia* parts	*Bosmina*	*Bosmina* parts	Chydorids	Harpac-ticoids	Cyclop-oids	Chironomid larvae	Plecoptera nymphs	Ephemeroptera nymphs
Ross T.R.	1	300	131	1	128	43	43	1903	1	0	0	0	1	0	9
	2	300	92	0	236	35	33	1570	0	0	0	0	1	0	0
Diablo F.B.	1	300	782	5	560	206	363	1045	3	0	0	5	0	0	0
	2	300	801	0	459	237	331	1117	0	0	0	4	2	0	0
Diablo T.R.	1	300	25	0	33	1	3	108	2	0	1	0	0	0	0
	2	300	34	2	53	0	3	107	3	0	1	2	2	0	0
Gorge F.B.	1	300	25	0	48	4	2	182	2	0	3	4	2	3	0
	2	300	44	1	64	1	4	171	4	0	3	3	3	1	0
County Line	1	300	83	0	147	28	34	295	0	2	1	0	4	4	0
	2	300	90	4	158	7	13	319	4	0	2	0	4	2	18
Talc Mine	1	300	21	2	69	3	3	288	4	0	4	0	4	3	9
	2	300	12	0	19	1	1	292	0	0	4	0	11	4	0
Marblemount	1	300	4	1	41	0	2	70	0	0	4	0	6	6	9
	2	300	4	1	20	1	1	32	3	0	2	0	0	2	0
Concrete	1	300	0	0	2	0	0	7	0	0	0	0	4	1	18
	2	300	1	0	0	1	2	7	0	0	1	4	8	4	9

Table 4.3 Numbers of organisms/m^3 from plankton pump samples, June 23-24, 1977.

Site	Sample replicate	Volume (gal.)	*Diaptomus*	*Diaptomus* parts	Nauplii	*Daphnia*	*Daphnia* parts	*Bosmina*	*Bosmina* parts	Chydorids	Harpac-ticoids	Cyclop-oids	Chironomid larvae	Plecoptera nymphs	Ephemeroptera nymphs
Ross T.R.	1	300	10966	0	6476	1910	5379	13	0	0	0	0	0	0	0
	2	300	16140	0	7304	1662	4014	2	0	0	0	0	1	0	0
Diablo F.B.	1	300	76	0	280	49	148	235	0	0	2	0	1	2	0
	2	300	86	0	461	74	122	209	0	0	0	2	0	0	0
Diablo T.R.	1	300	47	0	72	5	41	160	0	0	0	0	3	4	0
	2	300	30	0	244	2	48	119	0	2	2	2	7	4	0
Gorge F.B.	1	300	26	0	57	3	67	119	0	0	3	0	0	9	1
	2	300	14	1	163	4	12	164	0	0	0	0	1	9	5
County Line	1	300	6	0	59	4	4	323	0	0	3	0	32	18	2
	2	300	7	0	33	3	14	249	0	1	0	0	25	7	2
Talc Mine	1	300	2	0	9	0	4	158	0	1	2	0	20	4	3
	2	300	2	0	21	0	4	198	0	0	0	0	30	4	7
Marblemount	1	300	2	0	26	1	5	67	0	0	5	0	0	0	1
	2	300	0	0	6	1	1	91	0	0	1	0	20	4	1
Concrete	1	300	1	0	6	0	6	5	0	1	3	0	32	3	1
	2	300	0	0	0	0	2	10	0	1	0	0	22	0	0

Table 4.4 Numbers of organisms/m^3 from plankton pump samples, July 27-28, 1977.

Site	Sample replicate	Volume (gal.)	*Diaptomus*	*Diaptomus* parts	Nauplii	*Daphnia*	*Daphnia* parts	*Bosmina*	*Bosmina* parts	Chydorids	Harpac-ticoids	Cyclop-oids	Chironomid larvae	Plecoptera nymphs	Ephemeroptera nymphs
Ross T.R.	1	200	2226	0	421	99	28	20	0	0	1	0	0	0	0
	2	200	2657	0	821	132	40	11	0	1	0	0	0	0	0
Diablo F.B.	1	300	27	0	57	18	14	87	0	0	0	0	0	0	0
	2	300	40	0	134	19	25	53	0	0	3	1	0	0	0
Diablo T.R.	1	300	16	0	58	0	1	11	0	0	0	1	1	0	0
	2	300	18	0	101	5	6	42	0	0	0	0	0	0	0
Gorge F.B.	1	300	21	0	70	4	2	37	0	2	2	0	0	12	0
	2	300	27	0	116	5	1	40	0	2	2	0	0	8	0
County Line	1	300	1	0	2	0	1	9	0	0	0	0	172	37	2
	2	300	2	0	0	0	1	4	0	0	0	0	261	38	2
Talc Mine	1	300	4	0	11	2	0	38	0	1	0	1	88	29	1
	2	300	4	0	12	1	1	55	0	1	4	1	54	30	3
Marblemount	1	300	1	0	1	0	0	7	0	0	0	0	12	17	1
	2	300	3	0	3	0	1	21	0	0	0	2	42	69	6
Concrete	1	300	0	0	2	0	2	4	0	0	0	1	73	11	4
	2	300	0	0	0	0	0	0	0	0	1	0	81	26	0

Table 4.5 Numbers of organisms/m^3 from plankton pump samples, August 23-24, 1977.

Site	Sample replicate	Volume (gal.)	*Diaptomus*	*Diaptomus* parts	Nauplii	*Daphnia*	*Daphnia* parts	*Bosmina*	*Bosmina* parts	Chydorids	Harpac-ticoids	Cyclop-oids	Chironomid larvae	Plecoptera nymphs	Ephemeroptera nymphs
Ross T.R.	1	100	2167	42	496	37	24	79	0	3	0	32	0	0	3
	2	100	2410	40	950	48	16	53	0	3	0	129	0	0	0
Diablo F.B.	1	300	92	0	457	22	23	4	0	0	1	1	0	0	0
	2	300	95	0	450	6	25	2	0	0	0	1	1	0	1
Diablo T.R.	1	300	36	0	154	4	12	2	0	1	4	3	4	8	1
	2	300	46	0	122	6	10	6	0	1	1	4	7	7	1
Gorge F.B.	1	300	26	0	176	9	2	3	0	8	3	4	7	6	2
	2	300	23	0	171	2	4	2	0	3	6	5	11	6	1
County Line	1	300	6	0	77	0	0	1	0	4	7	2	936	1	125
	2	300	3	0	13	0	0	0	0	5	8	0	838	4	99
Talc Mine	1	300	7	0	12	1	0	2	0	7	4	1	314	1	42
	2	300	4	0	62	0	1	5	0	2	8	5	327	47	16
Marblemount	1	300	1	0	27	0	1	3	0	1	4	0	290	73	7
	2	300	1	0	18	0	2	6	0	0	1	0	202	42	4
Concrete	1	100	0	3	3	0	0	0	0	3	18	5	504	0	61
	2	100	0	0	3	0	0	3	0	3	21	0	354	0	37

Table 4.6 Numbers of organisms/m^3 from plankton pump samples, September 20-21, 1977.

Site	Sample replicate	Volume (gal.)	*Diaptomus*	*Diaptomus* parts	Nauplii	*Daphnia*	*Daphnia* parts	*Bosmina*	*Bosmina* parts	Chydorids	Harpac-ticoids	Cyclop-oids	Chironomid larvae	Plecoptera nymphs	Ephemeroptera nymphs
Ross T.R.	1	200	228	17	103	4	7	203	29	0	0	8	0	0	0
	2	200	218	11	59	1	11	234	36	1	0	12	3	0	0
Diablo F.B.	1	300	31	9	84	5	21	11	1	0	0	1	0	0	0
	2	300	57	1	57	24	22	10	0	1	0	0	0	0	0
	3	263	27	0	62	48	1	8	2	0	0	2	0	0	0
Diablo T.R.	1	300	31	4	13	8	5	3	0	1	0	0	0	0	1
	2	300	35	0	27	9	12	4	0	1	1	0	9	0	0
Gorge F.B.	1	350	28	0	21	2	4	2	0	3	0	1	3	0	0
	2	300	32	2	33	9	5	3	0	5	4	1	2	0	3
	3	378	50	1	76	30	1	1	1	13	1	5	8	0	1
County Line	1	345	6	0	6	0	1	2	0	10	10	0	322	0	142
	2	300	1	0	0	0	0	0	0	4	2	0	15	0	6
Talc Mine	1	300	2	0	2	1	0	0	0	8	2	0	61	1	14
	2	300	1	0	7	1	0	0	0	8	4	0	60	0	18
Marblemount	1	300	0	0	9	0	0	5	0	4	6	4	155	1	76
	2	300	2	0	19	0	1	2	0	4	11	0	114	1	52
Concrete	1	230	1	0	2	0	0	0	0	2	11	2	133	0	25
	2	200	0	0	5	0	0	0	0	3	17	1	176	0	17

Table 4.7 Numbers of organisms/m^3 from plankton pump samples, October 22-23, 1977.

Site	Sample replicate	Volume (gal.)	*Diaptomus*	*Diaptomus* parts	Nauplii	*Daphnia*	*Daphnia* parts	*Bosmina*	*Bosmina* parts	Chydorids	Harpac-ticoids	Cyclop-oids	Chironomid larvae	Plecoptera nymphs	Ephemeroptera nymphs
Ross T.R.	1	300	77	4	10	35	360	90	0	0	0	2	0	0	0
	2	300	77	6	8	36	318	170	0	1	0	11	0	0	0
Diablo F.B.	1	300	518	42	35	213	425	73	1	0	1	1	0	0	1
	2	300	752	54	70	133	524	108	0	0	1	2	0	0	0
Diablo T.R.	1	300	811	35	64	93	219	83	0	0	0	0	1	0	1
	2	300	492	26	74	35	111	70	0	0	0	1	1	0	1
Gorge F.B.	1	300	311	14	30	114	237	11	0	1	0	0	2	0	1
County Line	1	300	28	4	30	3	2	2	0	1	0	0	10	0	4
	2	300	26	2	56	1	2	7	0	3	2	0	28	0	3
Talc Mine	1	300	26	2	11	0	0	5	0	4	0	1	29	2	1
	2	300	19	0	14	0	1	4	0	3	4	0	13	0	4
Marblemount	1	300	8	0	18	0	0	0	0	1	1	0	11	0	2
	2	300	3	0	11	1	0	4	0	4	3	2	105	0	3
Concrete	1	300	1	0	6	0	0	1	0	1	1	1	10	0	1
	2	300	1	0	2	0	0	2	0	1	1	0	27	0	2

Table 4.8 Numbers of organisms/m^3 from plankton pump samples, November 19-20, 1977.

Site	Sample replicate	Volume (gal.)	*Diaptomus*	*Diaptomus* parts	Nauplii	*Daphnia*	*Daphnia* parts	*Bosmina*	*Bosmina* parts	Chydorids	Harpac-ticoids	Cyclop-oids	Chironomid larvae	Plecoptera nymphs	Ephemeroptera nymphs
Ross T.R.	1	300	61	12	1	18	114	50	1	0	0	3	4	0	1
	2	300	71	10	2	13	105	25	1	0	0	4	3	0	0
Diablo F.B.	1	300	490	26	48	31	250	462	0	1	0	1	0	0	1
	2	300	467	25	38	36	231	563	0	1	0	0	0	0	2
Diablo T.R.	1	300	452	48	14	7	80	315	4	4	2	0	0	0	2
	2	300	379	48	15	4	75	177	0	4	1	0	2	0	0
Gorge F.B.	1	300	165	11	4	1	49	13	0	3	0	0	2	0	1
	2	300	133	4	8	3	75	49	0	7	1	3	7	0	4
County Line	1	300	51	4	44	0	4	27	0	3	7	2	60	0	8
	2	300	41	5	18	1	2	18	0	3	3	4	30	0	9
Talc Mine	1	300	10	1	12	0	0	36	0	3	2	1	35	0	7
	2	300	4	0	4	1	1	7	0	3	0	0	23	0	1
Marblemount	1	300	0	1	6	1	0	13	0	0	4	3	14	1	4
	2	300	8	0	6	0	1	7	0	4	6	1	28	0	0
Concrete	1	300	0	2	1	0	7	3	0	10	11	1	6	0	5
	2	300	0	0	2	0	0	0	0	3	4	0	0	0	0

Table 4.9 Numbers of organisms/m^3 from plankton pump samples, December 19-20, 1977.

Site	Sample replicate	Volume (gal.)	*Diaptomus*	*Diaptomus* parts	Nauplii	*Daphnia*	*Daphnia* parts	*Bosmina*	*Bosmina* parts	Chydorids	Harpac-ticoids	Cyclop-oids	Chironomid larvae	Plecoptera nymphs	Ephemeroptera nymphs
Ross T.R.	1	300	24	1	8	16	193	38	0	0	1	0	0	0	0
	2	300	29	1	5	10	176	33	0	1	0	2	0	0	0
Diablo F.B.	1	300	27	2	4	27	73	40	0	0	0	1	1	0	0
	2	300	32	2	4	18	137	93	0	1	0	1	0	0	0
Diablo T.R.	1	300	26	2	6	6	99	36	0	0	0	0	1	0	0
	2	300	26	1	0	12	106	53	0	0	0	0	0	0	0
Gorge F.B.	1	300	30	3	3	14	80	70	0	3	2	0	0	0	0
	2	300	24	2	6	14	84	34	0	0	0	1	0	0	0
County Line	1	300	17	1	0	4	20	23	0	1	0	0	11	1	2
	2	300	12	1	6	0	21	29	0	0	1	2	9	0	3
Talc Mine	1	300	12	1	2	2	18	53	0	2	5	0	10	1	6
	2	300	18	1	0	2	9	7	0	0	0	0	3	0	3
Marblemount	1	300	8	0	1	2	7	18	0	0	10	0	11	0	0
	2	300	4	4	0	0	0	3	0	0	0	0	0	0	0
Concrete	1	300	2	0	0	0	1	4	0	3	4	1	19	0	3
	2	300	3	0	3	1	0	4	0	1	6	1	20	0	0

Table 4.10 Seattle City Light flow data for the Skagit plants, 1977. Mean discharge over a month in second-foot days, elevations of Ross Lake in ft above mean sea level, and average retention time in days based on full pool storage.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Ross												
Used for power	6467	3452	4409	1970	1479	215	567	111	730	1063	1177	4154
Spill	0	0	0	0	0	0	0	0	0	0	0	0
Elevations, max.	1569	1535	1522	1585	1526	1561	1570	1581	1583	1582	1587	1591
min.	1536	1522	1493	1490	1507	1528	1561	1571	1581	1580	1581	1584
Diablo												
Used for power	6377	3664	4624	2418	1963	1541	1505	1538	1281	1272	1778	4790
Spill	435	0	0	0	0	0	0	0	0	0	0	0
Avg retention	6.65	12.37	9.80	18.74	23.09	29.41	30.12	29.47	35.38	35.63	25.49	9.46
Gorge												
Used for power	6632	3841	4779	2730	2195	1928	1669	1393	1349	1327	2229	5313
Spill	426	0	12	0	0	0	0	0	0	0	0	0
Avg retention	0.70	1.28	1.03	1.80	2.24	2.55	2.95	3.53	3.65	3.71	2.21	0.93

Diablo Forebay had higher densities of Daphnia and Diaptomus than Ross Tailrace until December when the retention time was shortened to less than 10 days (Table 4.10). Thus, it appears that under certain circumstances, Diablo Reservoir may add substantial numbers of zooplankton to that which it receives from Ross Lake.

The retention time of Gorge Lake is very much shorter than that of Diablo (Table 4.10) and also shorter than the 15-day miminum retention time that Johnson (1964) found was needed for plankton development. The plankton densities in Gorge Lake at Diablo Tailrace and Gorge Forebay were similar. Wilcoxon sign rank tests were run on four groups--Daphnia, Bosmina, Diaptomus, and nauplii. The tests failed to show significant differences between the two sites for any of the four groups. It appears that Gorge Reservoir adds little to the plankton coming in from Diablo Reservoir.

The higher densities of Bosmina below Gorge Dam than in Gorge Forebay in April, May, and June (Tables 4.1,4.2, and 4.3, respectively) are difficult to explain. Nauplii densities in April, May, October, and November (Tables 4.1, 4.2, 4.7, and 4.8, respectively) and Diaptomus adult density in May (Table 4.2) were also higher at the County Line Station than at Gorge Forebay. If avoidance of the pump by these zooplankters in the reservoir were the cause, one would expect consistently lower forebay counts through the year. It could be that the plankton pump was not sampling the same stratum of Gorge Forebay that was entering the power intakes, although the short flushing time and lack of thermal stratification should make zooplankton stratification unlikely. Plankton sampling in Gorge Reservoir in 1973 and 1974 indicated little vertical stratification (Burgner 1977). Bosmina in Ross Lake in 1973 showed a slight tendency to be more dense than Diaptomus or Daphnia at depths greater than 50 ft from April through July (SCL 1974), but this tendency was not apparent in 1972 (SCL 1973). A common phenomenon in zooplankton is a migration toward the surface at night and a downward migration during the day. Perhaps diurnal migrations cause plankton density changes at the stratum entrained by the power intakes and the water that was sampled at the County Line Station left Gorge Lake at a time of high plankton entrainment, e.g., at night when they rise up from the bottom. However, as explained above, zooplankton stratification in Gorge Lake seems unlikely. Also, water travel time between Gorge Powerhouse and the County Line Station was only about 1 hr and the County Line and Gorge Forebay stations were sampled each month in the afternoon on adjacent days.

Seasonal fluctuations of plankton abundance are presented in Tables 4.11 to 4.18. At the forebay stations, there were peaks of Diaptomus, Daphnia, and Bosmina abundance in spring and again in late fall or winter (Tables 4.12 and 4.14). The spring peak of Diaptomus, however, was not distinct at the Diablo Tailrace Station (Table 4.13) or at the Gorge Forebay Station (Table 4.14). In 1972 and 1973, Ross Lake had only one peak of Daphnia and Diaptomus abundance which occurred in August or September. Only Bosmina showed a bimodal abundance curve (SCL 1974). Perhaps in a more typical generation year, the sites below Ross Lake would

Table 4.11 Seasonal fluctuations in numbers of organisms/m^3 at the Ross Tailrace Station. Parts are added to whole organisms. Replicates are averaged and rounded to the nearest integer.

Month	*Diaptomus*	Nauplii	*Daphnia*	*Bosmina*
April	17	68	80	123
May	112	182	77	1,737
June	13,553	6,890	6,483	8
July	2,441	621	149	15
August	2,330	723	62	66
September	237	81	11	251
October	82	9	374	130
November	77	1	125	38
December	27	7	197	36

Table 4.12 Seasonal fluctuations in numbers of organisms/m^3 at the Diablo Forebay Station. Parts are added to whole organisms. Replicates are averaged and rounded to the nearest integer.

Month	*Diaptomus*	Nauplii	*Daphnia*	*Bosmina*
April	105	40	9	56
May	794	510	569	1,082
June	81	371	197	222
July	33	96	38	70
August	93	453	38	3
September	41	65	38	10
October	683	52	648	91
November	504	43	274	513
December	31	40	128	66

Table 4.13 Seasonal fluctuations in numbers of organisms/m^3 at the Diablo Tailrace Station. Parts are added to whole organisms. Replicates are averaged and rounded to the nearest integer.

Month	*Diaptomus*	Nauplii	*Daphnia*	*Bosmina*
April	48	36	30	36
May	30	43	3	110
June	38	158	48	140
July	17	80	6	27
August	41	138	16	4
September	35	20	17	3
October	682	69	229	76
November	464	15	83	248
December	28	3	112	44

Table 4.14 Seasonal fluctuations in numbers of organisms/m^3 at the Gorge Forebay Station. Parts are added to whole organisms. Replicates are averaged and rounded to the nearest integer.

Month	*Diaptomus*	Nauplii	*Daphnia*	*Bosmina*
April	17	5	29	36
May	35	56	5	179
June	20	110	43	141
July	24	93	6	38
August	25	173	8	2
September	39	44	17	2
October	325	30	350	11
November	156	6	64	31
December	29	4	96	52

Table 4.15 Seasonal fluctuations in numbers of organisms/m^3 at the County Line Station. Parts are added to whole organisms. Replicates are averaged and rounded to the nearest integer.

Month	*Diaptomus*	Nauplii	*Daphnia*	*Bosmina*
April	15	36	22	47
May	88	153	41	309
June	7	46	13	286
July	1	< 1	< 1	7
August	4	45	0	< 1
September	4	3	< 1	1
October	30	43	4	4
November	51	31	4	22
December	15	3	22	26

Table 4.16 Seasonal fluctuations in numbers of organisms/m^3 at the Talc Mine Station. Parts are added to whole organisms. Replicates are averaged and rounded to the nearest integer.

Month	*Diaptomus*	Nauplii	*Daphnia*	*Bosmina*
April	7	4	1	19
May	18	44	4	292
June	2	15	4	178
July	4	12	2	47
August	6	37	< 1	4
September	1	4	< 1	0
October	23	13	< 1	4
November	8	8	< 1	22
December	16	< 1	15	30

Table 4.17 Seasonal fluctuations in numbers of organisms/m^3 at the Marblemount Station. Parts are added to whole organisms. Replicates are averaged and rounded to the nearest integer.

Month	*Diaptomus*	Nauplii	*Daphnia*	*Bosmina*
April	7	20	< 1	5
May	5	31	2	52
June	< 1	16	4	79
July	2	2	< 1	14
August	< 1	23	1	4
September	< 1	14	< 1	4
October	5	15	< 1	2
November	4	6	< 1	10
December	8	< 1	4	10

Table 4.18 Seasonal fluctuations in numbers of organisms/m^3 at the Concrete Station. Parts are added to whole organisms. Replicates are averaged and rounded to the nearest integer.

Month	*Diaptomus*	Nauplii	*Daphnia*	*Bosmina*
April	0	0	0	0
May	< 1	< 1	1	7
June	< 1	3	4	8
July	0	< 1	1	2
August	1	3	0	1
September	< 1	4	0	0
October	< 1	4	0	1
November	< 1	1	4	1
December	2	1	1	4

have reflected plankton density fluctuations more similar to those seen in Ross Lake in 1972 and 1973.

The bimodal trends in zooplankton abundance seen in the reservoirs were reflected at the County Line Station (Table 4.15) but the trend became less distinct farther downstream (Tables 4.16-4.18). Zooplankton densities at the downstream stations were low and sporadic.

Drifting aquatic insects were found at all sites (Tables 4.2, 4.3, 4.8), but in larger numbers below Gorge Dam. Plecoptera (stonefly) nymphs were most abundant in the river drift below Gorge in July (Table 4.4), while chironomid and Ephemeroptera (mayfly) nymphs were most abundant in August (Table 4.5).

Table 4.7 presents the results of a test for differences between the drift sampled in midstream and the drift in juvenile salmonid rearing areas conducted in October 1977. At the stations below Gorge Dam, sample 1 was taken in mid-channel while sample 2 was taken inshore. Diaptomus densities tended to be higher offshore and chironomid densities tended to be higher closer to the bank. However, the number of observations was so low that Wilcoxon sign rank tests cannot be applied to individual species. The planktonic groups--Diaptomus, nauplii, Daphnia, Bosmina, and chydorids--tested together, failed to show differences between inshore and offshore samples. A test of the river groups harpacticoids, chironomids, and Ephemeroptera nymphs indicated differences between the sample replicates at a 0.05 significance level, with the inshore samples having higher densities. The implication of these comparisons is that the juvenile salmonids have available more benthic organisms than the drift samples indicate but not more plankton.

Harpacticoids, chydorids, and cyclopoids occurred ubiquitously at low numbers. One species of chydorid, rarely found in the reservoirs, and a desmid, Closterium sp., never found in the reservoirs, was found at the Concrete Station. The desmid is normally found in small acid ponds, suggesting that some of the plankton found at the Concrete Station, well above the mouth of the Baker River, may have come from small ponds nearby.

5.0 SALMON AND STEELHEAD

5.1 General Freshwater Life History

Waters of the Skagit Basin downstream of Newhalem are utilized for spawning by all five species of Pacific salmon and by steelhead trout. The mainstem Skagit is utilized primarily by summer-fall chinook, pink (in odd years only) and chum salmon, while coho primarily use tributary streams. Sockeye and spring chinook salmon are restricted mainly to the Baker and the Sauk-Cascade systems, respectively. Steelhead trout utilize both mainstem Skagit and tributary spawning sites.

Spawning nests or "redds" are prepared in the gravel of the stream bottom by the female primarily, and mating occurs. Eggs are deposited in the redd by the female, fertilized there by a male, and covered with gravel by subsequent digging activities.

After fertilization salmon and trout eggs undergo embryonic development within the stream gravels. During this time the developing embryo receives nourishment from the yolk material. About midway through the incubation cycle the eggs hatch. The resulting alevins with their protruding yolk sac continue to absorb the yolk material. The yolk sac gradually recedes and the yolk finally becomes fully absorbed. At this point the juvenile fish becomes dependent on outside material for nourishment. The rate of development and the number of temperature units (TU) required for development between fertilization and yolk absorption are dependent on the temperature regime and differ among the several species.

Upon emergence from redds, fry of chinook salmon seek the quieter water along the banks of the larger streams such as the Skagit and Sauk rivers, and tend to distribute along shallow gravel bars and pool areas to feed. This tendency is also shown by juvenile coho and steelhead in their earlier stages after emergence. Pink salmon fry tend to move seaward at once. Chum salmon also are more prone to move seaward soon after emergence. Both pink and chum fry feed to a limited extent during their relatively short residence in freshwater and downstream migration.

Juvenile summer-fall chinook generally rear about 3 months (but perhaps up to 5 months) in freshwater prior to their seaward movement. Juvenile coho migrate seaward in the spring of their second year while juvenile steelhead trout probably rear 2 years in freshwater before their migration to saltwater.

5.2 Hatchery Production

Salmon and steelhead trout production in the Skagit River is supplemented by the Skagit Salmon Hatchery located near Marblemount (Fig. 1.1) which is maintained and operated by the Washington Department of Fisheries (WDF). Fish production from the Skagit Hatchery and fish plants in the Skagit system between Boyd Creek (river mile [RM] 44.7) and Newhalem are summarized in Table 5.1 for the period 1952 to 1977. Fall

Table 5.1 Fish production of the Skagit Hatchery and fish plants by WDF in the Skagit system from Boyd Creek (river mile 44.7) to Newhalem, 1952-1977.

Year planted	Brood year	Species		Number of fish: Skagit Hatchery production	Number of fish: Fish plants by WDF in the Skagit system from Boyd Creek to Newhalem
1977	75	Spring chinook	(yr)*	178,938	178,938
	76	Spring chinook	(fg)	157,121	157,121
	75	Fall chinook	(yr)	95,978	95,978
	76	Fall chinook	(yr)	87,860	0
	75	Coho	(yr)	1,346,647	973,327
	76	Coho	(fg)	2,828,893	2,828,893
1976	74	Spring chinook	(yr)	45,540	45,540
	75	Fall chinook	(fg)	668,304	0
	74	Coho	(yr)	1,169,862	581,562
	75	Coho	(fr)	0	1,152,000
	75	Chum	(fg)	27,946	27,946
	75	Pink	(fg)	2,576,817	2,576,817
1975	73	Spring chinook	(yr)	90,935	90,935
	74	Fall chinook	(fg)	2,199,052	0
	73	Coho	(yr)	2,185,360	1,071,420
	74	Coho	(fr)	3,316,920	231,678
	74	Chum	(fg)	4,586,410	4,586,410
1974	72	Spring chinook	(yr)	84,920	84,920
	73	Fall chinook	(fg)	3,381,221	0
	72	Coho	(yr)	2,454,154	2,454,154
	73	Coho	(fr)	1,000,128	648,960
	73	Coho	(fg)	485,289	485,289
	73	Chum	(fg)	3,709,336	3,709,336
	73	Pink	(fg)	476,216	476,216
	72	Steelhead	(yr)	30,248	30,248
1973	71	Spring chinook	(yr)	14,696	14,696
	71	Fall chinook	(yr)	28,624	28,624
	72	Fall chinook	(fg)	4,228,288	3,399,750
	71	Coho	(yr)	1,566,949	1,508,426
	72	Coho	(fr)	805,000	490,000
	72	Coho	(fg)	0	76,442
	72	Chum	(fg)	3,098,166	3,098,166
1972	71	Fall chinook	(fg)	3,257,907	3,257,907
	71	Fall chinook	(yr)	77,337	77,337
	70	Coho	(yr)	1,202,491	1,147,391
	71	Coho	(fr)	915,600	0
	71	Coho	(fg)	0	425,000
	71	Chum	(fg)	463,320	463,320
	71	Pink	(fg)	38,500	38,500

Table 5.1 Fish production of the Skagit Hatchery and fish plants by WDF in the Skagit system from Boyd Creek (river mile 44.7) to Newhalem, 1952-1977 - continued.

Year planted	Brood year	Species		Number of fish: Skagit Hatchery production	Number of fish: Fish plants by WDF in the Skagit system from Boyd Creek to Newhalem
1971	70	Fall chinook	(fg)	5,050,753	5,050,753
	69	Coho	(yr)	1,872,142	1,314,342
1970	69	Fall chinook	(fg)	3,032,222	1,740,934
	68	Coho	(yr)	1,711,493	1,870,790
	69	Coho	(fg)	492,350	492,350
1969	68	Fall chinook	(fg)	2,813,960	2,813,960
	67	Coho	(yr)	1,362,207	1,312,207
	68	Coho	(fr)	890,520	683,880
1968	67	Fall chinook	(fg)	2,829,807	2,829,807
	66	Coho	(yr)	1,682,568	1,682,568
	67	Coho	(fr)	568,980	568,980
1967	66	Fall chinook	(fg)	3,729,377	3,729,377
	65	Coho	(yr)	1,310,853	1,310,853
1966	65	Fall chinook	(fg)	2,730,084	1,376,296
	64	Coho	(yr)	1,250,415	1,049,085
1965	64	Fall chinook	(fr)	1,664,950	1,664,950
	64	Fall chinook	(fg)	2,560,151	2,037,340
	63	Coho	(yr)	546,130	498,530
1964	63	Fall chinook	(fr)	1,978,850	0
	63	Fall chinook	(fg)	2,674,686	1,275,443
	62	Coho	(yr)	822,128	635,557
	63	Coho	(fg)	89,175	89,175
	63	Coho	(yr	391,247	158,760
1963	62	Fall chinook	(fr)	1,585,292	250,200
	62	Fall chinook	(fg)	1,469,018	991,950
	61	Coho	(yr)	771,775	567,100
	62	Coho	(fr)	526,500	526,500
1962	60	Spring chinook	(yr)	130,400	0
	61	Spring chinook	(fg)	224,728	224,728
	61	Fall chinook	(fr)	1,888,580	964,444
	61	Fall chinook	(fg)	2,726,498	1,364,128
	60	Coho	(yr)	754,372	614,750
	61	Coho	(fr)	1,163,121	0
	61	Steelhead	(yr)	20,840	4,170

Table 5.1 **Fish production of the Skagit Hatchery and fish plants by WDF in the Skagit system from Boyd Creek (river mile 44.7) to Newhalem, 1952-1977 - continued.**

Year planted	Brood year	Species		Number of fish: Skagit Hatchery production	Number of fish: Fish plants by WDF in the Skagit system from Boyd Creek to Newhalem
1961	60	Fall chinook	(fg)	2,746,218	1,628,558
	59	Coho	(yr)	817,310	608,931
	60	Coho	(fr)	2,360,364	1,630,964
	60	Coho	(fg)	230,530	100,264
	60	Steelhead	(yr)	16,286	4,150
1960	59	Spring chinook	(fg)	1,029	1,029
	59	Spring chinook	(yr)	35,854	0
	59	Fall chinook	(fg)	3,626,140	607,136
	58	Coho	(yr)	550,238	436,538
	59	Coho	(yr)	88,518	88,518
	59	Chum	(fg)	196,620	0
	59	Pink	(fg)	80,870	80,870
	59	Steelhead	(yr)	24,312	0
1959	57	Spring chinook	(yr)	149,922	0
	58	Spring chinook	(fg)	18,480	0
	58	Fall chinook	(fg)	2,216,846	776,973
	57	Coho	(yr)	470,297	339,505
	58	Coho	(fg)	990,198	804,823
	57	Steelhead	(yr)	18,958	0
	58	Sockeye		0	38,560
1958	57	Spring chinook	(fg)	43,122	0
	57	Fall chinook	(fg)	3,788,289	1,533,542
	56	Coho	(yr)	668,957	423,301
	57	Coho	(fg)	113,723	113,723
	57	Coho	(yr)	135,692	135,692
	57	Pink	(fg)	21,107	21,107
	56	Steelhead	(yr)	21,829	0
1957	56	Spring chinook	(yr)	27,885	0
	56	Fall chinook	(fr)	2,689,249	1,035,827
	56	Fall chinook	(fg)	2,264,297	806,484
	55	Coho	(yr)	877,753	586,216
	56	Coho	(fg)	205,227	204,227
	56	Coho	(yr)	65,236	65,236
1956	54	Spring chinook	(yr)	74,888	0
	55	Spring chinook	(yr)	24,918	0
	55	Fall chinook	(fg)	670,839	239,227
	54	Coho	(yr)	630,441	435,351
	55	Coho	(fr)	0	20,100
	55	Steelhead	(yr)	29,862	0

Table 5.1 Fish production of the Skagit Hatchery and fish plants by WDF in the Skagit system from Boyd Creek (river mile 44.7) to Newhalem, 1952-1977 - continued.

Year planted	Brood year	Species		Number of fish: Skagit Hatchery production	Number of fish: Fish plants by WDF in the Skagit system from Boyd Creek to Newhalem
1955	53	Spring chinook	(yr)	36,922	0
	54	Fall chinook	(fg)	846,899	742,992
	53	Coho	(yr)	475,950	351,340
	54	Coho	(fr)	233,676	167,822
	54	Coho	(fg)	40,377	40,377
	54	Chum	(fr)	61,704	61,704
	54	Steelhead	(yr)	30,280	0
1954	53	Spring chinook	(fg)	100,764	0
	53	Spring chinook	(yr)	117,256	96,574
	52	Coho	(yr)	529,559	329,890
	53	Coho	(fr)	0	23,750
	53	Pink	(fg)	285,674	0
	53	Steelhead	(yr)	40,859	0
1953	52	Spring chinook	(fg)	438,877	260,662
	52	Fall chinook	(fg)	209,736	209,736
	51	Coho	(yr)	322,528	237,474
	52	Coho	(fr)	0	30,000
	52	Coho	(fg)	703,299	457,781
	51	Steelhead	(yr)	26,045	6,297
1952	50	Coho	(yr)	438,029	287,742
	51	Coho	(fg)	208,505	143,364

*yr = yearling (270 + days reared).
fg = fingerling (14-269 days reared).
fr = fry (0-14 days reared).

Ref.: WDF - 1977 Annual Report, in press.
WDF - 1976 Annual Report, Progress Report No. 30, July 1977.
WDF - 1975 Annual Report, October, 1976.
WDF - Hatchery Statistical Records Report No. 1 (2nd Edition).
WDF - Hatchery Statistical Records Report No. 2.

chinook and coho salmon have been the principal species produced, but in recent years increased emphasis has been placed on producing spring chinook, pink, and chum salmon. Three to five million fall chinook fingerlings were released per year in the early 1970's. Between 1974 and 1976 no fall chinook were released in the Skagit system between Boyd Creek and Newhalem. In 1977 about 96,000 fall chinook yearlings were released. Production of steelhead trout occurred primarily before 1963.

A steelhead trout rearing facility is maintained and operated by Washington Department of Game (WDG) in Barnaby Slough, near Rockport (Fig. 1.1).

Details of the 1974-1977 salmon and trout plants by WDF and WDG for the Skagit system between Concrete and Ross Dam are listed in Table 5.2.

5.3 Escapement

Skagit system natural spawning escapements have been estimated for recent years by WDF for chinook (summer-fall and spring), pink, chum, and coho salmon (Table 5.3).

Summer-fall chinook escapement levels were relatively stable for the 1965 to 1977 period while spring chinook escapements were at low levels from 1974-1976. The lower than average escapement in 1977 may be attributable to the lack of hatchery released fish in 1974 from the 1973 brood. However, the effect and proportion of naturally spawning hatchery produced fish on the wild chinook stocks is not known (Orrell 1976). Escapement estimates for coho, pink, and chum salmon showed greater year-to-year variability than for summer-fall chinook, but neither a general upward nor downward trend was apparent. Chum salmon escapement estimates show a 2-year cyclic pattern with peaks occurring in even years. The low cycle escapements for chums coincide with odd year runs of Skagit pink salmon. This relationship possibly reflects estuarine rearing conditions or capacity since Skagit River chum salmon return predominantly as 4-year-old fish (R. Orrell, personal communication) and pinks, of course, return as 2-year-old fish. Skagit River escapement goals for 1977 were set at 14,850 for summer-fall chinook (Ames and Phinney 1977), and 27,000 for coho salmon (Zillges 1977).

Escapement levels to the Skagit Salmon Hatchery from 1949 to 1977 are shown in Table 5.4.

5.4 Steelhead Catch

While no spawning escapement estimates were available for steelhead trout, WDG has calculatd and compiled catch statistics for the Skagit River system (Tables 5.5-5.7). For the 1961-1977 period, 92.7 percent of the total sport harvest came from the mainstem Skagit with the remainder distributed between the Sauk (6.6 percent) and Cascade (0.6 percent) systems. Winter-run (caught November through April) and summer-run

Table 5.2 Summary of fish plants in the Skagit River system between Concrete and Ross Dam, 1974-1977 (WDF, WDG).

	Brood year	Species	Date planted	Number planted	Location of plant
1974	72	Spring chinook	5/15	84,920	Clark Creek
	72	Coho	5/15	1,187,908	Clark Creek
	72	Coho	8/1	1,266,246	Clark Creek
	72	Steelhead	5/15	30,248	Clark Creek
	73	Coho	4/6	106,900	Bacon Creek
	73	Coho	4/6	106,060	County Line
	73	Coho	4/6	124,750	Illabot Creek
	73	Coho	5/3	253,001	Cascade River
	73	Chum	6/4	3,118,356	Clark Creek
	73	Chum	6/17	590,980	Clark Creek
	73	Pink	6/4	476,216	Clark Creek
	72	Rainbow	8/14	1,750	Cascade River
	73	Rainbow	4/9	70,000	Diablo Lake
	73	Rainbow	6/5	1,056	County Line Beaver Ponds
1975	73	Spring chinook	3/13	90,935	Clark Creek
	73	Coho	5/13	1,071,420	Clark Creek
	74	Coho	3/21	231,678	Illabot Creek
	74	Chum	5/19	56,800	Clark Creek
	74	Chum	6/10	4,529,610	Clark Creek
	74	SR steelhead	4/18-4/28	10,968	Lucas Slough
	74	SR steelhead	5/5-5/16	39,445	Lucas Slough
	74	SR steelhead	5/7-5/19	26,775	Cascade River
	74	WR steelhead	4/18-4/28	35,886	Lucas Slough
	74	WR steelhead	5/2-5/15	22,892	Lucas Slough
	74	WR steelhead	5/2-5/3	20,400	Cascade River
	74	WR steelhead	5/13	2,737	Rockport
	74	WR steelhead	5/13	8,383	Goodell Creek
	74	Rainbow	6/3	34,452	Diablo Lake
	74	Rainbow	8/20	3,658	Cascade River
	74	Rainbow	8/20	1,000	Bacon Creek
1976	74	Spring chinook	3/1	45,540	Clark Creek
	74	Coho	5/5	581,562	Clark Creek
	75*	Coho	3/22	492,000	Sauk River
	75*	Coho	4/14	540,000	Sauk River
	75	Pink	4/15	1,844,817	Clark Creek
	75	Pink	4/23	671,000	Clark Creek
	75	Pink	5/4	61,000	Clark Creek
	75	Chum	6/14	27,946	Clark Creek
	75	SR steelhead	4/15-5/11	36,470	Lucas Slough

Table 5.2 **Summary of fish plants in the Skagit River system between Concrete and Ross Dam, 1974-1977 (WDF, WDG) - continued.**

	Brood year	Species	Date planted	Number planted	Location of plant
1976	75	SR steelhead	4/29-5/3	15,369	Cascade River
	75	WR steelhead	4/16-5/13	88,933	Lucas Slough
	75	WR steelhead	4/27	10,980	Steelhead Club Park
	75	WR steelhead	4/30	8,840	Young's Bar
	75	WR steelhead	4/26	10,800	Goodell Creek
	75	WR steelhead	4/22-4/30	28,457	Cascade River
	75	Rainbow	5/21	75,068	Diablo Lake
	75	Rainbow	5/26	53,414	Gorge Lake
	75	Rainbow	6/18	179	Ladder Creek
	75	Rainbow	6/29	1,729	Cascade River
	76	Cutthroat	10/ 7	4,000	Thornton Lakes
1977	75	Spring chin.	3/28	178,938	Clark Creek
	75	Fall chinook	3/28	95,978	Clark Creek
	76	Coho	4/ 4	141,990	Cascade River
	76	Coho	4/ 5	27,000	Diobsud Creek
	76	Coho	4/ 5	69,000	Bacon Creek
	76	Coho	4/ 5	33,000	Goodell Creek
	76	Coho	4/ 5	39,000	Illabot Creek
	76	Coho	4/ 6	6,000	Clark Creek
	76	Coho	5/ 1	585,337	Clark Creek
	76	Chum	4/22	201,390	Newhalem Ponds
	76	Chum	5/16	2,627,503	Clark Creek
	76	Spring chin.	6/ 3	157,121	Clark Creek
	76	SR steelhead	4/25	7,920	Hatchery
	76	SR steelhead	4/25	8,010	Cascade River Park
	76	SR steelhead	4/26-4/28	16,020	Goodell Creek
	76	SR steelhead	5/ 3-5/ 6	12,255	Bacon Creek
	76	SR steelhead	5/ 6-5/10	5,687	Lucas Slough
	76	SR steelhead	4/18	5,310	Sauk River
	76	WR steelhead	4/18-4/20	19,987	Sauk River
	76	WR steelhead	4/20	5,017	Clear Creek
	76	WR steelhead	4/19-4/21	14,784	Steelhead Park
	76	WR steelhead	4/19-5/12	201,654	Lucas Slough
	76	WR steelhead	4/21-5/4	16,901	Young's Bar
	76	WR steelhead	4/22-4/25	15,021	Faber's Ferry
	76	WR steelhead	4/26-4/29	19,945	Baker River Mouth
	76	Rainbow	5/18	35,175	Gorge Lake
	76	Rainbow	5/26	1,701	Cascade River
	76	Rainbow	5/31	65,450	Diablo Lake
	76	Rainbow	6/ 8	175	Ladder Creek
	76	Rainbow	6/28	1,513	Lake Shannon
	76	Rainbow	6/28	23,100	Baker Lake

*Samish Hatchery Plants

Ref. WDF - 1974 Annual Report.
WDF - 1975 Annual Report, October 1976.
WDF - 1976 Annual Report, Progress Report No. 30, July 1977.
WDF - 1977 Annual Report, in press.
WDG - Hatchery planting records, Seattle office.

Table 5.3 Estimated Skagit River system spawning escapements (Washington Department of Fisheries).

Year	Summer-fall chinook[1]	Spring chinook[2]	Pink[2]	Chum[3]	Coho[4]
1959			200,000		
1961			400,000		
1963			1,190,000		
1965	18,266	3,937	150,000		24,000
1966	12,026	2,967			20,000
1967	8,117	1,479	100,000		13,000
1968	12,330	1,164		47,000	18,000
1969	9,613	2,318	100,000	14,900	9,000
1970	18,872	2,673		52,900	18,000
1971	18,760	2,664	300,000	24,400	12,000
1972	23,234	2,506		49,100	12,000
1973	17,809	2,349	250,000	12,500	13,000
1974	12,901	594		42,800	22,000
1975	11,555	804	100,000	7,800	10,000
1976	14,479	804		85,000	5,000
1977	9,602[2]		500,000[3]	32,130	24,000[2]
Mean	14,428	2,022	329,000	36,853	15,385

[1]WDF-Technical Report No. 29, May, 1977.

[2]WDF-R. Orrell, personal communication.

[3]WDF-R. Orrell, personal communication, considered provisional and subject to revision.

[4]WDF-Technical Report No. 28, April, 1977.

Table 5.4 Salmon escapement to the Skagit Hatchery racks, 1949-1977 (WDF).[a]

	Coho	Chinook	Pink	Chum
1949	190			
1950	1,908			
1951	4,599[b]			
1952	1,611			
1953	841			
1954	913			
1955	642			
1956	275			
1957	468			
1958	1,135			
1959	1,680			
1960	3,758			
1961	1,479			
1962	1,164[c]			
1963	1,352			
1964	1,139			
1965	923	159		
1966	2,173	556		
1967	3,530	133		
1968	7,997	259		
1969	16,005	346		
1970	22,204	1,995		
1971	32,668	801	555	
1972	15,319	758		79
1973	11,246	924	1,181	
1974	32,930	745		
1975	28,090	1,107	3,135	
1976	16,072	606		72
1977	12,671	238	4,924	6,486

[a]Ref: Department of Fisheries, Annual Report, 1970, pp. 122, 125. WDF Progress Report No. 30, July 1977, pp. 4-7. WDF Annual Report, 1977 in press.

[b]Includes Cascade River fish.

[c]Spawned fish only.

(caught May through October) steelhead made up 97.2 percent and 2.8 percent, respectively, of the estimated Skagit system sport harvest.

Skagit system winter-run sport catches for the past 16 cycle years (Table 5.5) have averaged 11,681 fish per cycle year and have shown a sharp decline in recent years (5,743 in 1974-1975; 1,647 in 1975-1976; and 1,220 in 1976-1977). This was due in part to the increased harvest by treaty Indians (Table 5.7) under the "Boldt Decision" that Indians be allowed to catch up to 50 percent of the harvestable anadromous salmon and steelhead in certain western Washington waters. Treaty Indian catches of winter-run steelhead were 15,968 in 1974-1975; 6,338 in 1975-1976; 1,469 in 1976-1977.

Table 5.5 **Sport harvest of Skagit system winter-run (Nov-Apr) steelhead trout, 1961-1962 through 1976-1977 (WDG). Figures are corrected for nonresponse bias.**

	Skagit	Sauk	Suiattle	Cascade
1961-62	11,125	656	0	0
1962-63	12,852	832	0	0
1963-64	20,939	1,301	0	0
1964-65	12,497	850	0	4
1965-66	16,010	700	0	0
1966-67	14,900	1,943	10	2
1967-68	18,914	1,525	0	5
1968-69	13,157	568	0	17
1969-70	6,865	665	13	46
1970-71	10,379	667	12	26
1971-72	13,678	1,000	13	126
1972-73	8,471	716	28	58
1973-74	6,134	527	17	38
1974-75	5,463	184	15	81
1975-76	1,512	100	2	33
1976-77	1,029	168		23
Mean	10,870	775	7	29

Table 5.6 Sport harvest of Skagit system summer-run (May-Oct) steelhead trout, 1962 through 1976 (WDG). Figures are corrected for nonresponse bias.

	Skagit	Sauk	Suiattle	Cascade
1962	46	26	0	0
1963	110	26	0	0
1964	88	14	0	0
1965	94	11	6	0
1966	67	0	0	0
1967	110	16	0	8
1968	199	17	0	7
1969	186	7	0	9
1970	88	23	0	0
1971	130	43	0	4
1972	343	58	0	59
1973	1,165	28	0	277
1974	731	22	0	163
1975	472	16	10	37
1976	269	24		36
Mean	273	22	1	40

Table 5.7 **Skagit system Treaty Indian harvest of winter-run steelhead, 1953-1954 through 1976-1977 (WDG). Gaps in data are for years when no information was available.**

	Steelhead taken
1953-54	41
1956-57	715
1957-58	438
1958-59	7
1959-60	457
1960-61	493
1961-62	1,937
1973-74	3,668
1974-75	15,968+343 1975 cycle summer-run steelhead
1975-76	6,338
1976-77	1,469+ 19 1976 cycle summer-run steelhead

6.0 SPAWNING

6.1 Introduction

The focus of these studies was on the adult chinook (Oncorhynchus tshawytscha), pink (O. gorbuscha), chum (O. keta), and coho salmon (O. kisutch), and steelhead trout (Salmo gairdneri) which spawn in the "upper" Skagit River between the confluence of the Baker River and Gorge Powerhouse. The present study was undertaken as part of a larger effort to establish a data base for the upper river upon which possible effects of future modifications or additions to the Skagit Project could be gaged.

The principal objectives were: 1) To determine the distribution and timing of the salmon and steelhead trout spawning stocks in the upper Skagit River; 2) to develop the relationship between spawnable area and discharge; and 3) to estimate the amount of potential spawning area for Skagit River salmon above and below the proposed Copper Creek Dam site.

Secondary objectives were to determine the depths and velocities "preferred" by spawning Skagit River salmon and to observe the effects of fluctuating water level on redds and spawning adult fish.

These studies were conducted primarily in 1975 and 1976, with followup work in 1977.

6.2 Description of Study Area

The area consisted of 37.7 river miles from the Gorge Powerhouse at river mile (RM) 94.2 downstream to the confluence of the Baker River at RM 56.5 (Fig. 6.1). The discharge of the upper Skagit River was first regulated in 1924 and is presently influenced by Gorge, Diablo, and Ross reservoirs with a combined capacity of 1,535,000 acre-foot (U.S. Geological Survey--USGS--1977). Flows may fluctuate on a diurnal or even hourly basis, depending on the demand for hydroelectric power and the operational constraints exercised. Analysis of discharge data for 1975 and 1976 indicated periods of low flow in late summer and early fall with much higher flows in early summer and late fall (Figs. 6.2 and 6.3). Mean annual discharge varied from 4,511 cfs at Newhalem (1908-1976) to about 12,600 cfs just above the Baker River (1924-1976).

Twenty sample transects were established for systematic hydrological investigation with one transect for every 1.9 river miles on the average (Table 6.1 and Fig. 6.1). In addition, four reference reaches were established for biological and detailed hydrological investigations. Two reference reaches were established above the proposed Copper Creek Dam site and two in the river below (Fig. 6.1). Reference Reach 1 was the farthest upstream and was located at RM 91.6, 2.6 mi below the Gorge Powerhouse. Reference Reach 2 was at RM 84.3, 0.3 mi above the proposed Copper Creek Dam site. Reference Reach 3 was established at RM 79.4, near Marblemount, 1.3 mi above the confluence of the Cascade River. Reference

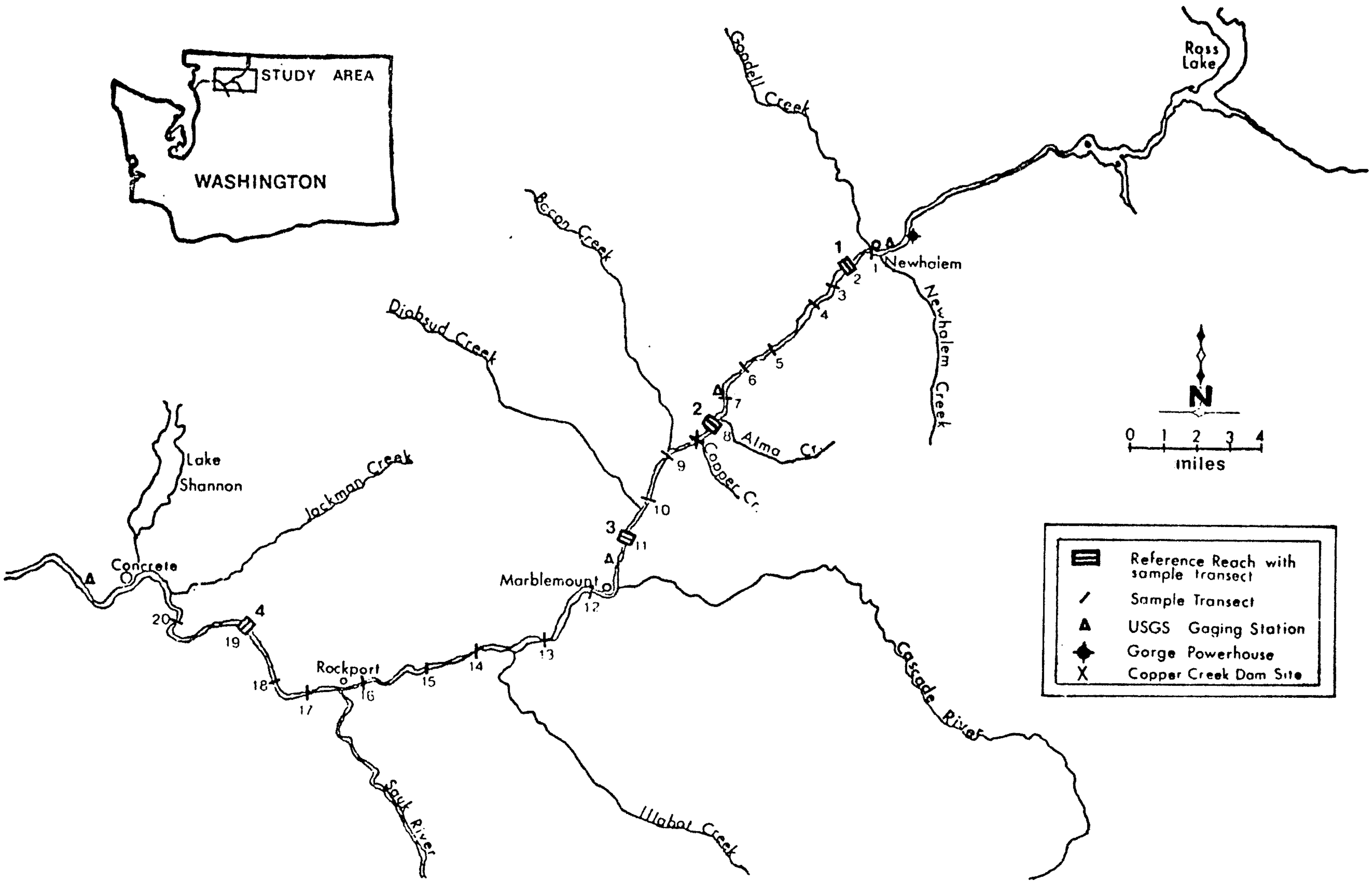

Fig. 6.1 Skagit River sample transects (1-20, lighter numbers) and reference reaches (1-4, bold numbers) between the Gorge Powerhouse (Newhalem) and the Baker River (Concrete). The Copper Creek Dam site and the USGS gaging stations are shown.

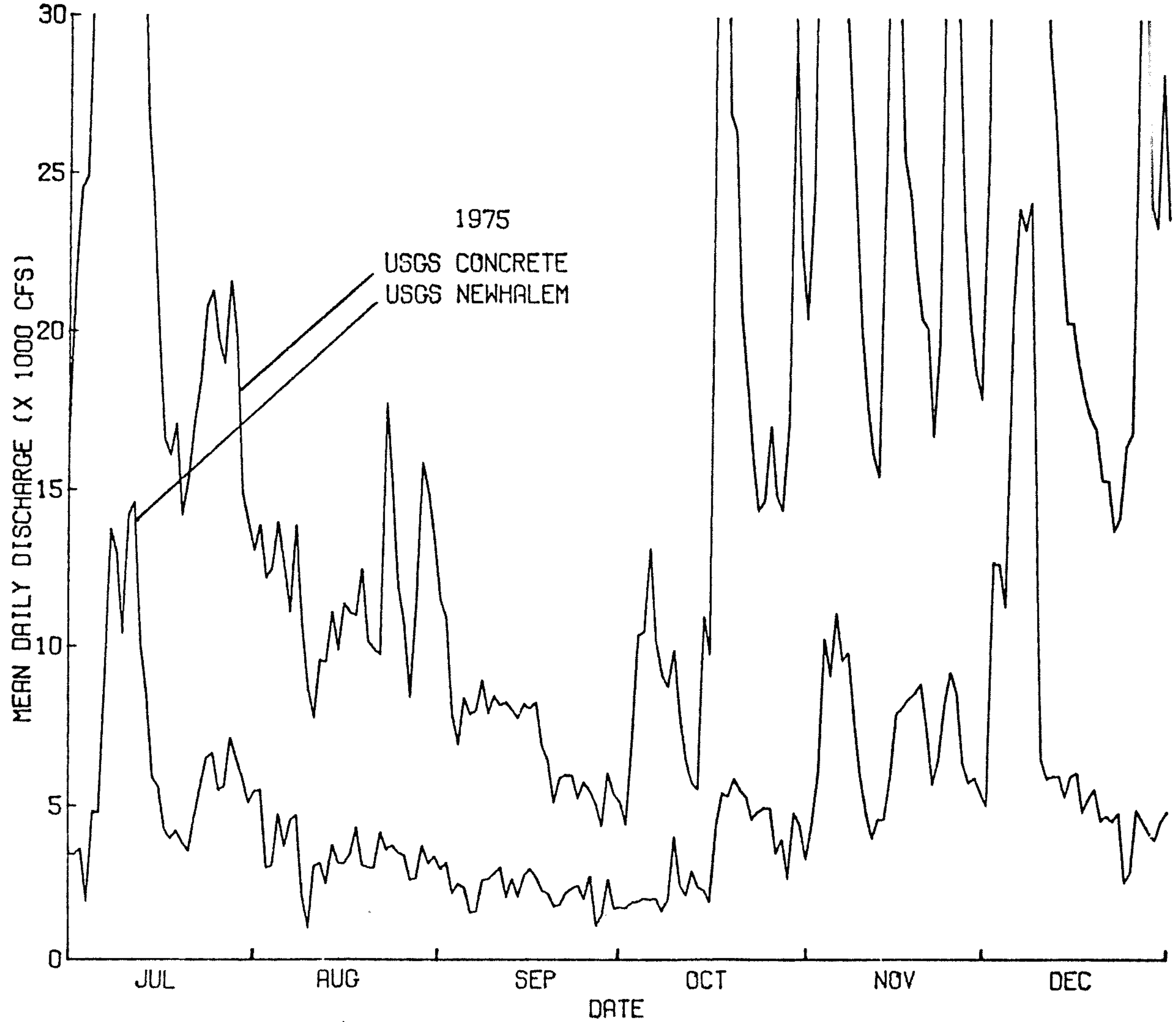

Fig. 6.2 Skagit River hydrographs of mean daily discharge at two gaging sites for the period from July to December 1975 (U.S. Geological Survey 1976).

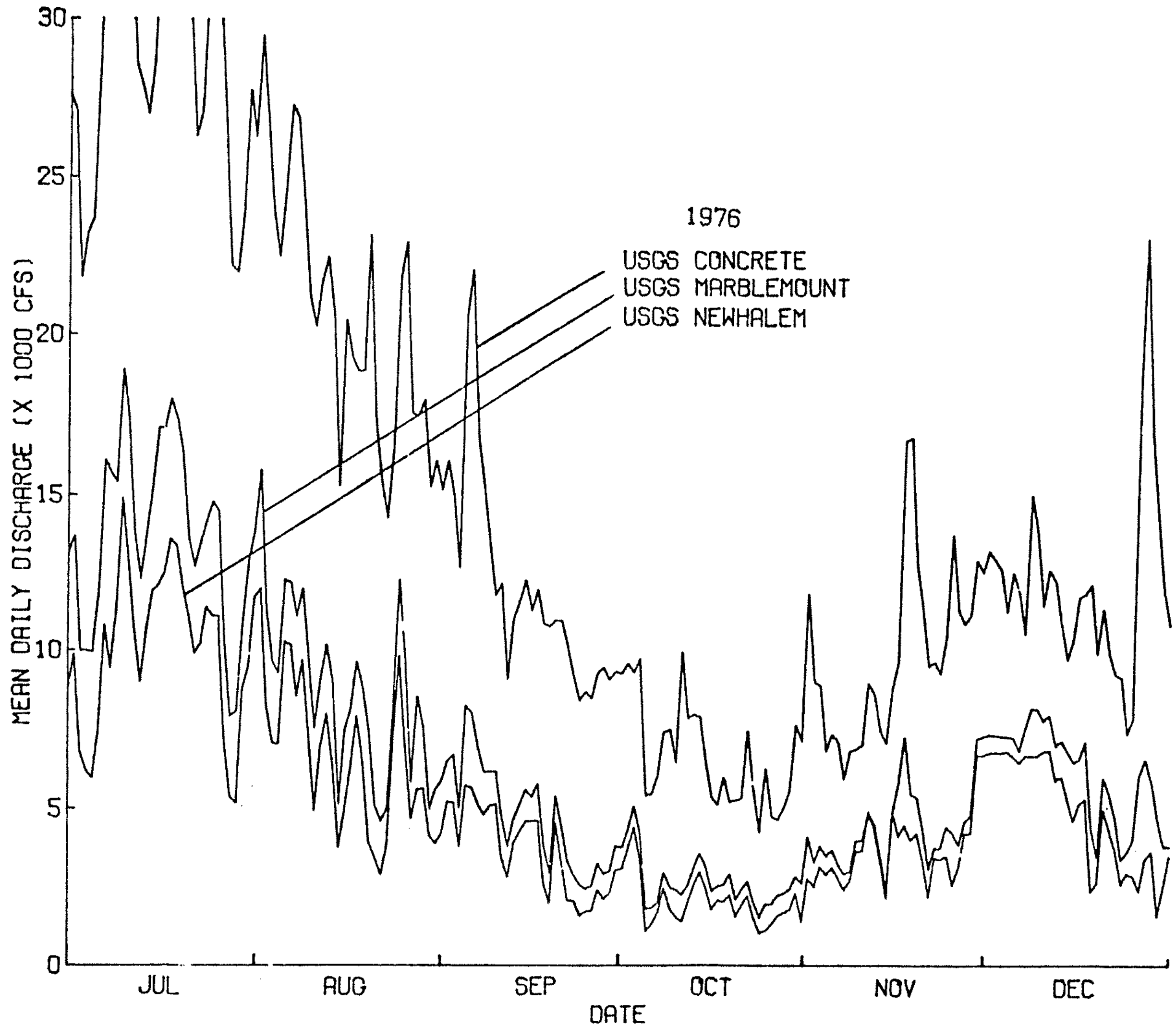

Fig. 6.3 Skagit River hydrographs of mean daily discharge at three gaging sites for the period from July to December 1976 (U.S. Geological Survey 1977).

Table 6.1 Location of Skagit River sample transects by river mile.

Sample transect or prominent feature	River mile
Gorge Powerhouse	94.2
1	92.9
2	91.6
3	90.5
4	89.4
5	88.4
6	86.6
7	85.8
8	84.3
Copper Cr. Dam Site	84.0
9	82.9
10	80.8
11	79.4
Cascade River	78.1
12	77.2
13	74.6
14	72.7
15	70.6
16	68.1
Sauk River	67.0
17	65.8
18	63.8
19	61.2
20	59.3
Baker River	56.5

Reach 4 was the farthest downstream at RM 61.2, 5.8 mi below the mouth of the Sauk River and 4.7 mi above the confluence of the Baker River with the Skagit.

6.3 Materials and Methods

6.3.1 Spawning Depths and Velocities

Depth and velocity were measured over active chinook, pink, and chum salmon and steelhead trout redds according to techniques established by Heiser (1971). Active redds were those with fish present. A Gurley current meter was placed at the upstream lip of each redd 0.5 ft above the bottom. From these measurements, the 80-percent ranges of depth and velocity for spawning Skagit River chinook, pink, and chum salmon and steelhead trout were established by elimination of the highest and lowest 10 percent of the measurements.

6.3.2 Spawner Observations

Timing of spawning for chinook, pink, and chum salmon was investigated by the use of boat surveys to observe spawning fish and redds at regular intervals. Chinook salmon redds within the reference reaches were marked with numbered, large rocks when first observed and were then inspected during subsequent surveys to determine the length of time the redds remained visible.

Aerial photographs were taken during the peak of the Skagit River chinook runs on September 18-19, 1975, and September 21, 1976, to determine spawner distribution between Newhalem and Sauk River. Redds were counted directly from the photographs. During the 1976 chum salmon run, boat surveys were made along the left bank between Newhalem and Sauk River to determine spawner distribution.

An aerial survey was conducted on October 11, 1977, to determine the pink salmon spawning distribution in the mainstem Skagit between Rockport and Newhalem. The portions of the streambed which were utilized for spawning were outlined on aerial photographs. The area of the outlined sections were measured and compiled to determine relative utilization.

Aerial surveys were conducted jointly by Washington Department of Game (WDG) and Fisheries Research Institute (FRI) in 1975, 1976, 1977, and 1978 to determine the number and distribution of steelhead redds in the Skagit and Sauk rivers (mainstems only) and assess the spawning timing.

Observations were conducted during extreme low water periods to determine if chinook redds became exposed and to record the behavior of adult fish over the redds as the water became shallower. The areas chosen for these particular observations were ones in which the active chinook redds lay in unusually shallow water for this species.

Spawner surveys were conducted on foot in Goodell Creek to determine the presence of adult salmon and steelhead trout. Three were done in

1975, one in 1976, and six in 1977. The usual area surveyed in 1976 and 1977 extended from the highway bridge, upstream about 3/8 mi to a large pool. The three surveys made in 1975 and one in 1977 extended an additional 1 to 2 mi upstream of the usual survey area.

6.3.3 Relationships of Spawnable Area to Discharge

Four reference reaches were established for intensive studies. Selection of the reference reaches was based on the two following criteria: 1) Observed salmon spawning activity; and 2) river channel stability, to allow sampling over a range of discharges without major streambed shifting. The reference reaches ranged in length from 600-700 ft and in width from 200-550 ft, depending on location and streamflow. Five transects and a staff gage were located in each reference reach.

A systematic study of river depths and velocities was conducted over a variety of discharges. During a 2-year period, each reference reach was surveyed three to seven times. Sampling was conducted using techniques described by Collings (1974). Between 20 and 30 measurements of depth and velocity were made along each one of the five transects in a reach during each survey. Measurements were made from an 18.5-ft boat operated at the speed of the river current to maintain it in a stationary position. The distance between measurements was kept fairly uniform by two-way radio communication with the shore-based mapping crew using a telescopic alidade.

Velocity measurements were made with a direct readout Gurley current meter at a depth 0.5 ft above the bottom. The current meter was attached to a 30-pound lead weight which was lowered by a cable to a stationary position on the river bottom. River depth at the same point was measured with a graduated steel rod. The locations of all measurements were mapped by plane table methods. If the river level fluctuated more than 0.2 ft during the time a reference reach was surveyed, the data were discarded.

A contour-graphic computer program, SYMAP (Dougenik and Sheehan 1977), was used to map the area of each reference reach over a range of river discharges (Stober and Graybill 1974). Each measurement of depth and velocity along a transect was classified with respect to the 80-percent preferred spawning ranges for each species. The mapped areas that fell within these ranges were designated the estimated spawnable area.

6.3.4 Potential Spawnable Area

Twenty sample transects were established for estimation of the potential spawning area available to chinook, pink, and chum salmon and steelhead trout in the upper Skagit River (Fig. 6.1). These transects provided a systematic sample from which an average river width and spawnable width for the river could be obtained (Curtis 1959). Each transect was divided into sections by the 20-30 measurements of depth and velocity taken along its length. The distance in each section between the two measurements was divided into 1-ft intervals. The depth and velocity measurements on either end of a section were averaged and prorated to each of the 1-foot intervals. Each interval was then classified with respect to the 80-percent preferred spawning ranges of depth and velocity for each salmonid species. Computations were then made of the total spawnable width in feet (Thompson 1972) and the percentage of each transect suitable for spawning.

An estimate of the potential spawnable area available to each salmonid species in the upper Skagit was obtained by multiplying the mean spawnable width for each species by length of the river section in question. The length of river for any given sample transect was defined as the distance from the point midway between the transect and the adjacent upstream transect to the point midway between the transect and the adjacent downstream transect. An estimate of the total wetted area was obtained by multiplying the mean weighted river width by the river length. The mean river width was weighted by the distance around each transect.

Discharge for both sample transect and reference reach surveys was obtained primarily from the three U.S. Geological Survey (USGS) gaging stations at Newhalem, above Alma Creek, and at Marblemount (Fig. 6.1). Except for Sample Transect 1 and Reference Reaches 2 and 3, which were very close to the gaging stations, discharge at all other sites was estimated by taking the flow at the nearest gage and adding to it the discharges of the appropriate major tributaries, depending on the distance downstream. Discharges for ungaged major tributaries were estimated by comparing the size of their drainage basins to the size of similar type drainage basins for gaged streams in the upper Skagit watershed. By multiplying the discharge of the gaged stream by the appropriate drainage basin size ratio, an estimate of the discharge of the ungaged stream was obtained.

In 1975 before the installation of the USGS gaging station at Marblemount, discharges for surveys downstream of Marblemount were measured and computed directly using the standard stream method (Corbett 1962). The gaging station at Marblemount was installed in May 1976 and direct discharge measurements were then no longer required.

6.4 Results and Discussion

6.4.1 Spawning Depths and Velocities

6.4.1.1 Chinook Salmon. Depths and velocities were measured over 436 chinook salmon redds. Depths measured over chinook redds ranged from 0.6-7.1 ft (Fig. 6.4) with a mean of 2.89 ft (SD = 0.99). Velocities ranged from 0.5-4.9 ft/sec (Fig. 6.5) with a mean of 2.72 ft/sec (SD = 0.71). The 80-percent intervals were 1.7-4.2 ft for depth and 1.8-3.7 ft/sec for velocity.

6.4.1.2 Pink Salmon. Depths measured over 347 pink salmon redds ranged from 0.3 to 4.2 ft (Fig. 6.6) with a mean of 1.66 ft (SD = 0.68). Velocities ranged from 0.1 to 4.3 ft/sec (Fig. 6.7) with a mean of

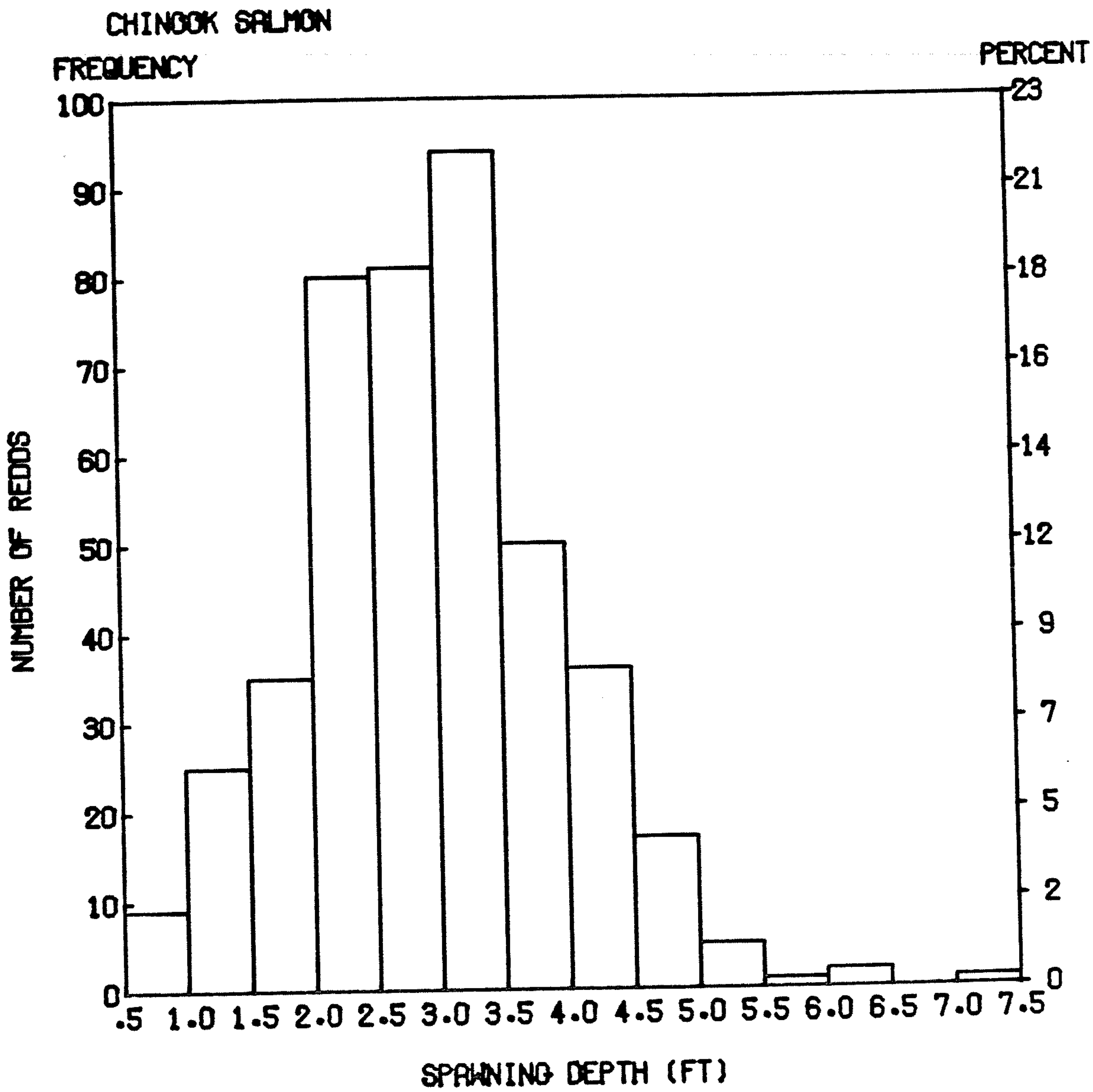

Fig. 6.4 Frequency distribution of chinook salmon spawning depths in the Skagit River measured at 436 redds.

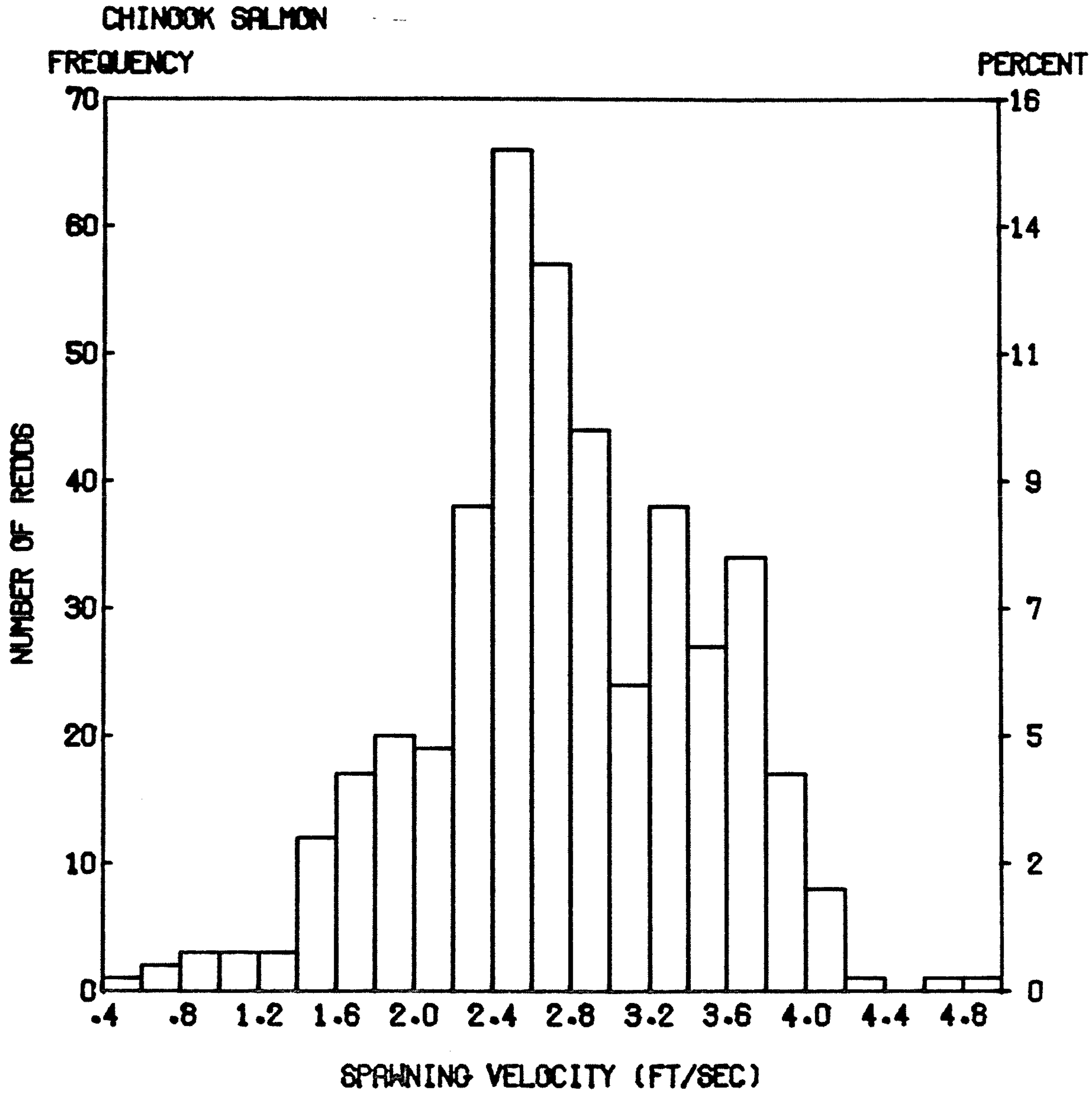

Fig. 6.5 Frequency distribution of chinook salmon spawning velocities in the Skagit River measured at 436 redds.

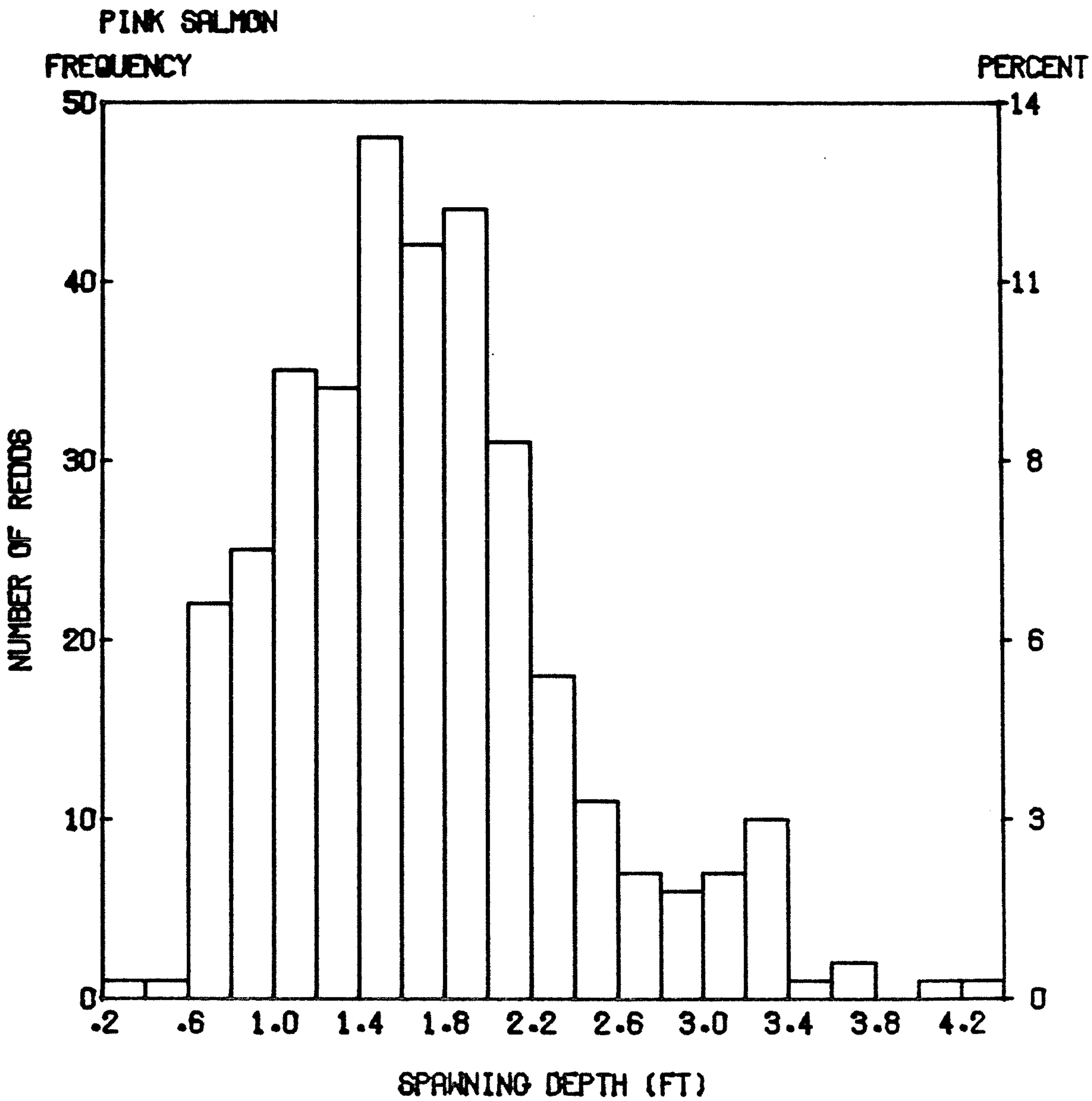

Fig. 6.6 Frequency distribution of pink salmon spawning depths in the Skagit River measured at 347 redds.

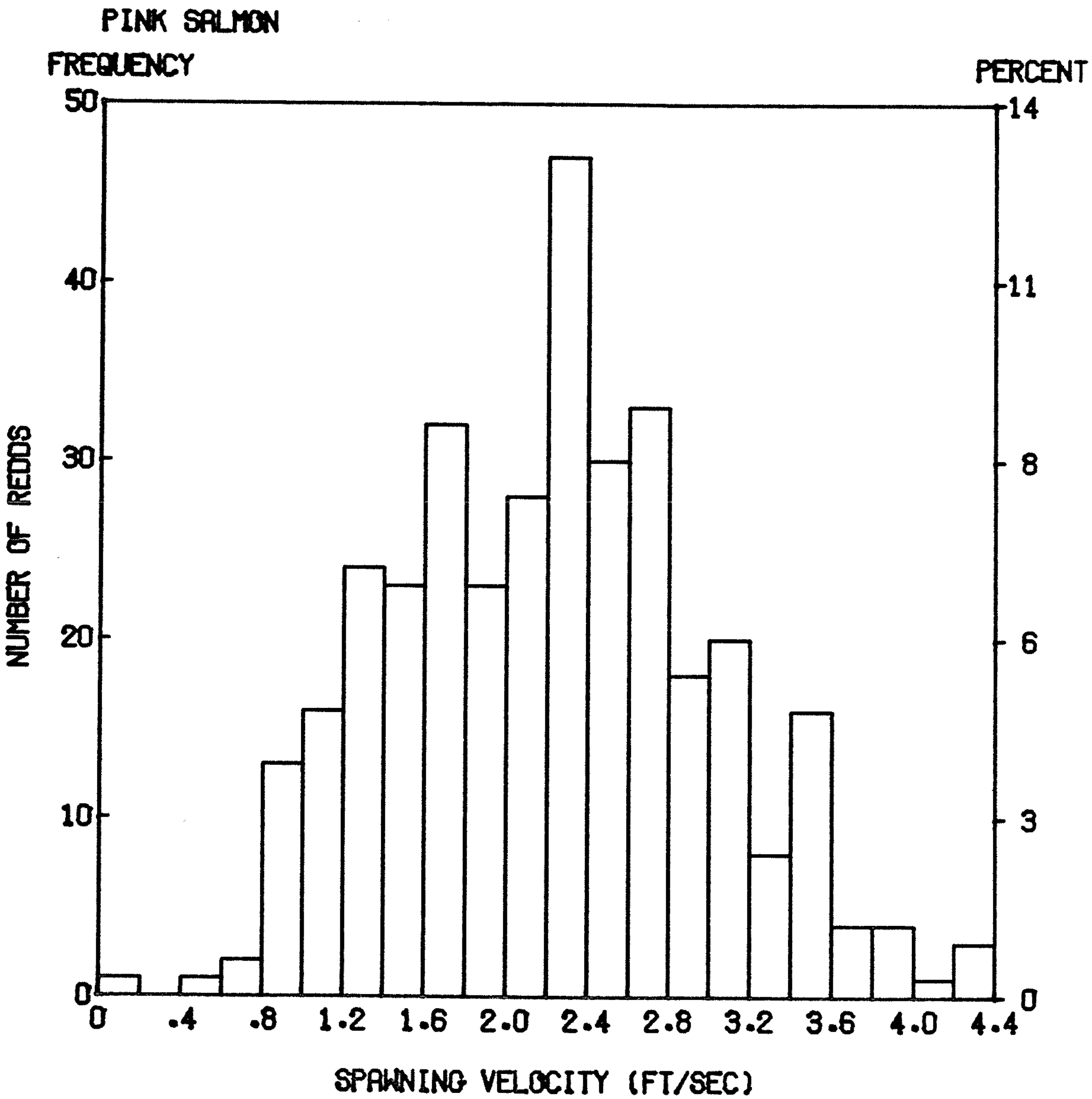

Fig. 6.7 Frequency distribution of pink salmon spawning velocities in the Skagit River measured at 347 redds.

2.18 ft/sec (SD = 0.77). The 80-percent intervals were 0.9 to 2.5 ft for depth and 1.2 to 3.2 ft/sec for velocity.

6.4.1.3 Chum Salmon. Depth measured over 227 chum salmon redds ranged from 0.5 to 6.4 ft (Fig. 6.8) with a mean of 2.69 ft (SD = 1.14). Velocities ranged from 0.0 to 4.0 ft/sec (Fig. 6.9) with a mean of 1.61 ft/sec (SD = 1.01). The 80-percent intervals were 1.4 to 4.4 ft for depth and 0.2 to 3.0 ft/sec for velocity.

6.4.1.4 Steelhead Trout. Depths measured over 164 steelhead trout redds ranged from 0.6 to 4.0 ft (Fig. 6.10) with a mean of 1.80 ft (SD = 0.74). Velocities ranged from 0.7 to 4.3 ft/sec (Fig. 6.11) with a mean of 2.27 ft/sec (SD = 0.66). The 80-percent intervals were 0.9 to 2.9 ft for depth and 1.5 to 3.0 ft/sec for velocity.

6.4.1.5 Comparison to Literature Values. Depth and velocity ranges preferred by spawning salmon and steelhead trout are compared in Table 6.2. The ranges listed for salmon without specific river citations are mean figures from streams usually considerably smaller than the Skagit (Chambers et al. 1955, Heiser 1971). Skagit River chinook and pink salmon appeared to spawn in both deeper and faster water than the same species in most smaller streams. Depth seemed to be the less critical of the two criteria.

The velocity range for Skagit River chum salmon compared favorably with those values obtained by Heiser (1971) (Table 6.2). However, the chum salmon depth range, 1.4-4.4 ft, was higher and wider than the range in the literature. On November 29, 1976, the discharge at Gorge Powerhouse was raised abruptly from the November mean discharge of 3,692 cfs, and the mean discharge for the first 2 weeks of December was then sustained at around 6,500 cfs (Fig. 6.3). The majority of chum salmon redd measurements utilized in this study were taken during the first few days of December. Depths and velocities measured over many of these redds may have been unnaturally high if the redds were actually constructed earlier at lower discharges.

The depth and velocity ranges for Skagit River steelhead trout were similar to those reported by Hunter 1973 (Table 6.2). Other velocity ranges reported by Hooper 1973, Smith 1973, and Thompson 1972 were also similar to that determined for Skagit steelhead while these authors listed only a single figure (usually a minimum) for the depth criterion.

6.4.2 Timing of Spawning

6.4.2.1 Chinook Salmon. Chinook salmon in 1975 were first observed at Reference Reach 2 on August 29 (Fig. 6.12). No spawning of chinook salmon (or any other species) was observed in Reference Reach 4 which was the farthest downstream reach. Visibility there was often limited by the turbidity of the water due to the input of the Sauk River which joined the Skagit 5.8 mi upstream. In spite of this, visibility improved enough upon occasion to confirm the absence of any fish or redds.

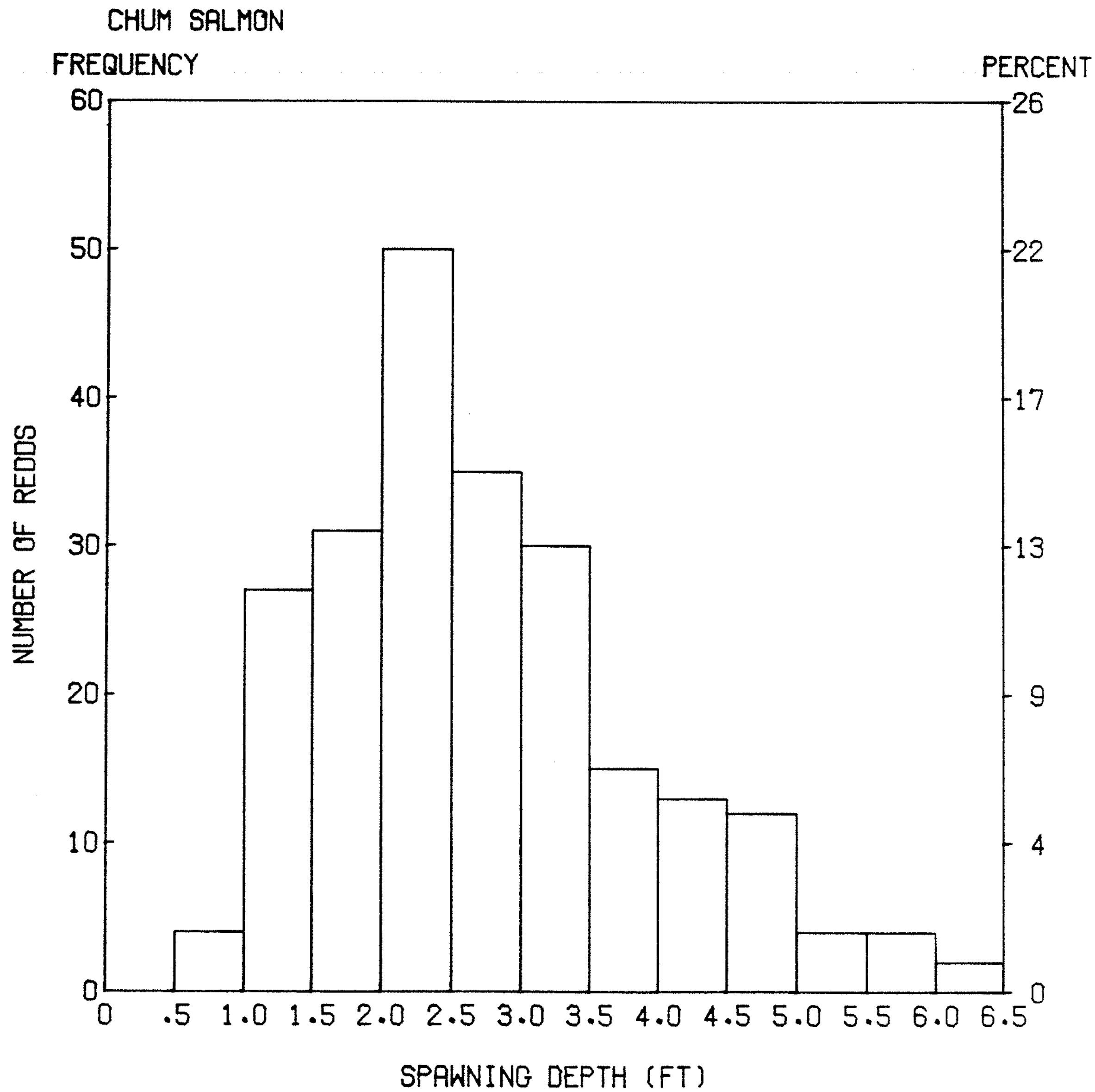

Fig. 6.8 Frequency distribution of chum salmon spawning depths in the Skagit River measured at 227 redds.

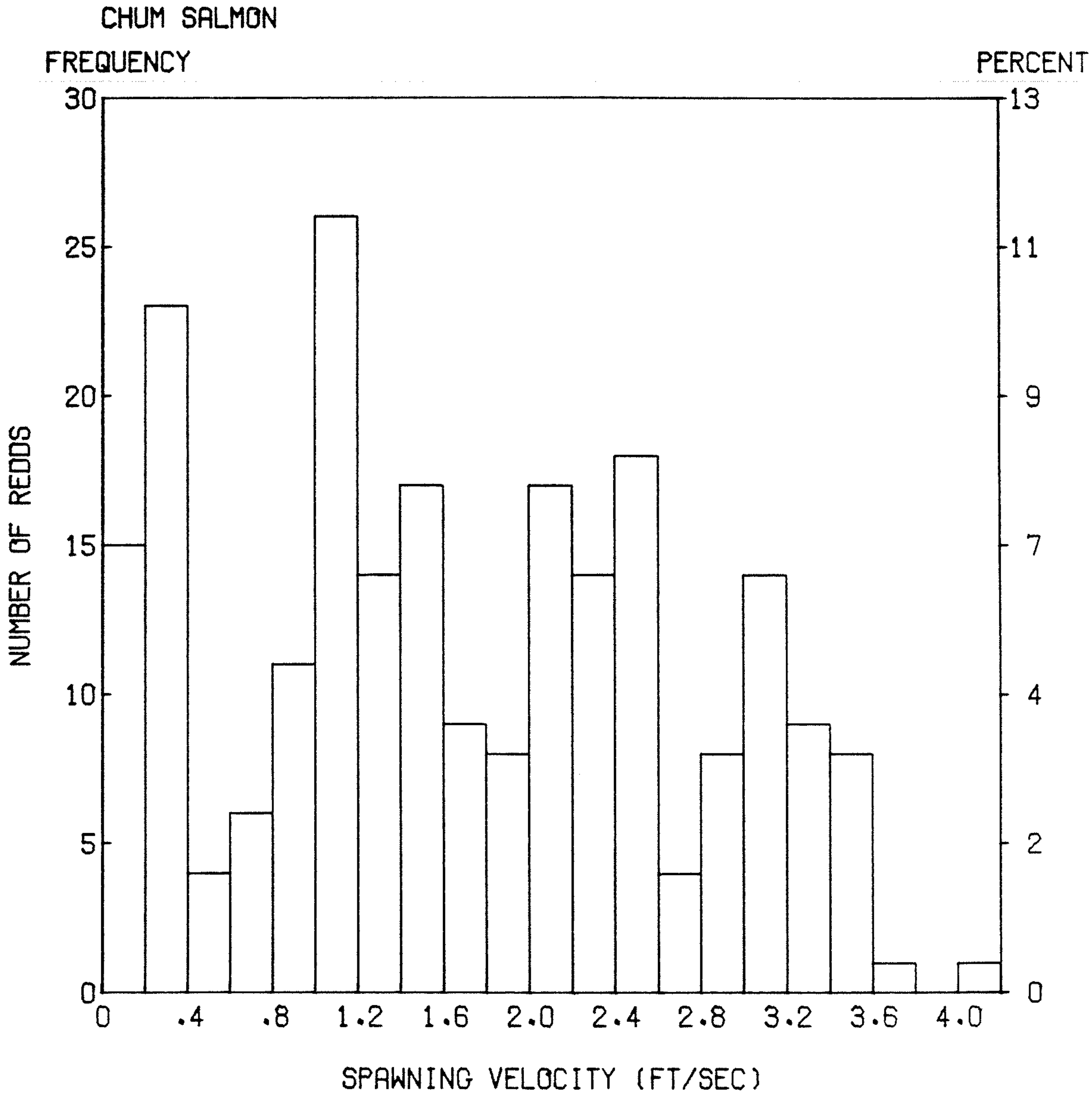

Fig. 6.9 Frequency distribution of chum salmon spawning velocities in the Skagit River measured at 227 redds.

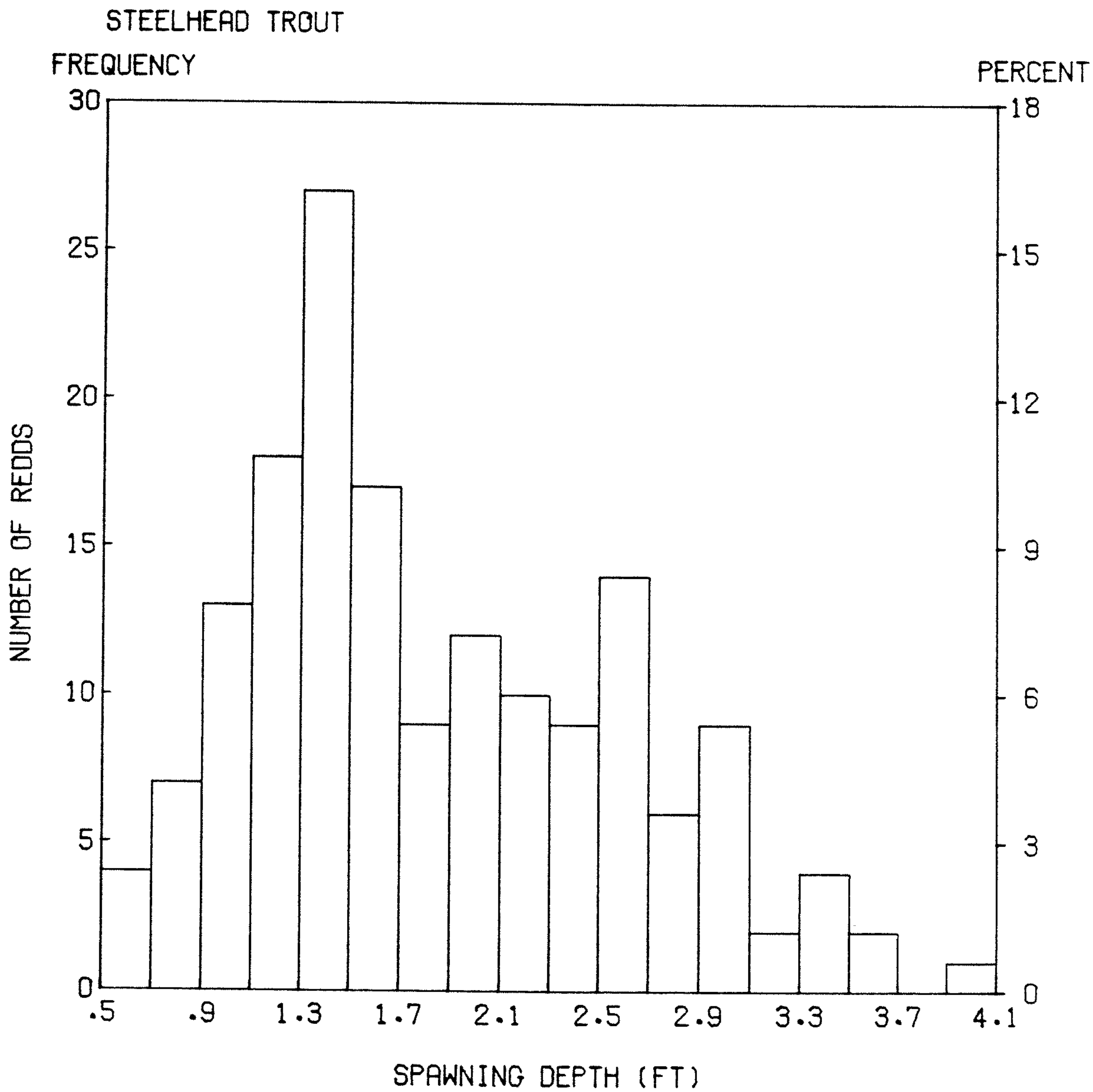

Fig. 6.10 Frequency distribution of steelhead trout spawning depths in the Skagit River measured at 164 redds.

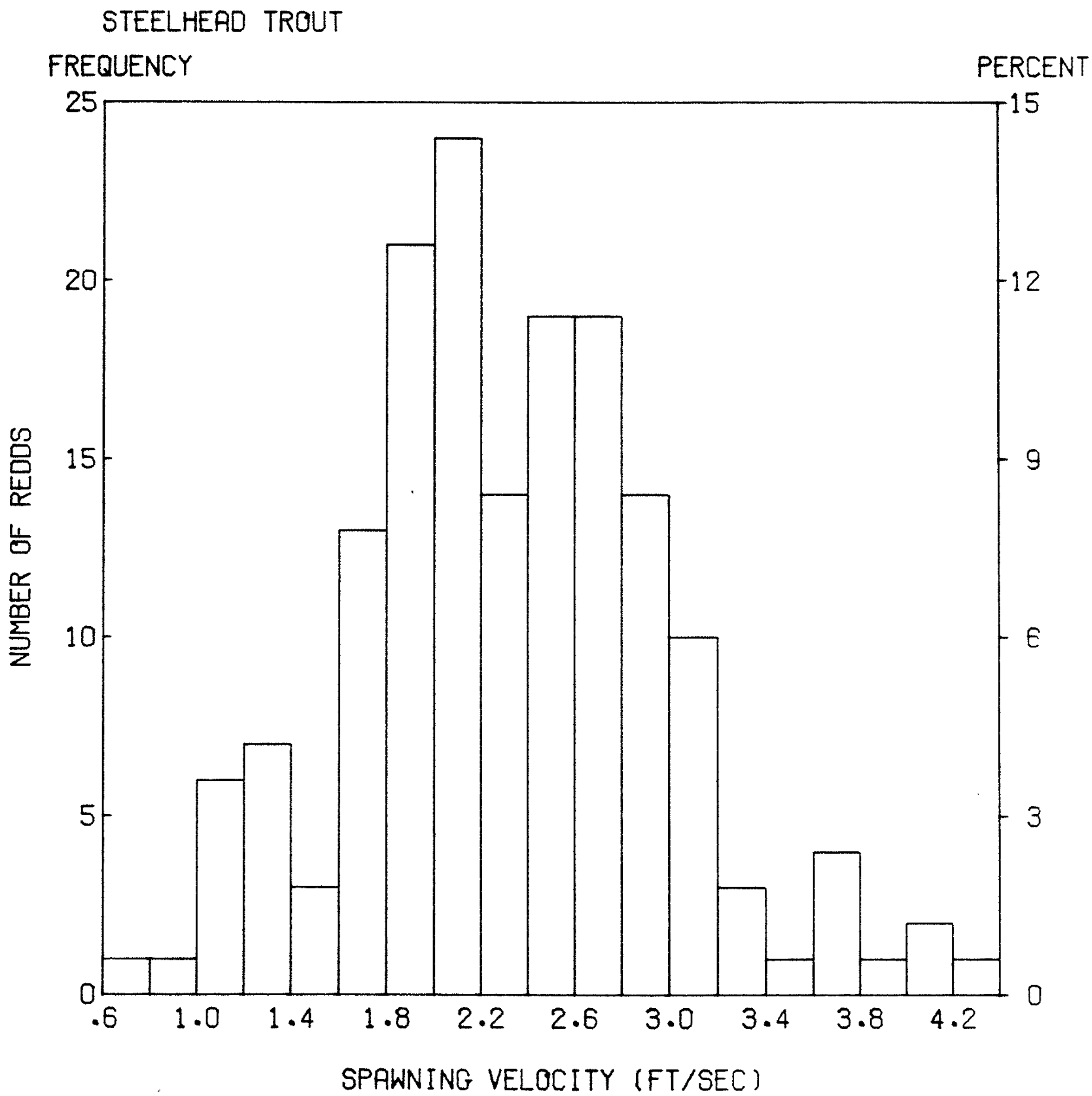

Fig. 6.11 Frequency distribution of steelhead trout spawning velocities in the Skagit River measured at 164 redds.

Table 6.2 Depth and velocity criteria for depths and velocities preferred by spawning salmon and trout including the 80% ranges for Skagit River chinook, pink, and chum salmon, and steelhead trout.

Salmon and trout species	Depth (ft)	Velocity (ft/sec)
Chinook		
Skagit River	1.7-4.2	1.8-3.7
Fall chinook[1]		
Columbia River	4.00-6.50	2.75-3.75
Spring chinook[1]		
Cowlitz River	1.00-3.50	1.0-1.75
Chinook[1]	1.0-1.75	1.0-2.25
Pink		
Skagit River	0.9-2.5	1.2-3.2
Pink[2]	0.53-1.75	0.85-3.30
Chum		
Skagit River	1.4-4.4	0.2-3.0
Chum[2]	0.44-1.63	0.3-2.9
Steelhead		
Skagit River	0.9-2.9	1.5-3.0
Steelhead[3]	0.4-2.3	1.2-3.57

[1] Chambers, Allen, and Pressey (1955).

[2] Heiser (1971).

[3] Hunter (1973).

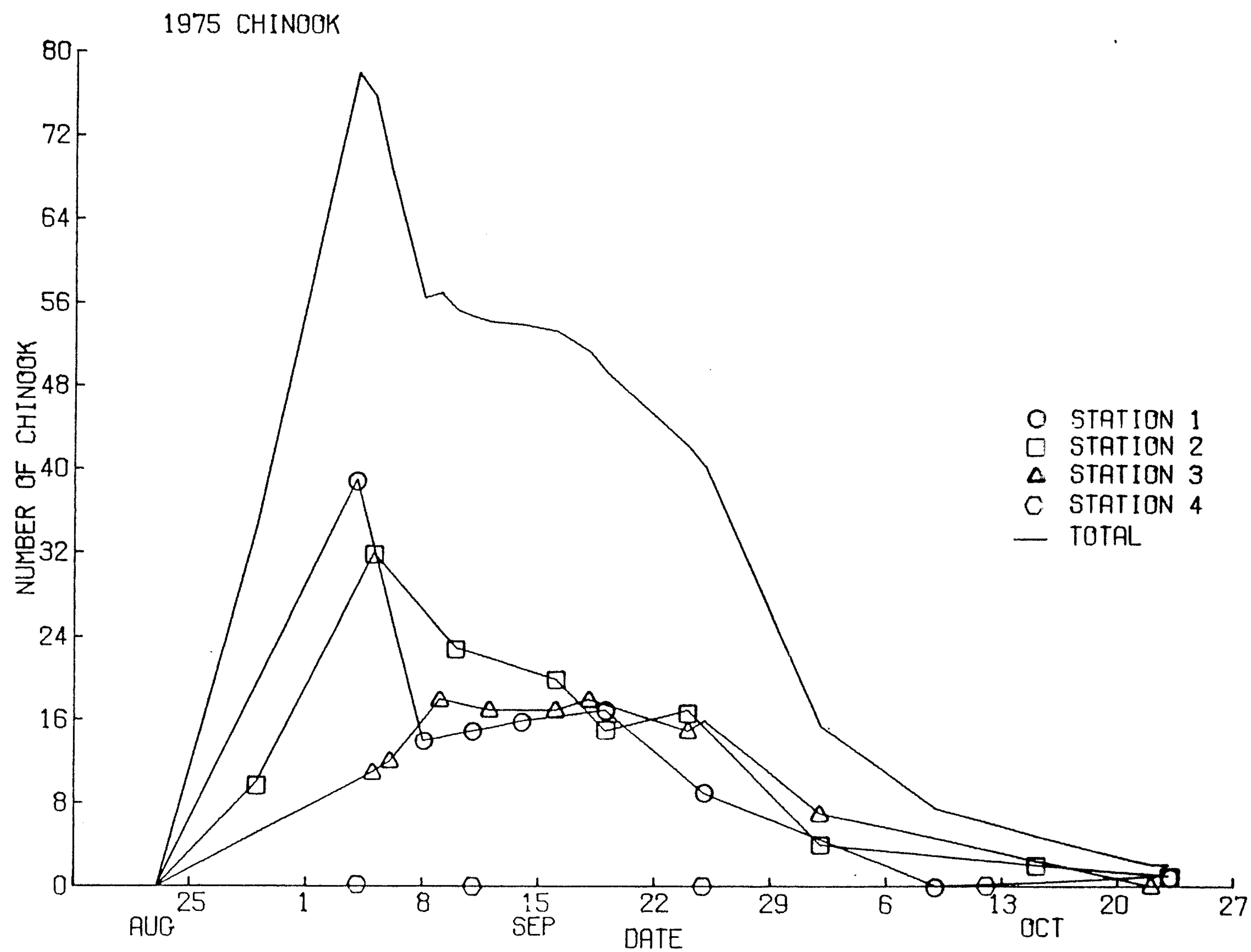

Fig. 6.12 Numbers of chinook salmon observed in the reference reaches cver the 1975 spawning season.

The spawning trend observed in Reference Reaches 1-3 was one in which the maximum spawner utilization progressed downstream with the season (Fig. 6.12). The later timing of spawner utilization at Reference Reach 3 may be due in part to the influence of adults destined for the Marblemount Hatchery which may "stray" and spawn in the mainstem Skagit. Because of the proximity of the two sites and because of WDF's emphasis through 1973 (Table 5.1) to produce "fall" chinook which may spawn later than native populations, a later spawning timing might be expected at Reference Reach 3. A curve representing the combined observations on all three reaches indicated that the peak spawning activity occurred on September 4. After about the third week in September, the numbers of chinook salmon observed in the reference reaches declined rapidly, but small numbers of fish were seen as late as October 23.

Chinook salmon in 1976 were first observed at Reference Reach 1 on August 27 (Fig. 6.13). A curve representing the combined observations on all three reaches indicated that the peak spawning activity occurred on September 10, 6 days later than the 1975 chinook salmon peak. Fish were seen until October 29, 1976, 6 days later than the last fish were seen in 1975. Except for this approximate 1-week time displacement, both the combined 1975 and 1976 reference reach observations showed very similar patterns in the total number and timing of spawning chinook salmon.

In 1976, along with fish counts, the number of chinook redds was observed on each reference reach survey. The maximum number of redds observed was on September 21-22 when 92 were seen (Fig. 6.14). New redds were marked with numbered, large rocks to differentiate them from the older ones. The number of new redds seen was divided by the number of days since the last survey (usually 3 or 4), and the result was the number of new redds constructed per day. Figure 6.14 shows the rate of redd construction over the entire spawning season. As would be expected, the number of new redds per day in 1976 appeared correlated with the number of chinook salmon seen in the reference reaches. The maximum number of new chinook redds constructed per day was on September 8-10, and the total number of chinook salmon observed was highest at about the same time on September 10 (Figs. 6.13 and 6.14).

After new chinook redds were initially observed and marked, they were reinspected every 3 to 4 days to determine the length of time they remained visible. The mean number of days before invisibility for 168 redds over two spawning seasons was 25.9 days.

Observations of chinook salmon spawning activity during 1977 were severely hampered by the excess turbidity of the water. The visibility was monitored through much of the spawning season by use of a Secchi disk. Table 6.3 shows the increasing visibility as the spawning season progressed. Redd visibility was considered adequate after September 22. It should be noted that redd visibility was considerably less than Secchi disk visibility and conditions for spawning observations were poorer in 1977 than in previous years.

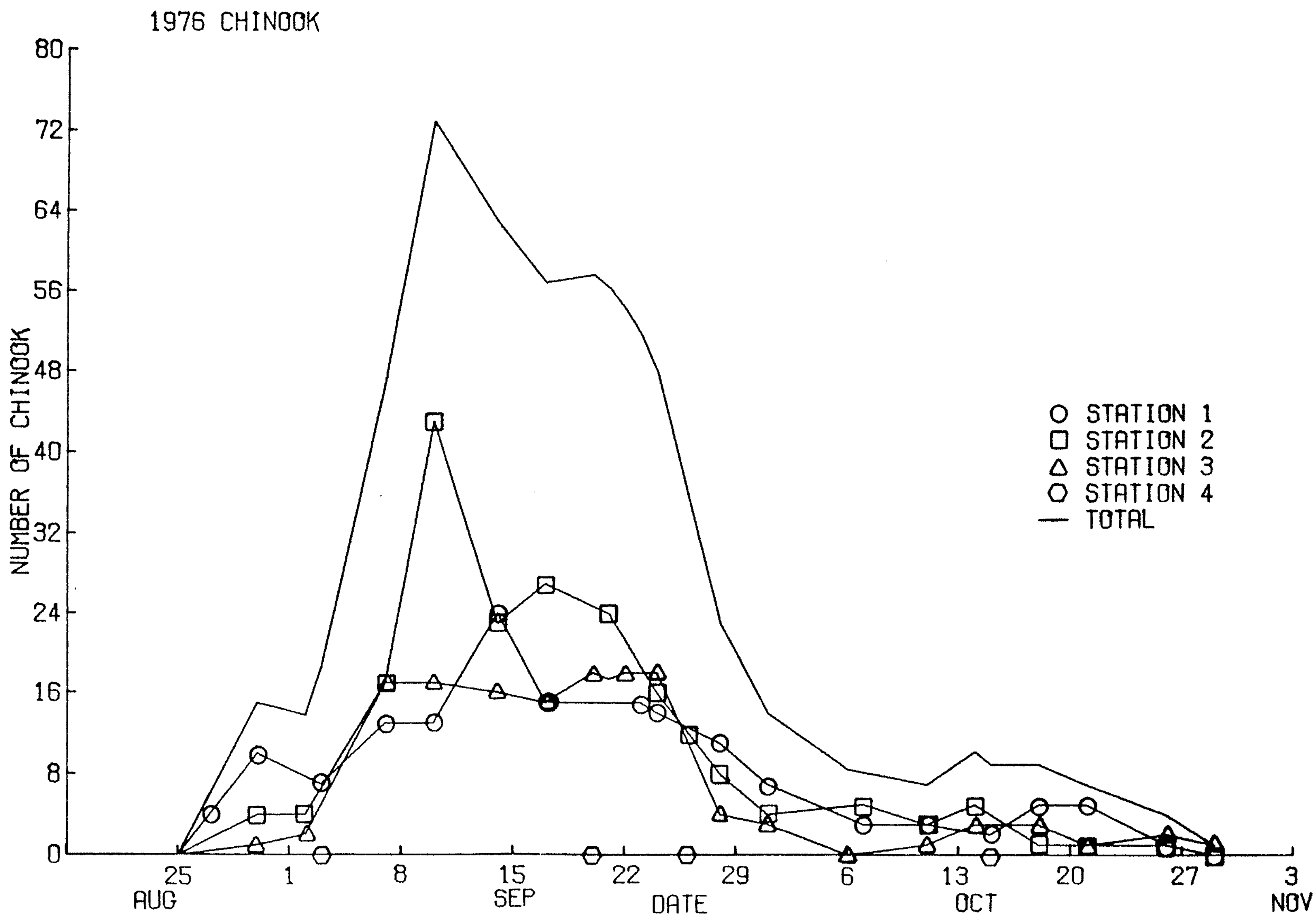

Fig. 6.13 Numbers of chinook salmon observed in the reference reaches over the 1976 spawning season.

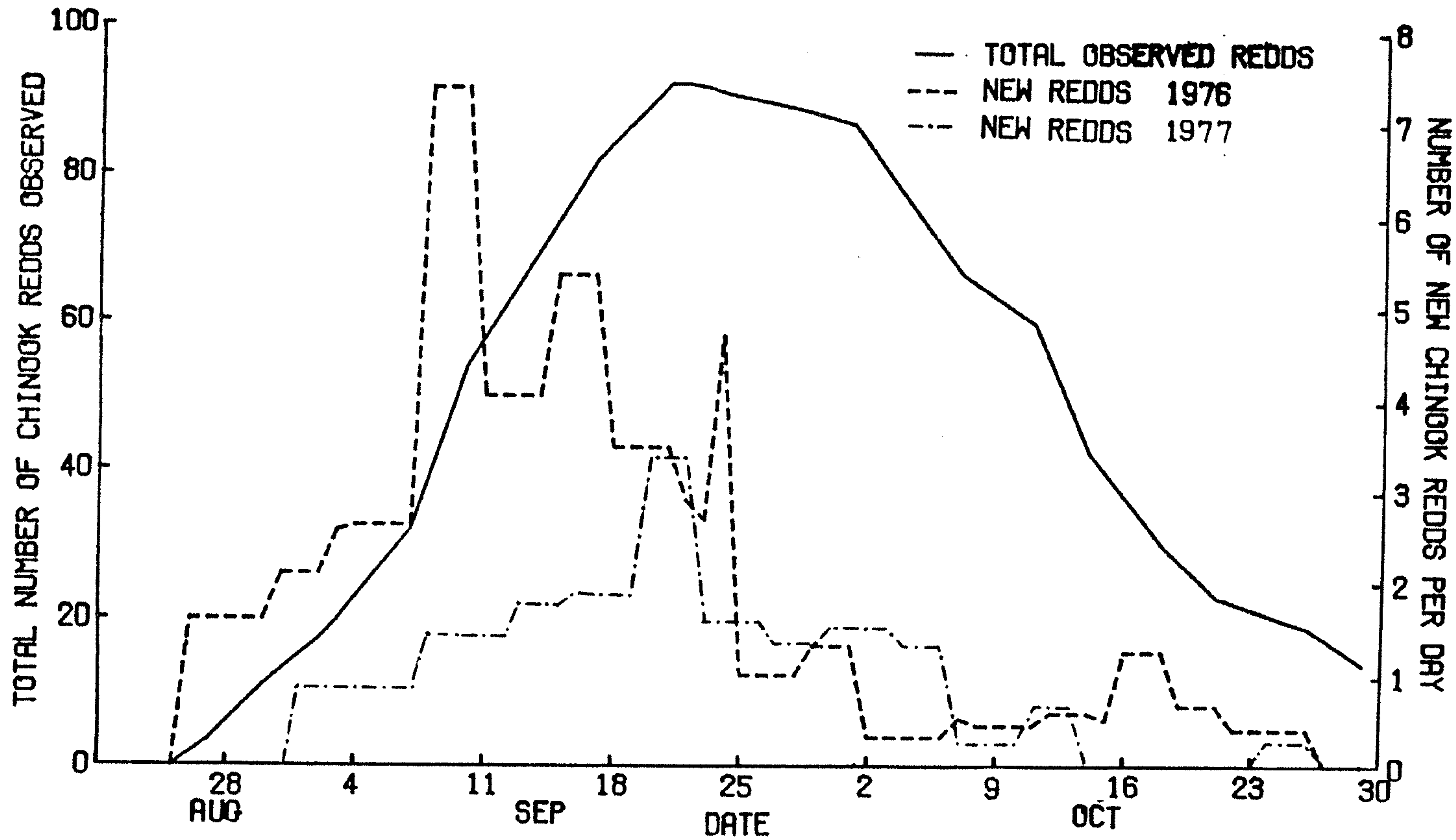

Fig. 6.14 Numbers of chinook salmon redds observed per day in 1976 and numbers of new redds constructed per day in the reference reaches over the 1976 and 1977 spawning season.

Table 6.3 Secchi disk readings (in inches) at three study locations in the Skagit River, 1977.

Date	Location		
	Newhalem	Talc Mine	Marblemount
1977			
8-31	40	-	45
9-7	54	47	48
9-12	56	57	56
9-15	60	68	71
9-19	66	72	78
9-22	92	88	>84*
9-26	readings not taken		
9-29	108	114	-*

* Secchi disk visible at deepest area found.

Under these poor visibility conditions chinook salmon redds in 1977 were first observed at Reference Reach 1 on September 7 when six were counted. The number of new redds per day (Fig. 6.14) increased only gradually from first sighting to September 22, 1977, in sharp contrast to the pattern for 1976 (Fig. 6.14). After September 22 the patterns for the 2 years were more similar. The last new redd was observed on October 26. The observed pattern for 1977 was most likely the result of visibility conditions and probably did not indicate a shift in the spawning timing.

WDF salmon spawning ground records back to 1952 were examined and while the data were incomplete, no evidence could be found that the spawning pattern and timing for Skagit chinooks have undergone a change.

6.4.2.2 Pink Salmon. In 1975 pink salmon spawned in all reference reaches except Reference Reach 4. Reference Reach 1 was very heavily spawned, with an estimated 1,428 fish observed on October 9 (Fig. 6.15). Many of the older chinook salmon redds in the reach were obliterated from view by this intensive spawning of pink salmon in 1975. In comparison, Reference Reaches 2 and 3 were utilized by considerably fewer fish, with a maximum number of 62 and 9, respectively. Pink salmon were observed in the reference reaches from September 24 until October 23.

In 1977 pink salmon spawned in Reference Reaches 1-3. As in 1975, Reference Reach 1 was heavily utilized with an estimated 1,816 fish observed on October 6 (Fig. 6.16). In Reference Reaches 2 and 3, the maximum numbers observed were 107 on October 6 and 14 on October 3, respectively. Fish were observed in the reference reaches as early as September 12, but counts were not made until September 26 because of poor visibility. Pink salmon were observed in the references reaches until October 26.

6.4.2.3 Chum Salmon. Of the four reference reaches chum salmon spawned only in Reference Reach 3 near Marblemount. Major flooding during the first part of December 1975 (Fig. 6.2) made it difficult to observe chum redds. When the river finally cleared up by December 12, many of the chum salmon appeared to be in poor physical condition and dead fish were observed, whereas few had been seen before the flood. It was not known whether fish spawned during the flood but very few redds were found afterward.

In 1976 most of the spawning at Reference Reach 3 was concentrated in a side channel. The first chum salmon were observed on November 23 (Fig. 6.17). Before then, fish in low numbers were seen in other parts of the river as early as the first week of November. In the side channel the highest counts of the season occurred on December 1, 8, and 15, when 111, 147, and 117 chum salmon were counted, respectively. These side channel counts, combined with other observations, seemed to indicate a 1976 chum spawning season of approximately 2 months' duration. It ran from early November until late December, with the heaviest spawning taking place during the first 2 weeks of December (Fig. 6.17).

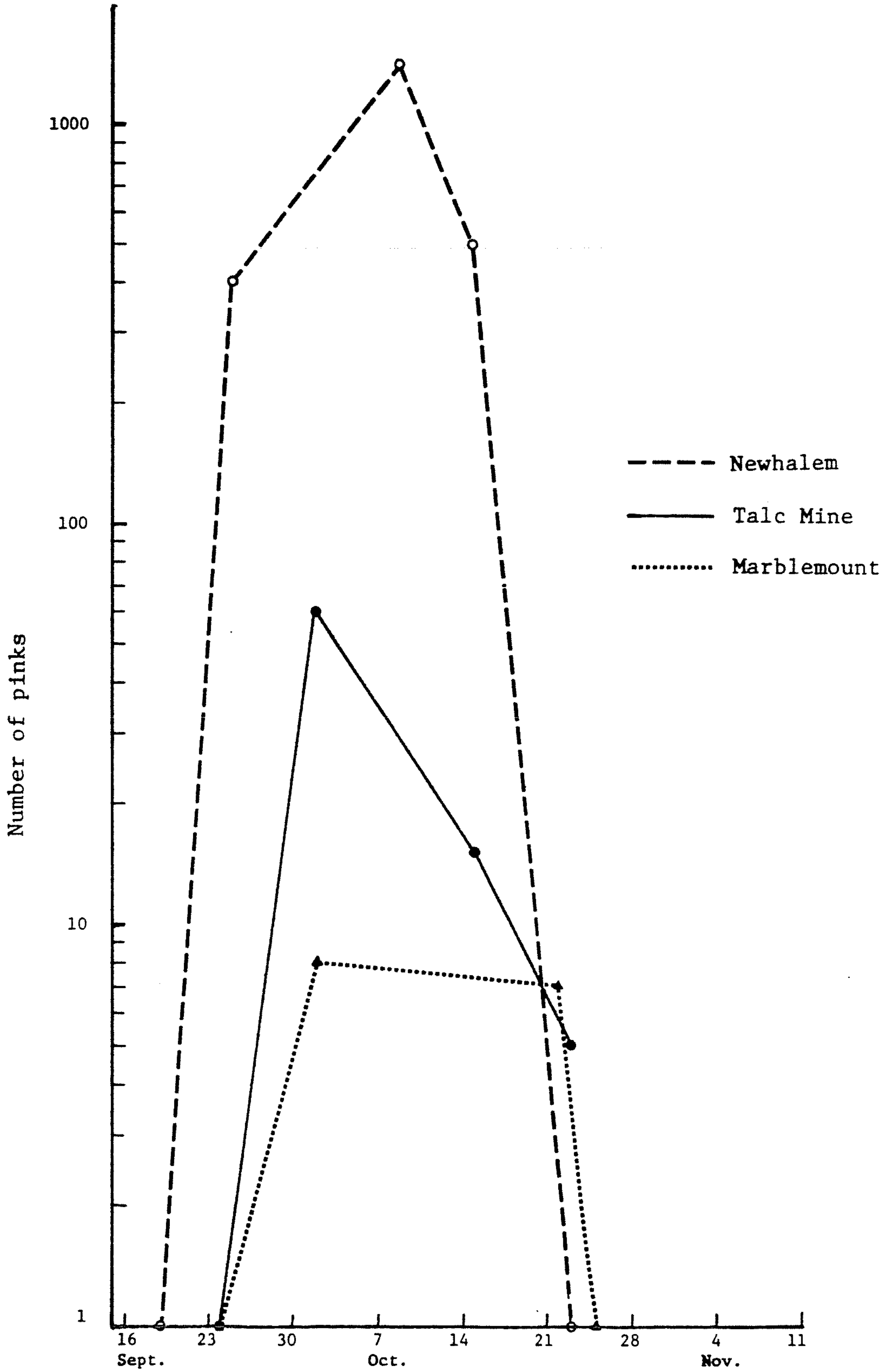

Fig. 6.15 Pink salmon counts in 1975 at three reference reaches on the Skagit River.

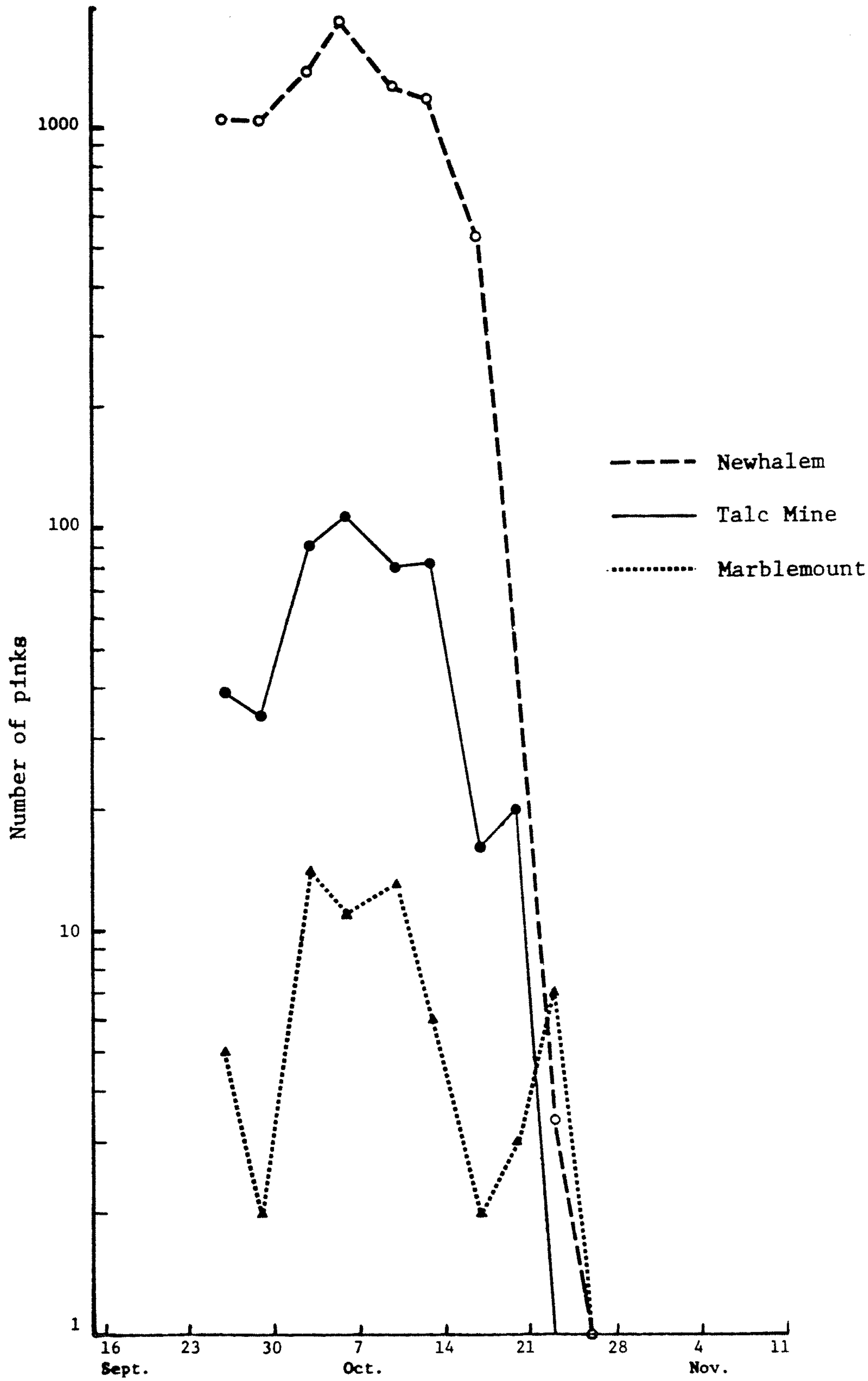

Fig. 6.16 Pink salmon counts in 1977 at three references reaches on the Skagit River.

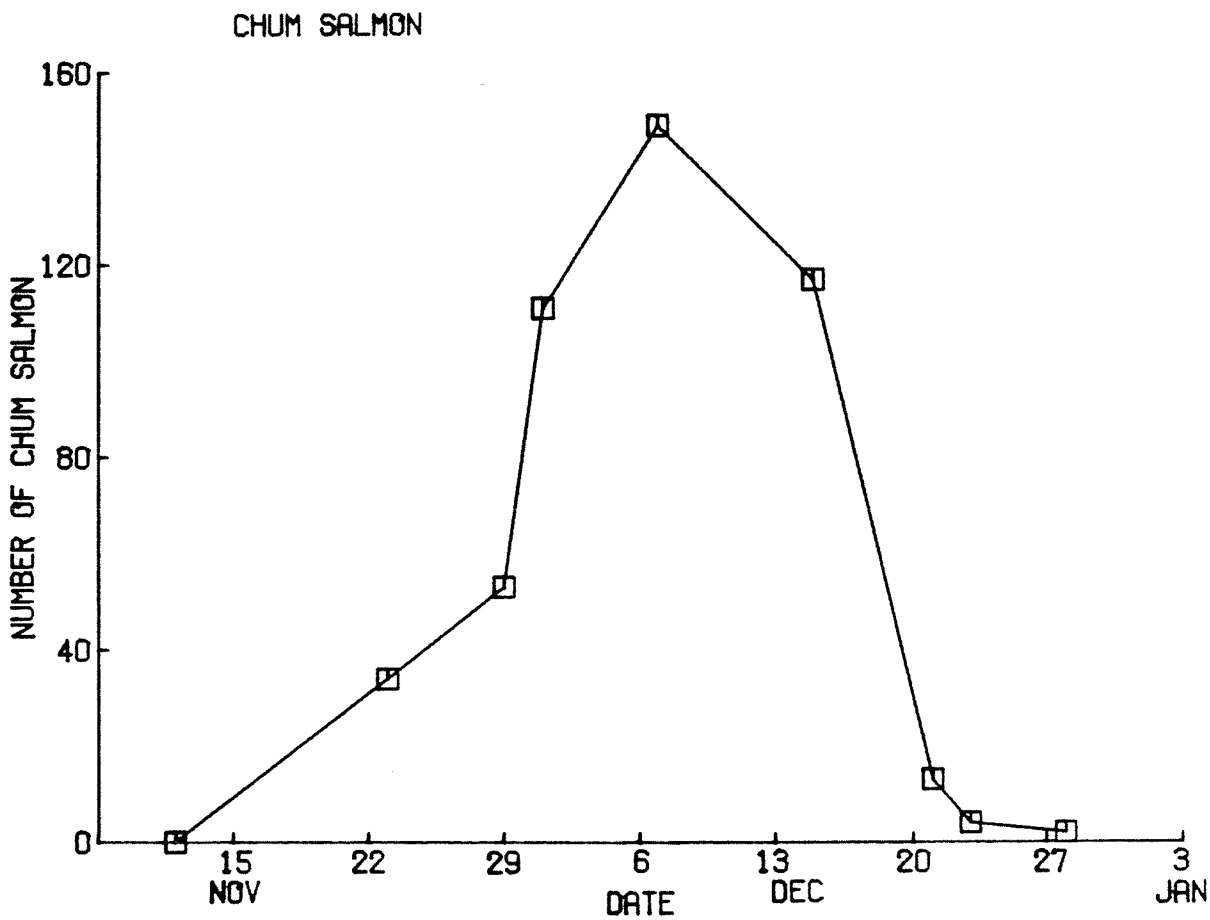

Fig. 6.17 Numbers of chum salmon observed in the Marblemount side channel over the 1976 spawning season.

6.4.2.4 Coho Salmon. Coho spawning in some areas of the Skagit River system commences as early as mid-October with many areas containing actively spawning fish until mid-January (Williams et al. 1975).

6.4.2.5 Steelhead Trout. Aerial surveys were conducted during the 1975 to 1978 steelhead spawning seasons for the Skagit and Sauk rivers by WDG (Gary Engman and Tony Oppermann, personal communication) in cooperation with Seattle City Light (SCL) and FRI for part of that time. Steelhead redd counts from these surveys are summarized in Table 6.4.

Peak numbers of redds were observed on April 18, 1975; April 29, 1976; May 19, 1977; and May 18, 1978 in the mainstem Skagit River from Sedro Woolley to Newhalem, with redd counts of 178, 54, 234, and 337, respectively. The later peak which occurred in 1977 and 1978 possibly resulted from either the prolonged clear water conditions in those years, resulting in improved visibility later than usual into the seasons, or the early closure of the fishing season in both years which may have allowed higher escapement levels for the later segments of the runs.

During 1975 and 1976 the peak counts in the Sauk River occurred later than peak counts in the Skagit while in 1977 and 1978 the peak counts coincided. However, subsequent surveys were not conducted in 1977 (Table 6.4). The spawning timing of Skagit River steelhead may be advanced over Sauk River steelhead by the releases of smolts from the Barnaby Slough rearing facility which are derived from an earlier spawning stock of steelhead from Chambers Creek. This trend was not present in 1978, however. The effect on spawning timing of warmer water temperature (Fig. 2.29) experienced by 1977 spawners in the Skagit River is unknown.

6.4.3 Spawner Distribution

6.4.3.1 Chinook Salmon. Based on WDF data for 1973 to 1976 (Ames and Phinney 1977), estimated spawning escapement of chinook salmon to the mainstem Skagit averaged 78.2 percent of the total estimated Skagit Basin escapement, with the remainder distributed among the mainstem Sauk River (13.6 percent), Cascade River (3.8 percent), other tributaries (2.7 percent), and Baker River (1.7 percent). Of the mainstem Skagit escapement, an average 66.4 percent was attributed to the river section upstream of the Sauk River, and 33.6 percent downstream.

Aerial photographs were taken of the Skagit River between Newhalem and the Sauk River shortly after the peak of the chinook salmon runs in 1975, on September 18-19, and in 1976, on September 21, so as to maximize the number of redds photographed. Photographs were not taken of the Skagit River below the Sauk because of the turbidity.

A summary of the chinook salmon redd counts made from aerial photographs is presented in Table 6.5. Between Newhalem and the Sauk River in 1975 and 1976, totals of 990 and 1,143 redds, respectively, were counted. The 2.6-mi section between Diobsud Creek and the Cascade River accounted for over 25 percent of the total chinook spawning between Newhalem and the Sauk (Table 6.5) while it comprised 9.6 percent of the

Table 6.4 Summary of steelhead trout redd counts from aerial surveys of mainstem Skagit and Sauk rivers, 1975-1978 (WDG).

		STEELHEAD REDD COUNTS - 1975 and 1976 (WDG)						
		1975				1976		
		3-28	4-18	5-9	6-18	4-29	5-18	6-3
SKAGIT RIVER								
River section								
Newhalem to Bacon Creek	(11.3 mi)	1	1	2	0	0	0	6
Bacon Creek to Cascade River	(4.8 mi)	3	35	5	7	2	11	11
Cascade River to Sauk River	(11.1 mi)	7	89	61	4	21	12	12
Sauk River to Baker River	(10.5 mi)	4	15	18	(b)	9	3	4
Baker River to Sedro Woolley	(33.7 mi)	1	38	58	(b)	22	8	5
Sedro Wooley to Mt. Vernon	(11.4 mi)	0	(a)	0	(b)	(a)	(a)	(a)
Total	(82.8 mi)	16	178(c)	144	11	54(c)	34	38
SAUK RIVER								
River section								
Mouth to Suiattle River	(13.2 mi)	8	26	31	(b)	19	17	14
Suiattle River to Darrington Bridge	(8.2 mi)	6	32	48	(b)	1(d)	37	10
Darrington Bridge to White Chuck River	(10.5 mi)	19	7	21	(b)	(a)	5	8
White Chuck River to Sauk River forks	(7.8 mi)	4	6	1	(b)	(a)	(b)	0
Sauk River forks to North Fork falls	(1.4 mi)	(a)	0	0	(b)	(a)	(b)	(a)
Total	(41.1 mi)	37	71	101(c)	(b)	20	59(c)	32

Table 6.4 Summary of steelhead trout redd counts from aerial surveys of mainstem Skagit and Sauk rivers, 1977-1978 (WDG) - continued.

		STEELHEAD REDD COUNTS - 1977 and 1978 (WDG)								
		1977			1978					
		4-1	4-20	5-19	3-20	4-6	4-24	5-18	6-1	6-19
SKAGIT RIVER										
River section										
Newhalem to Bacon Creek	(11.3 mi)	1	2	8	4(e)	3(e)	8	1	3(d)	(b)
Bacon Creek to Cascade River	(4.8 mi)	3	6	45	3(f)	7(f)	4	18	30	1(d)
Cascade River to Sauk River	(11.1 mi)	22	38	83	13	16	18	86	86	11
Sauk River to Baker River	(10.5 mi)	8	13	32	18	33	35	54	43	4
Baker River to Sedro Woolley	(33.7 mi)	17	50	66	60	37	53	178	146	27
Sedro Woolley to Mt. Vernon	(11.4 mi)	4	2	0	(a)	(a)	(a)	4	1	0
Total	(82.8 mi)	55	111	234(c)	98	96	118	341(c)	309	43
SAUK RIVER										
River section										
Mouth to Suiattle River	(13.2 mi)	5	15	70	10	6	11	74	38	(b)
Suiattle River to Darrington Bridge	(8.2 mi)	2	23	115	13	22	50	70	61	(b)
Darrington Bridge to White Chuck River	(10.5 mi)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(b)
White Chuck River to Sauk River forks	(7.8 mi)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(b)
Sauk River forks to North Forks falls	(1.4 mi)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(b)
Total	(41.4 mi)	7	38	185(c)	23	28	61	144(c)	99	(b)

(a) No count.
(b) Too turbid to count.
(c) Peak count.
(d) Incomplete count.
(e) Newhalem to Alma Creek (9.0 mi).
(f) Alma Creek to Cascade River (7.1 mi).

Table 6.5 Chinook salmon redd counts from aerial photographs of the Skagit River from Newhalem to the Sauk River.
[Photographs taken on September 18-19, 1975 and September 21, 1976]

River section	Number of redds 1975	Number of redds 1976	Percent of total redds 1975	Percent of total redds 1976	River miles	Percent of total river miles
Newhalem to County Line	186	171	18.8	14.9	4.8	17.6
County Line to Copper Creek Dam Site	105	121	10.6	10.6	5.4	19.9
SUBTOTAL (NEWHALEM TO COPPER CREEK DAM SITE)	291	292	29.4	25.5	10.2	37.5
Copper Creek Dam Site to Bacon Creek	23	38	2.3	3.3	1.1	4.0
Bacon Creek to Diobsud Creek	73	182	7.4	15.9	2.2	8.1
Diobsud Creek to Cascade River	253	304	25.6	26.6	2.6	9.6
Cascade River to Corkindale Creek	79	68	8.0	5.9	4.0	14.7
Corkindale Creek to Illabot Creek	55	59	5.5	5.2	2.5	9.2
Illabot Creek to Sauk River	216	200	21.8	17.5	4.6	16.9
SUBTOTAL (COPPER CREEK DAM SITE TO SAUK RIVER)	699	851	70.6	74.4	17.0	62.5
TOTAL (NEWHALEM TO SAUK RIVER)	990	1143	100	100	27.2	100

river length. Another important area during 1976 was the river section between Bacon and Diobsud creeks where in 2.2 river miles 15.9 percent of the 1976 total redds were counted. In 1975, however, only 7.4 percent of the total spawning occurred in this area.

Of the mainstem chinook spawning above the Sauk, 29.4 percent in 1975 and 25.5 percent in 1976 (or 27.5 percent combined) occurred in the area that would be affected by the Copper Creek project (Table 6.5). This 10.2-mi section of the river comprised 37.5 percent of the Skagit above the Sauk.

For the Skagit system as a whole 15.3 percent in 1975 and 13.2 percent in 1976 (or 14.3 percent combined) of chinook spawning was estimated to have occurred upstream of Copper Creek Dam site.

Table 6.6 lists two chinook salmon redd counts made by the WDF from helicopter surveys on September 24, 1975, and September 20, 1976 (Russ Orrell, personal communication). A larger number of redds was seen in the helicopter surveys, but the percentages of redds observed in most river sections were generally similar to the percentages of redds counted in those sections from the aerial photographs.

6.4.3.2 Pink Salmon. Pink salmon spawner distribution data for 1969 obtained from WDF (Russ Orrell, personal communicaiton) indicated that 91 percent of the Skagit system spawners utilized the mainstem Skagit and 9 percent utilized the tributaries. Of the mainstem spawners, 84 percent utilized the section from Newhalem to Rockport. The section-by-section utilization between Newhalem and Rockport was as follows:

Newhalem to "canyon" (RM 89)	- 33 percent
"canyon" to Marblemount	- 57 percent
Marblemount to Rockport	- 10 percent

A helicopter survey was conducted between Newhalem and the Sauk River to determine the 1977 pink salmon spawner distribution. The results of this survey are summarized in Table 6.7. The area utilized for spawning in the sections between Newhalem and Copper Creek Dam site was approximately proportional to the lengths of the sections; overall 39.5 percent of the total area spawned were contained in these sections which represented 37.5 percent of the total river miles. Spawner utilization was disproportionately high for sections between Copper Creek Dam site and Cascade River and disproportionately low between Cascade River and Sauk River than expected based on river miles.

For the Skagit River as a whole about 30 percent of pink salmon spawning was estimated to have occurred upstream of Copper Creek Dam site.

Comparisons based on these data showed that utilization was lower in 1977 in the Newhalem to County Line section at 18.6 percent than in 1969 with 33 percent for the comparable sections (RM 89 is approximately 0.5 mi downstream of County Line). Utilization was higher in 1977 than in 1969

Table 6.6 Chinook salmon redd counts made by the Washington Department of Fisheries from helicopter surveys of the Skagit River from Newhalem to the Sauk River.
[Surveys made on September 24, 1975 and September 20, 1976]

River section	Number of redds		Percent of total redds		River miles	Percent of total river miles
	1975	1976	1975	1976		
Newhalem to County Line	179	190	15.1	12.5	4.8	17.6
County Line to Copper Creek	81	125	6.8	8.2	5.1	18.8
SUBTOTAL (NEWHALEM TO COPPER CREEK)	260	315	21.9	20.7	9.9	36.4
Copper Creek to Bacon Creek	16	56	1.3	3.7	1.4	5.1
Bacon Creek to Diobsud Creek	138	162	11.6	10.7	2.2	8.1
Diobsud Creek to Cascade River	373	462	31.4	30.3	2.6	9.6
Cascade River to Corkindale Creek	96	135	8.1	8.9	4.0	14.7
Corkindale Creek to Illabot Creek	57	94	4.8	6.2	2.5	9.2
Illabot Creek to Sauk River	249	297	20.9	19.5	4.6	16.9
SUBTOTAL (COPPER CREEK TO SAUK RIVER)	929	1206	78.1	79.3	17.3	63.6
TOTAL (NEWHALEM TO SAUK RIVER)	1189	1521	100	100	27.2	100

Table 6.7 Area spawned by pink salmon as determined from helicopter survey of the Skagit River from Newhalem to the Sauk River, October 11, 1977.

River section	Area spawned ($ft^2 x 10^3$)	Percent of total area spawned	Area spawned per river mile ($ft^2 x 10^3/mi$)	River miles	Percent of total river miles
Newhalem to County Line	980.4	18.6	204.3	4.8	17.6
County Line to Copper Creek dam site	1,098.1	20.9	203.4	5.4	19.9
Subtotal (Newhalem to Copper Creek dam site)	2,078.5	39.5	203.8	10.2	37.5
Copper Creek dam site to Bacon Creek	626.5	11.9	569.6	1.1	4.0
Bacon Creek to Diobsud Creek	888.8	16.9	404.0	2.2	8.1
Diobsud Creek to Cascade River	983.2	18.7	378.2	2.6	9.6
Cascade River oto Corkindale Creek	229.6	4.4	57.4	4.0	14.7
Corkindale Creek to Illabot Creek	57.2	1.1	22.9	2.5	9.2
Illabot Creek to Sauk River	399.2	7.6	86.8	4.6	16.9
Subtotal (Copper Creek dam site to Sauk River)	3,184.5	60.5	187.3	17.0	62.5
Total (Newhalem to Sauk River)	5,263.0	100.0	193.5	27.2	100.0

between County Line and Cascade River, 68.4 percent versus 57 percent, and between Cascade River and Sauk River, 13.1 percent versus 10 percent.

The relatively high spawner utilization suggested by these data for the more upstream areas in 1969 and 1977 may relate to flow conditions during the incubation period 2 years earlier. Major high flow events occurred during early December 1975; late October, early November, and mid-December 1967; and mid-January 1968. These peak flows were probably detrimental to incubating eggs and alevins. Miller (1976) showed that flood flows during incubation had a significant effect on the resulting number of returning sockeye salmon adults to the Cedar River.

It is difficult to know to what extent the river sections immediately below the present site of Gorge Dam and Powerhouse near Newhalem might have been influenced by flood flows under natural conditions during the incubation period. The magnitude of the discharge per unit drainage area was lower for the watershed upstream of Newhalem than downstream (Table 2.2). Also because of the higher general elevation in the watershed upstream of Newhalem a higher proportion of the winter precipitation would be in the form of snow. On the other hand, because it is drier the watershed upstream of Newhalem may be less able to "hold" moisture resulting from the more transient storm events that predominate this period. Some degree of flood protection is provided by SCL dams on the Skagit. For example the peak daily regulated flow during early December 1975 was 24,100 cfs while the peak daily natural flow for that period was calculated to be 31,950 cfs (Fig. 2.22). Flood protection from whatever source would be progressively reduced in the downstream sections below Newhalem because of unregulated natural inflow and below the Sauk River would probably be minimal.

These relationships seemed more critical for pink salmon than for the other species in question but probably applied to the others as well. Adult pinks return almost exclusively as 2-year-old fish while the other species upon return have mixed age compositions so that factors affecting a single brood year can be more critical. Also, in contrast to chinook, coho, and steelhead, Skagit River pink salmon production has been primarily natural and therefore more dependent on environmental conditions. Finally pink salmon being the smallest species in question probably deposit their eggs in shallower redds and so may be more susceptible to the effects of high flows.

The foregoing discussion supports the contention that relatively high utilization of upstream areas by spawning pink salmon may relate to flow conditions. This does not minimize, however, the importance of the upstream sections and particularly the section between Newhalem and Copper Creek Dam site. On the contrary it indicates the valuable role of these sections as buffers against adverse flow conditions.

6.4.3.3 Chum Salmon. Chum salmon distribution data was obtained from WDF (Russ Orrell, personal communication) for the 1976 run. These data based on carcass recoveries indicated that about two-thirds of the spawners utilized the mainstem Skagit and the other one-third utilized the tributaries. Of the mainstem spawners, 92.5 percent were between Newhalem and Concrete. The distribution by section was as follows:

Newhalem to "canyon" (RM 89)	- 8.3 percent
"canyon" to Marblemount	- 5.3 percent
Marblemount to Rockport	- 65.6 percent
Rockport to Concrete	- 20.8 percent

In proportion to their lengths the Marblemount to Rockport section was utilized more than expected; the "canyon" to Marblemount and Rockport to Concrete sections were utilized less than expected; and the Newhalem to "canyon" section utilized by a similar proportion. By assuming that spawner distribution was uniform between "canyon" and Marblemount, approximately 11 percent of chum spawning above Concrete took place upstream of Copper Creek Dam site. This would amount to about 7 percent for the Skagit Basin as a whole.

Boat surveys were attempted between Newhalem and the Sauk River to determine the 1976 chum salmon spawner distribution on a direct visual basis. Due to time limitations, the surveys were restricted to the left riverbank only. The last survey was conducted on November 23-24. By the next scheduled survey date river discharge levels had increased (Fig. 6.3) and this made further observations difficult and the surveys were terminated. Thus, the last spawner distribution count was conducted up to 3 weeks before the peak of the run (based on the peak spawner counts in Reference Reach 3 side channel). Several areas of heavy chum spawning were observed in mid-December which had exhibited relatively low spawner activity at the time of the November 23-24 boat survey. Riverside channels comprised a significant part of the total Skagit River chum spawning area but were not included in the boat survey counts. Because of these factors the validity of the surveys was questionable and results are not presented.

6.4.3.4 Coho Salmon. Specific quantitative spawner distribution data were not available for coho salmon in the Skagit River system. Spawning occurs primarily in smaller tributary streams and is probably minimal in the mainstem Skagit. This contention was supported by the observed timing to first appearance of coho fry in upper Skagit tributaries compared to that in the mainstem (Sec. 8.4.4.1). Fry were present up to 6 weeks earlier in tributary streams such as Cascade River, Goodell, and Bacon creeks than they were at mainstem Skagit and Sauk river sampling sites. This delay probably represents the time for fry to redistribute from spawning and incubation areas in the smaller streams to rearing areas in the larger streams and rivers.

Nearly all accessible streams and tributaries within the Skagit Basin are utilized by spawning coho salmon with additional spawning in the mainstem Skagit, Cascade, Sauk, and Baker rivers (Williams et al. 1975). Coho spawner distribution above the Copper Creek Dam site was estimated using accessible stream and river length data presented by Zillges (1977). He estimated about 490 mi were accessible to coho in the Skagit system including the mainstems. The accessible stream length for tributaries about the size of the Cascade River and smaller was about 345 mi while mainstem length (Skagit, Sauk, and Baker) was about 145 mi. The Cascade River and tributaries of comparable size and smaller were grouped because early timing of first appearance indicated they were probably more heavily utilized for spawning than mainstem areas.

On a per length basis 3.1 mi or 0.9 percent of tributaries and 10.2 mi or 7 percent of mainstem length were upstream of Copper Creek Dam site (RM 84). If the mainstem versus tributary utilization was as high as 25 percent versus 75 percent then the combined distribution upstream of the project site would be 2.4 percent. This estimate represents a maximum value since the relative utilization of mainstem areas is probably less than 25 percent.

6.4.3.5 Steelhead Trout. Based on the peak counts from 1975 to 1978 aerial surveys (Table 6.4), approximately two-thirds of the redds were located in the mainstem Skagit (from Sedro Woolley to Newhalem) with one-third in the mainstem Sauk (primarily from the mouth to Darrington). Of the mainstem Skagit redds 62 percent were observed between Newhalem and the Baker River. For the Newhalem to Baker River reach the breakdown by section was as follows:

Newhalem to Bacon Creek	- 2 percent
Bacon Creek to Cascade River	- 20 percent
Cascade River to Sauk River	- 56 percent
Sauk River to Baker River	- 22 percent

(Note: The highest number observed between Newhalem and Bacon Creek was eight redds out of 118 (6.8 percent) on April 24, 1978 (Table 6.4).

The high redd counts in the Cascade River to Sauk River section probably resulted from the return of spawners to the vicinity of Barnaby Slough rearing facility.

For the mainstem Skagit and Sauk rivers combined the estimated steelhead distribution upstream of Bacon Creek, near Copper Creek Dam site, was less than 1 percent based on peak counts from 1975 to 1978. For the April 24, 1978, count it amounted to 2.8 percent.

Thirteen steelhead redds were observed in the lower 1/2 mi of Bacon Creek during the May 19, 1977, survey and two fish were seen in Goodell Creek during the April 20, 1977, survey.

No other estimates were available for the numerous other tributary streams in the Skagit Basin where steelhead are known to spawn.

6.4.3.6 Spawner Surveys--Goodell Creek. Goodell Creek is the largest of several tributaries that enters the Skagit River between Newhalem and Copper Creek Dam site (Fig. 1.1). Spawner surveys were conducted on foot in 1975, 1976, and 1977 to determine the presence of adult salmon and steelhead trout in Goodell Creek. The results are summarized in Table 6.8.

Table 6.8 Spawner surveys for Goodell Creek, 1975, 1976, and 1977.

Date	Starting point	Distance surveyed	Chinook #fish	Chinook #redds	Pinks #fish	Pinks #redds	Coho #fish	Coho #redds	Steelhead #fish	Steelhead #redds	Comments
1975											
9-17	1/4-mi. above bridge	∿1-mi.					∿40				All holding in pool.
10-16	" "	∿1.5-mi.					∿12				" " "
12-22	" "	∿1-mi.					∿30				" " "
1976											
11-19	Mouth	∿1/2-mi. to pool					5				All holding in pool. Described as coho size, possibly steelhead.
1977											
9-8	Highway bridge	5/8-mi. to group campground	5	2	2	0					
9-16	Highway bridge	3/8-mi. to pool	5	2	27	2+					Plus one mass spawned pink area.
9-27	Highway bridge	3/8-mi. to pool	5	2	235	88+					Plus mass pink spawning in tail of pool.
10-7	Highway bridge	3/8-mi. to pool	1	0	306	68+					Plus 5 areas of mass pink spawning.
10-12	Group camp-ground	2-mi. upstream							4		No salmon carcasses or redds observed.
10-18	Highway bridge	3/8-mi. to pool			96	55+	∿30				∿20 areas of mass pink spawning, coho holding in deep part of big pool separate from pinks.

No chinook salmon were observed during the surveys in 1975 or 1976. Counts ranged from one to five fish and zero to two redds during the September and early October 1977 surveys. Spawning pink salmon were seen only during the 1977 surveys. Pinks were observed on the first sampling date, September 8, and the peak count of 306 fish occurred on October 7. Individual redd counts were made where possible; however, numerous areas of the creek were mass spawned, i.e., spawning activity of sufficient intensity that individual redds could not be distinguished.

Coho were observed in Goodell Creek each year from the earliest survey date, September 1975, to the latest, December 22, 1975. When observed, the coho were holding in the big pool approximately 1/2 mi upstream of the mouth. Active spawning was not observed for coho salmon in Goodell Creek. No spawning salmon or salmon carcasses were observed during a survey on October 12, 1977, of an approximately 2-mi section above the big pool; however four steelhead were seen. While this upper area may be used for spawning by steelhead trout and presumably by coho salmon, it appeared that chinook and pink spawning was confined to the lower 1/2 mi of Goodell Creek from its mouth to the large pool.

6.4.4 Low Flow Observations

6.4.4.1 Chinook Salmon. In 1975 five active chinook salmon redds were observed lying in unusually shallow water in the vicinity of Reference Reach 3. During the night of September 6-7, the USGS gage above Alma Creek 6.7 mi above Reference Reach 3 recorded discharges dropping from 2,215 cfs to 1,396 cfs. The latter discharge was near the seasonal minimum for the 1975 chinook spawning season (USGS 1976). Two of the five female chinook salmon under observation were driven off their redds as the water dropped as low as 0.4 ft deep over two of the redds. Those female chinook that remained displayed a tendency to stay in the deepest part of the excavated redd. If water levels dropped enough, it seemed possible that fish could become trapped in this small pool of water in the redd pot. With water depths too low everywhere else, their escape route would be cut off, and they could become stranded. Nothing like this was ever actually observed, however.

It should be noted that the Reference Reach 3 observation area was selected because its redds were in unusually shallow water. With the water level still low, a survey in the early morning of September 7 from the redd observation site to a point 6.4 mi upstream revealed few other chinook salmon redds in water as shallow as those redds observed near Reference Reach 3. Below the Cascade and Sauk rivers even fewer redds would be expected to be subject to exposure because of the dampening effect of these major tributaries on the fluctuations of the Skagit discharge.

Exposure of chinook salmon redds or the phyically forced evacuation of redds by adult fish because of fluctuating low water levels did not appear to be a significant problem during the 1975 chinook spawning season.

In 1976 the mean daily discharges below Gorge Powerhouse were relatively high during the first part of the chinook spawning season but generally dropped to lower levels by the third week of September (Fig. 6.3). Chinook redds constructed before September 20 were generally built closer to the shore where the water was shallower. This phenomenon was apparent along the left bank at Reference Reach 3 (Fig. 6.18). On the morning of October 6, with the USGS gage at Marblemount recording a flow of 1,610 cfs, a survey of Reference Reach 3 showed 14 redds whose surfaces, at least, were completely out of the water. The distances from the exposed redds to the river's wetted edge varied from less than 1 ft to an extreme case of 56 ft.

Meekin (1967) reported that the fluctuating flow levels which exposed chinook salmon redds in the Columbia River had negligible effects, if any, on salmon eggs because the residual water in the redds was adequate to provide for the well-being of eggs and fry. On several occasions some of the exposed redds at Reference Reach 3 were examined by removing rocks from their surface. Water was always found only a few inches beneath the surface and live eggs were uncovered in a few instances.

6.4.4.2 Pink Salmon. Although pink salmon in 1975 generally spawned in shallower water than chinooks, very few redds were seen in locations which looked as if they could become exposed and no redds were observed either exposed or with only a few inches of water over them. This could possibly reflect the fact that most of the pink salmon redds were constructed during periods of low flow in late September and during the first week of October 1975, and mean river discharges after that period generally increased (Fig. 6.2).

6.4.5 Relationships of Spawnable Area to Discharge

The relationships between spawnable area and discharge in the reference reaches for chinook, pink, and chum salmon and steelhead trout are graphed in Figs. 6.19-6.26. The data points representing the estimated spawnable area were obtained from the 80 percent ranges of preferred depth and velocity which were used in the SYMAP analysis (Graybill 1974). Starting with a zero discharge, the estimated spawnable area will increase with discharge until it reaches some maximum value (where the slope of the tangent equals zero), and then will begin to decline with further increases in discharge.

The peak spawning discharge was defined as the flow that created the estimated maximum spawnable area (Collings 1974). Since the relationship between spawnable area and discharge was not linear, a curve was fitted to the points by polynomial regression. The peak spawning discharge was calculated from the polynomial equation for each reach by setting the first derivative equal to zero and solving. In those cases where the polynomial equation did not appear to define a peak spawning discharge, the highest point on the spawnable area versus discharge curve was then used as an estimate of the peak spawning discharge. When this occurred, it was usually due to the lack of a sufficient number of depth and velocity surveys made at low flows (generally below 1,900 cfs). Since

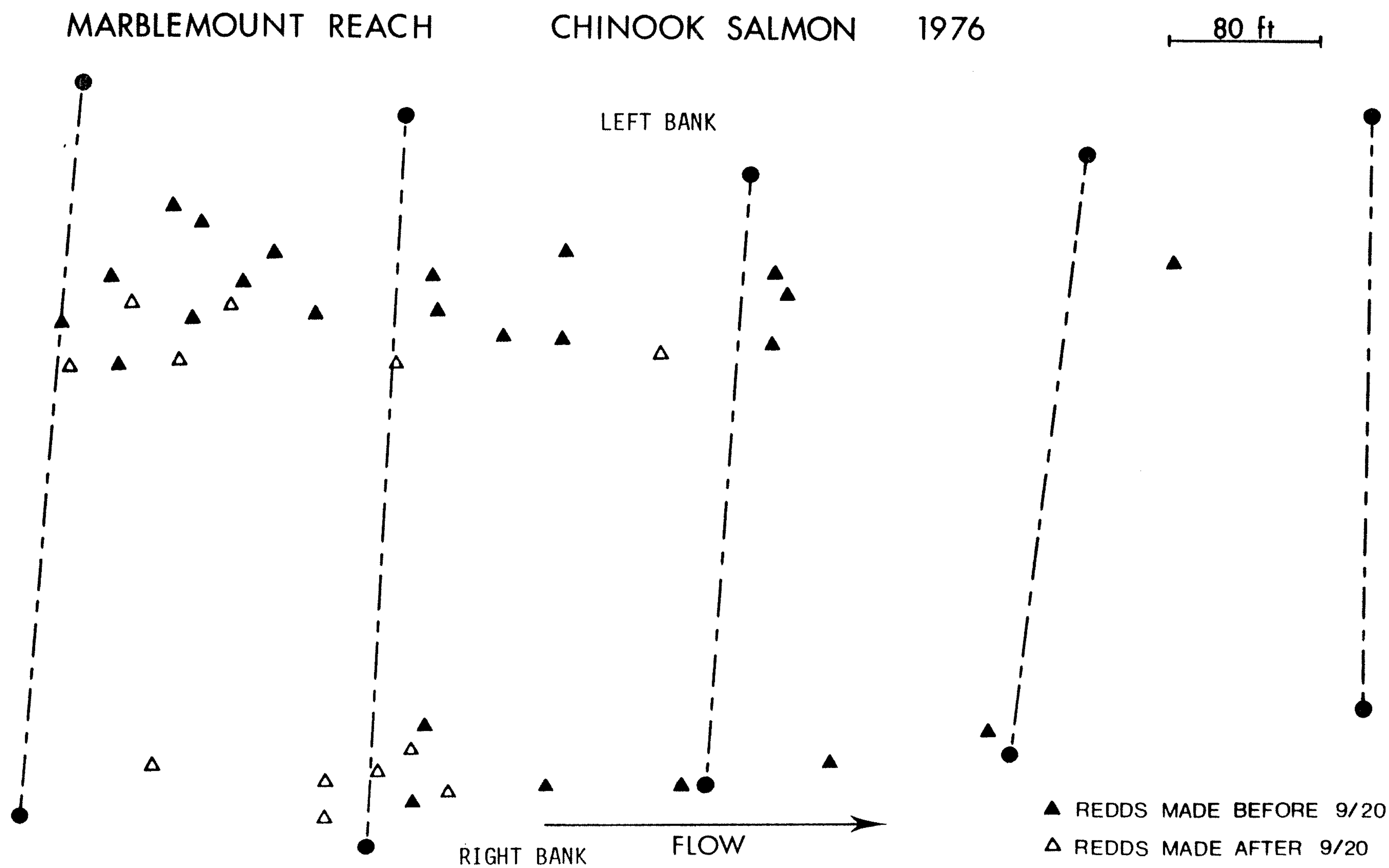

Fig. 6.18 Locations of chinook salmon redds in Marblemount Reference Reach (3) constructed before and after 20 September 1976.

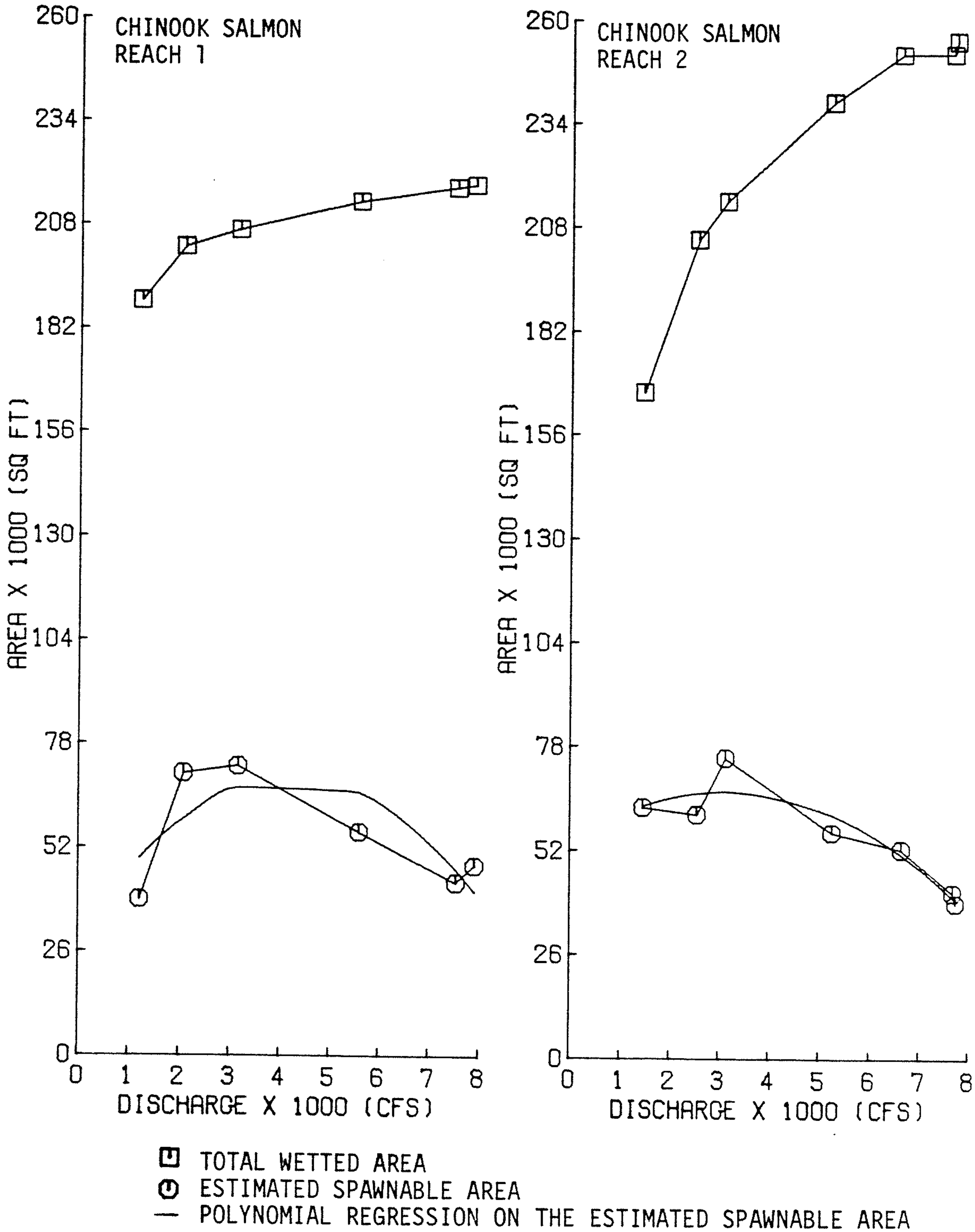

Fig. 6.19 Relationship between estimated spawnable area, polynomial regression on the estimated spawnable area, and total wetted area for chinook salmon at Reference Reaches 1-2.

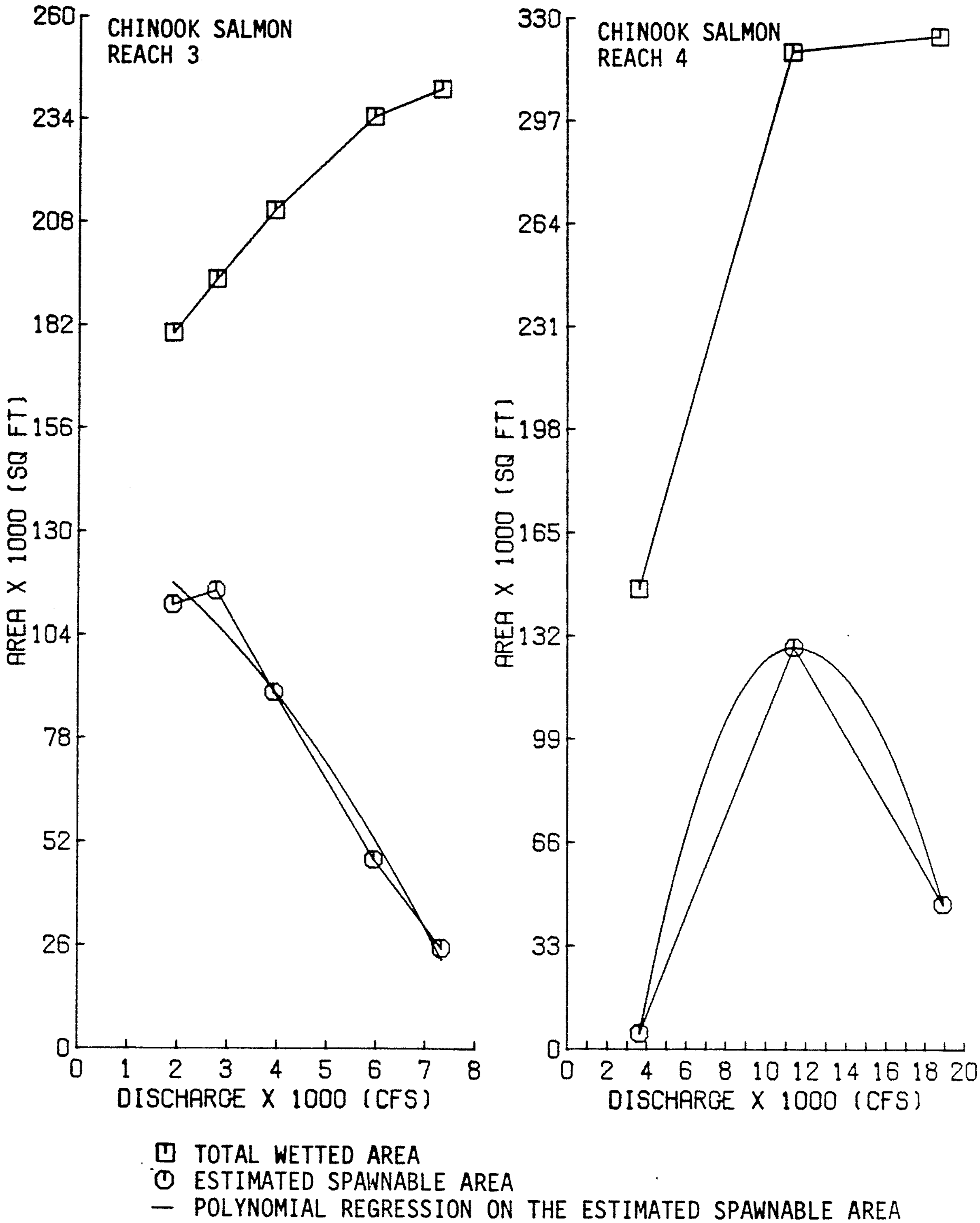

Fig. 6.20 Relationship between estimated spawnable area, polynomial regression on the estimated spawnable area, and total wetted area for chinook salmon at Reference Reaches 3-4.

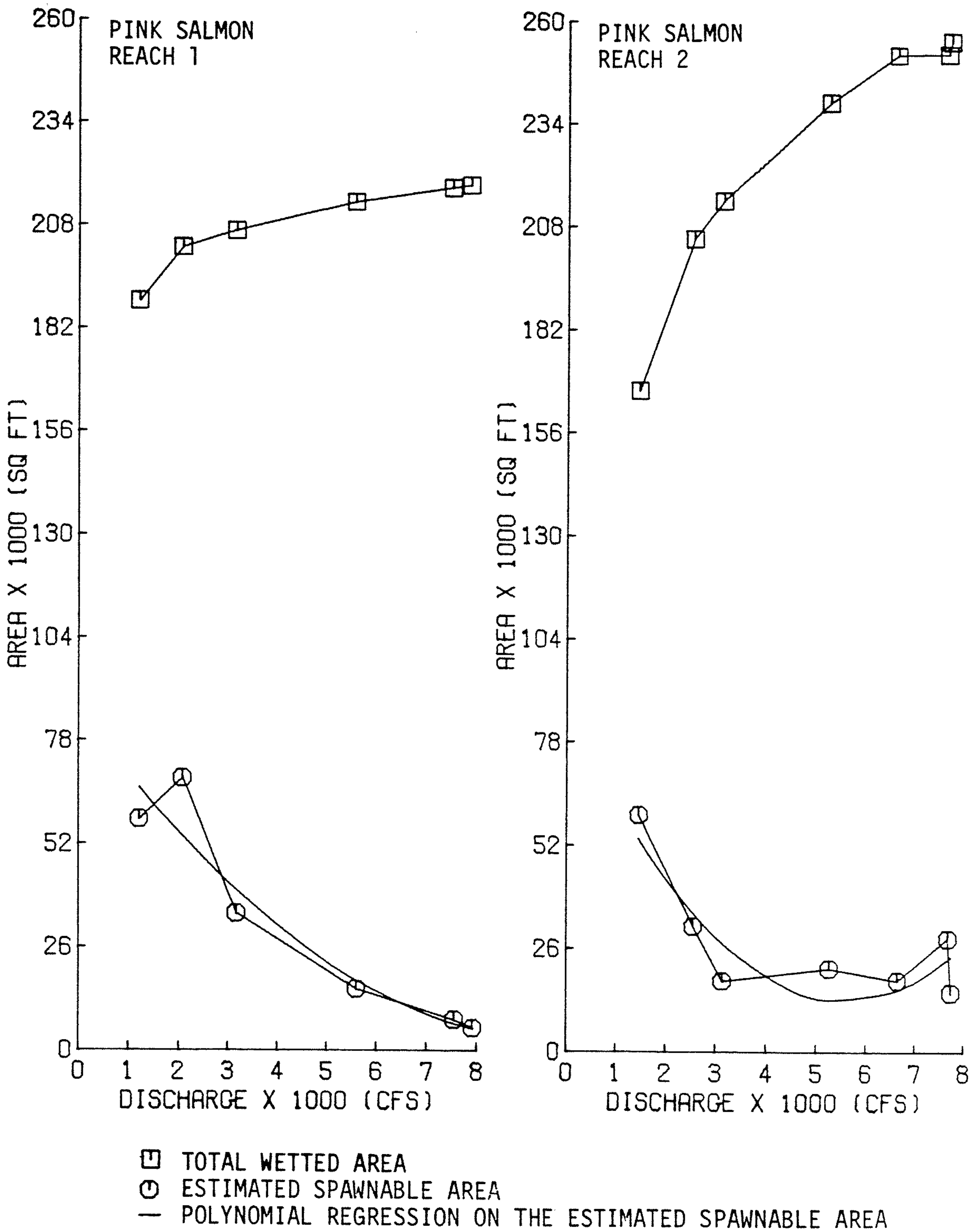

Fig. 6.21 Relationship between estimated spawnable area, polynomial regression on the estimated spawnable area, and total wetted area for pink salmon at Reference Reaches 1-2.

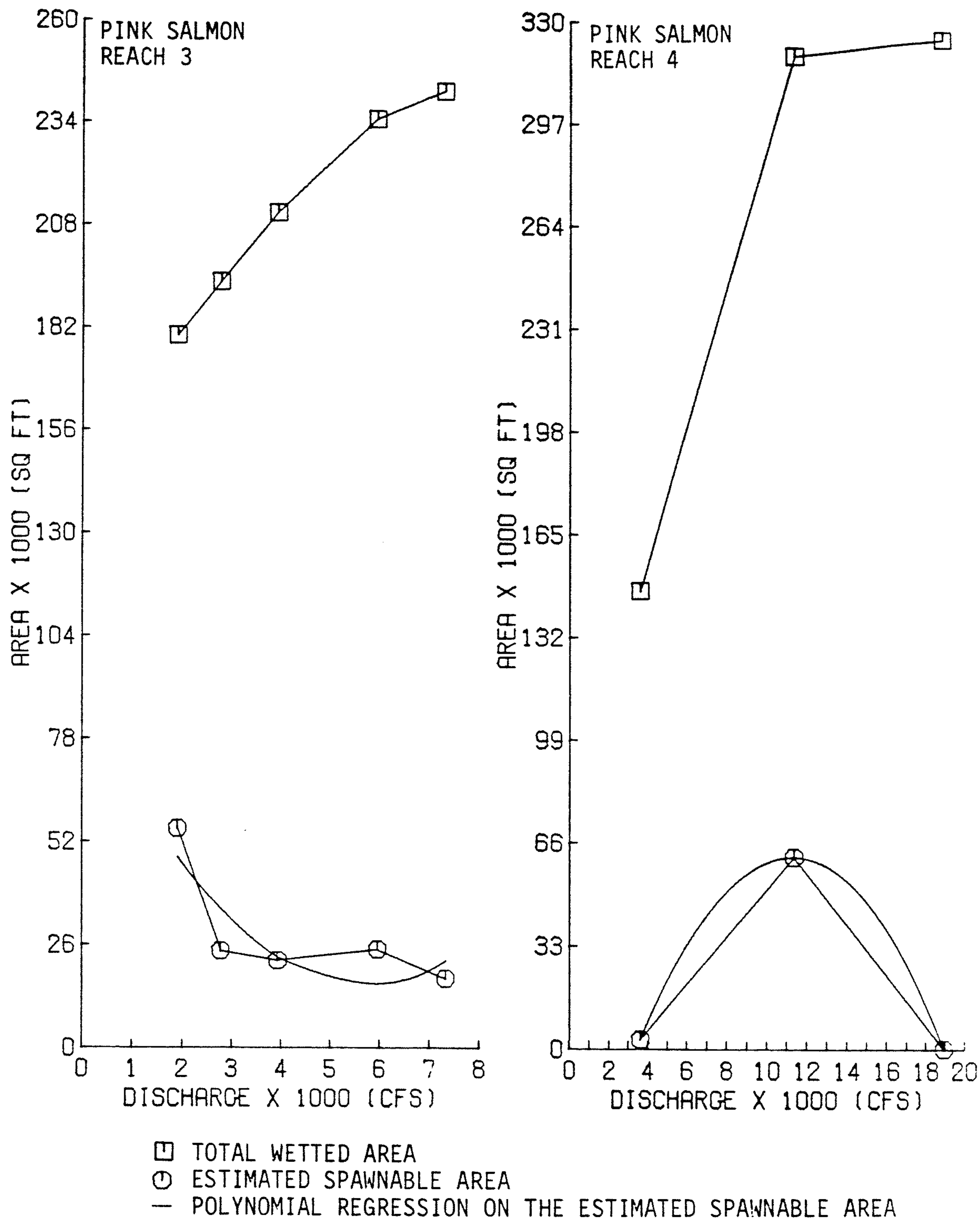

Fig. 6.22 Relationship between estimated spawnable area, polynomial regression on the estimated spawnable area, and total wetted area for pink salmon at Reference Reaches 3-4.

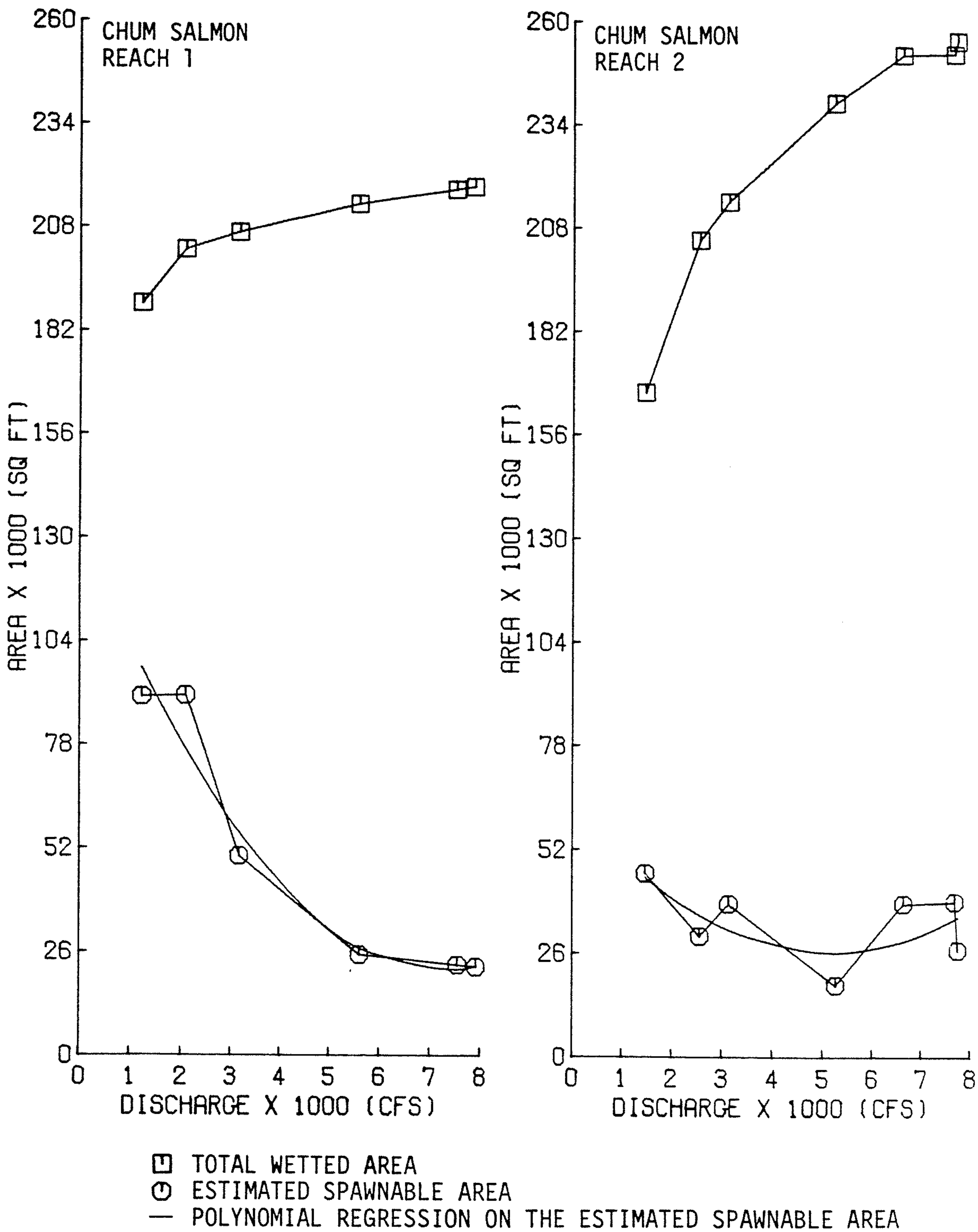

Fig. 6.23 Relationship between estimated spawnable area, polynomial regression on the estimated spawnable area, and total wetted area for chum salmon at References Reaches 1-2.

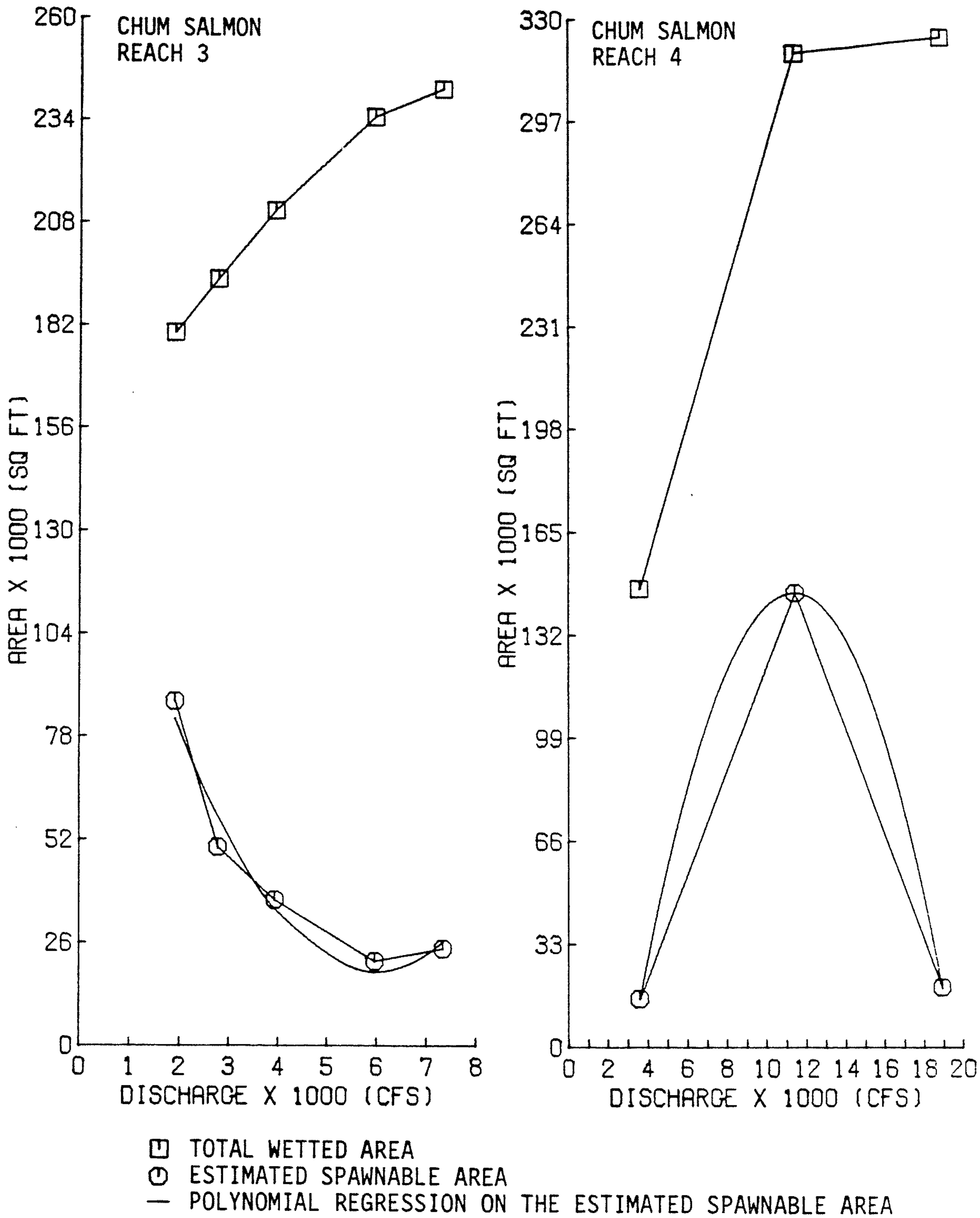

Fig. 6.24 Relationship between estimated spawnable area, polynomial regression on the estimated spawnable area, and total wetted area for chum salmon at Reference Reaches 3-4.

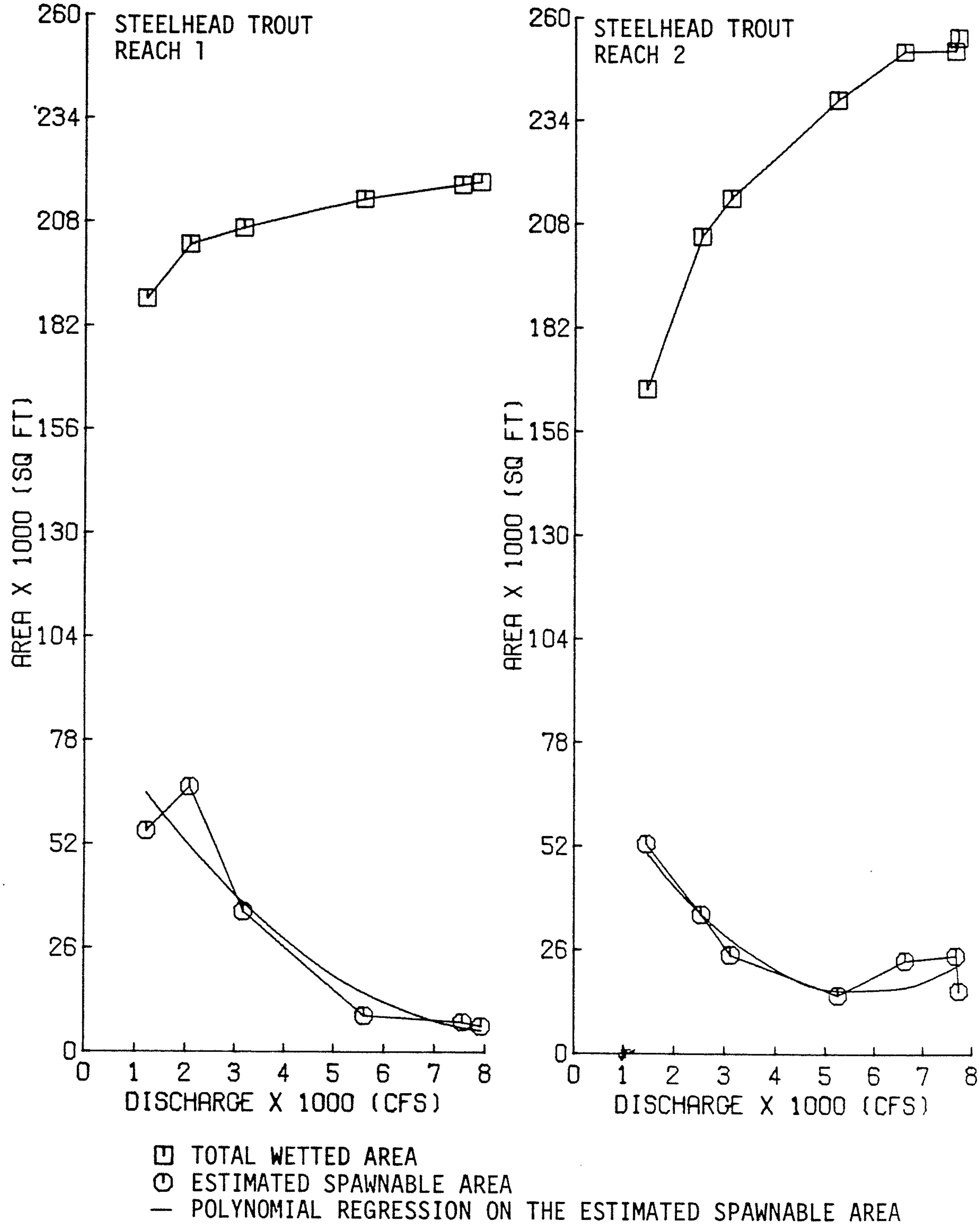

Fig. 6.25 Relationship between estimated spawnable area, polynomial regression on the estimated spawnable area, and total wetted area for steelhead trout at Reference Reaches 1-2.

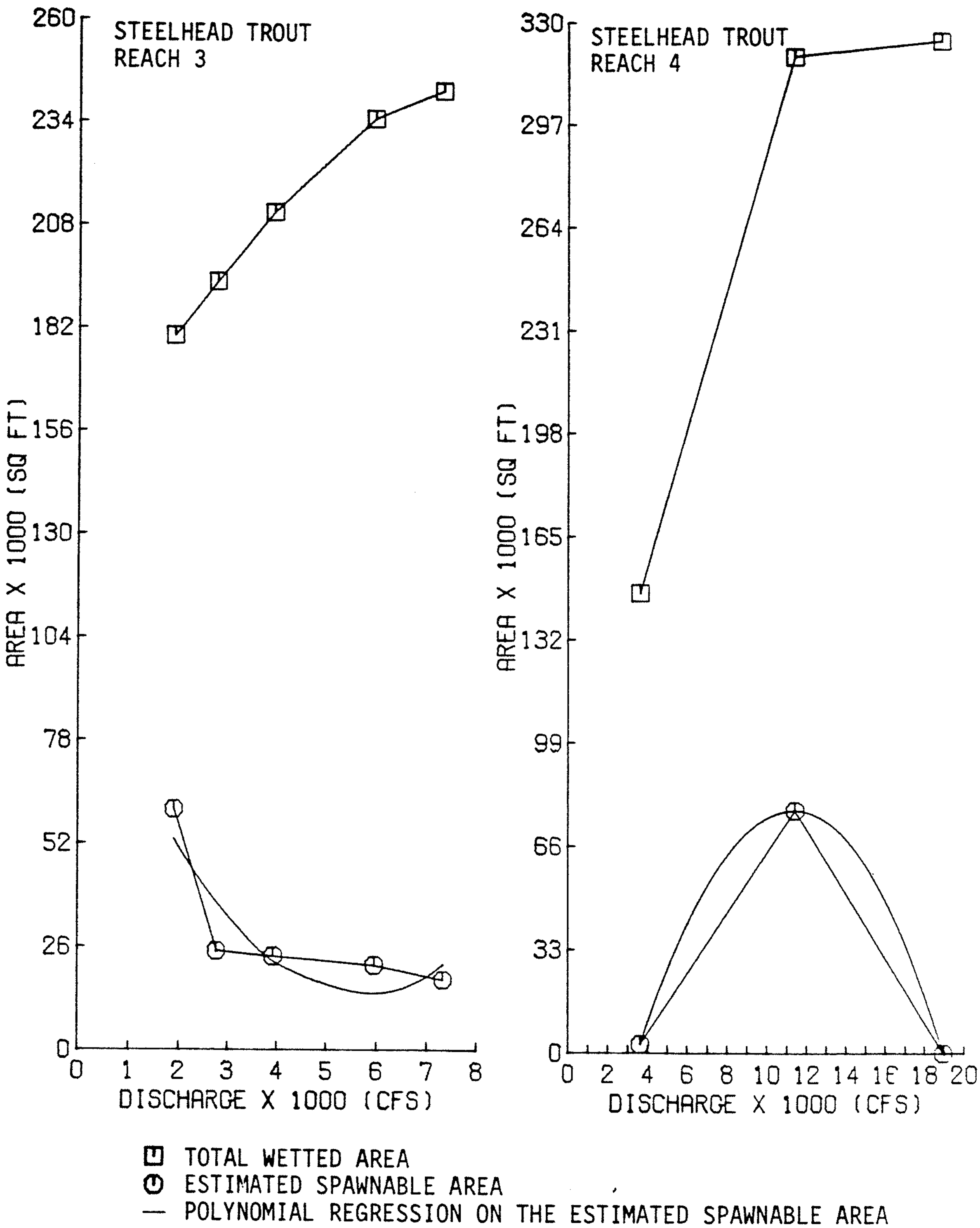

Fig. 6.26 Relationship between estimated spawnable area, polynomial regression on the estimated spawnable area, and total wetted area for steelhead trout at Reference Reaches 3-4.

1,000 cfs was the minimum flow below Gorge Powerhouse by Federal Power Commission license stipulation, it was often difficult to conduct surveys at discharges less than 1,900 cfs because the additional inflows from tributary streams increased the 1,000 cfs from Gorge beyond 1,900 cfs.

Total wetted area versus discharge was also plotted for each reach in Figs. 6.19-6.26. The curve for Reference Reach 1 rose slightly with increasing discharge, indicating a fairly channelized streambed with steep sides. The wetted area curves for Reference Reaches 2-4 increased sharply and these reaches were characterized by large, shallow sloping gravel bars that greatly increased the wetted area when submerged at higher discharges.

Plan views showing estimated spawnable area at Reference Reaches 1, 2, and 3 for pink, chinook, and chum salmon, respectively, at three different discharges are provided in Figs. 6.27-6.29.

6.4.5.1 Chinook Salmon. The chinook salmon peak spawning discharge, the maximum area suitable for spawning, and the polynomial equation for each reach were obtained from the spawnable area versus discharge curves (Figs. 6.19 and 6.20) and are listed in Table 6.9. The peak spawning discharges for Reference Reaches 1, 2, and 3 were 4,295, 3,171, and 2,784 cfs, respectively. The mean peak spawning discharge for Reference Reaches 1-3 was 3,417 cfs. The peak spawning discharge for Reference Reach 4 was 11,429 cfs. Only three surveys were made at Reference Reach 4, but its location downstream of the Cascade and Sauk rivers made it less susceptible to SCL's regulated discharge influence. The value of Reference Reach 4 stemmed from its indication that whatever the exact peak spawning discharge in this lower section of the river study area was, it would be considerably larger than the 3,417 cfs figure described by Reference Reaches 1-3 further upstream.

6.4.5.2 Pink Salmon. The peak spawning discharges for pink salmon in Reference Reaches 1, 2, and 3 were 2,090, 1,468, and 1,914 cfs, respectively (Table 6.9 and Figs. 6.21 and 6.22). The mean peak spawning discharge for Reference Reaches 1-3 was 1,824 cfs. The peak spawning discharge for Reference Reach 4 was 11,429 cfs.

The 80 percent ranges of depth and velocity for pink salmon indicated that they preferred slower spawning velocities and much shallower depths than those preferred by spawning chinook salmon. In a large river like the Skagit, both of these conditions were enhanced by relatively low discharges. From the SYMAP analysis, it was apparent that at higher flows the areas within the 80 percent ranges of preferred depth and velocity for pink salmon occurred primarily along the sides of the river. As the discharge decreased to lower levels, these areas tended to move into the channel and away from the sides. Once this had occurred, a much greater area along the river bottom fell within the limits of the preferred range of depth and velocity and was classified as potentially spawnable. Thus,

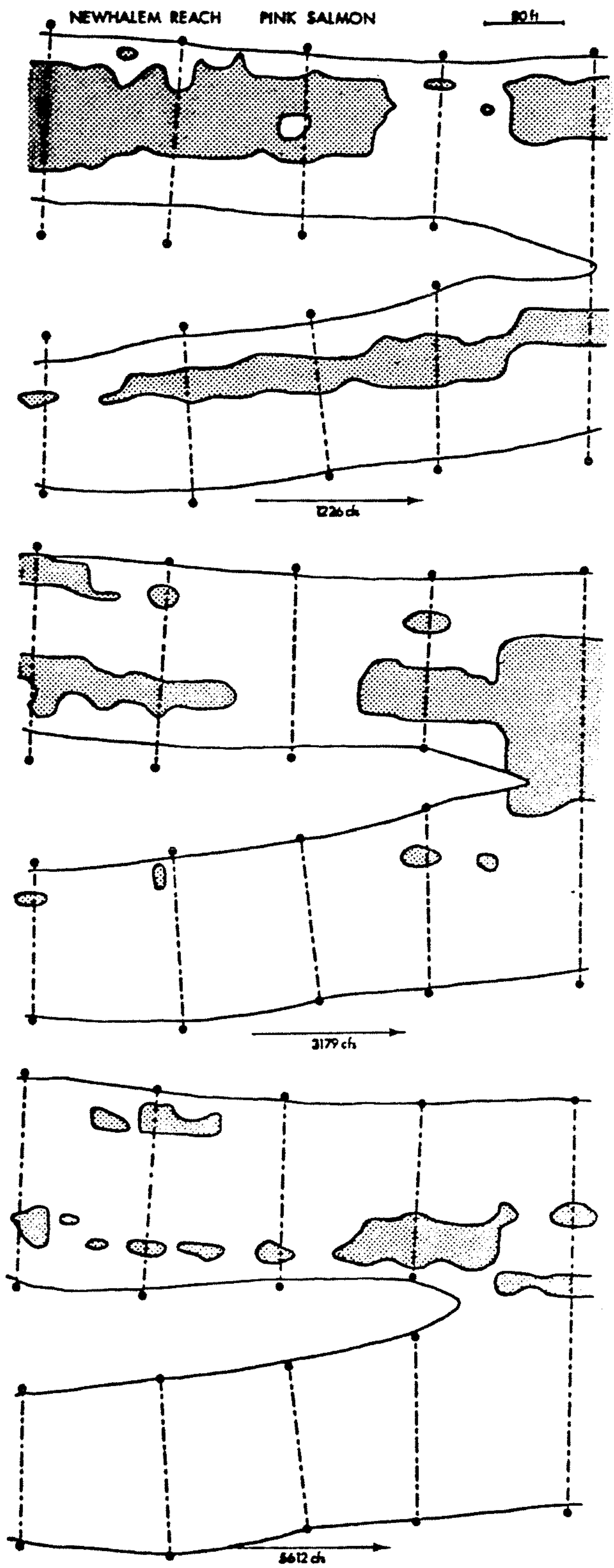

Fig. 6.27 Plan views of Reference Reach 1 (Newhalem) showing changes and movement of the estimated spawnable area for pink salmon (shaded) at three discharges.

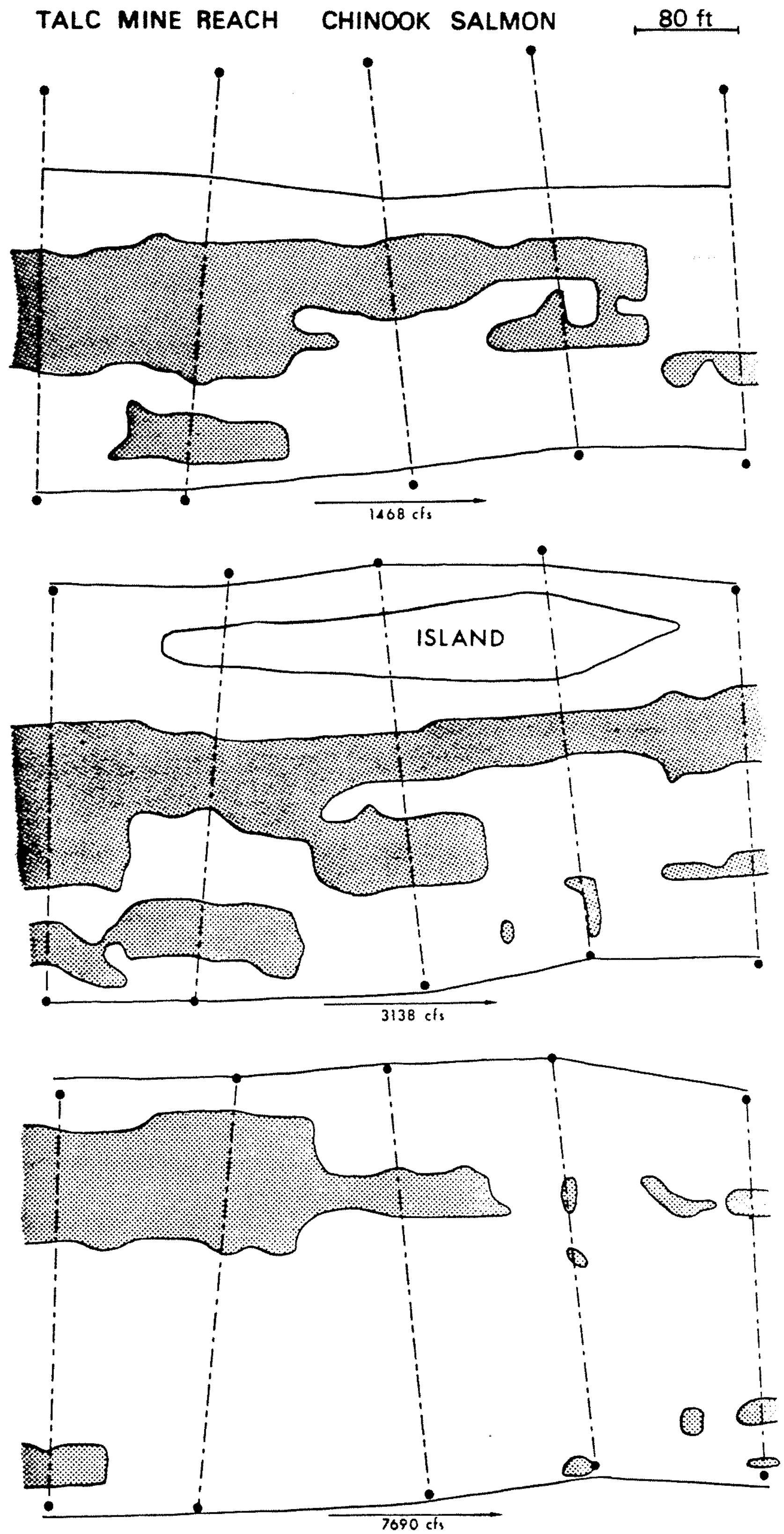

Fig. 6.28 **Plan views of Reference Reach 2 (Talc Mine) showing changes and movement of the estimated spawnable area for chinook salmon (shaded) at three discharges.**

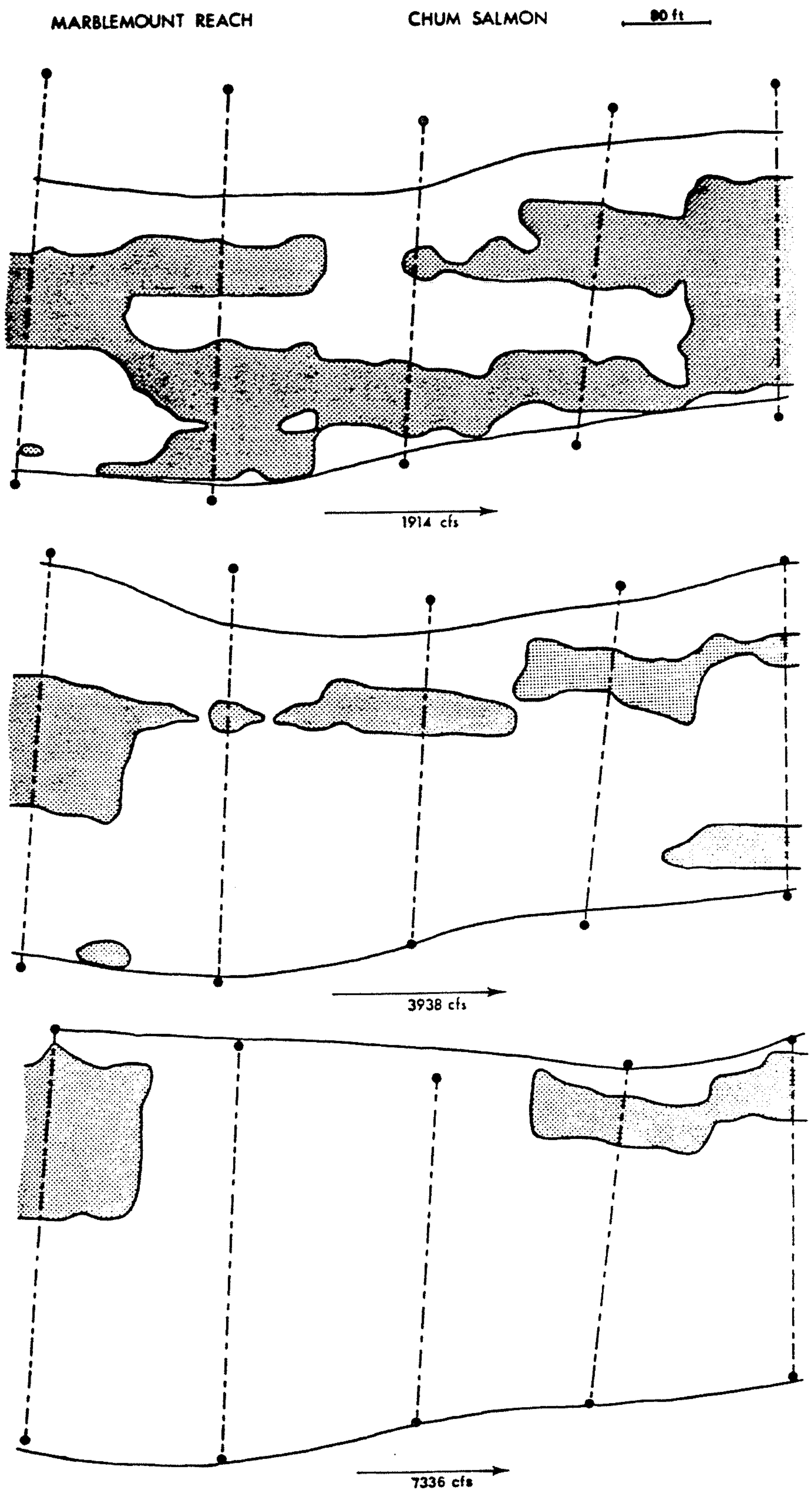

Fig. 6.29 Plan views of Reference Reach 3 (Marblemount) showing changes and movement of the estimated spawnable area for chum salmon (shaded) at three discharges.

Table 6.9 The peak spawning discharges and associated areas suitable for spawning for chinook, pink, and chum salmon, and steelhead trout, in each of the four reference reaches. The polynomial equations of the estimated spawnable area versus discharge curves are listed.

Species	Reference Reach	Peak discharge (cfs)	Maximum area ($ft^2 \times 10^3$)	Polynomial equation
Chinook	1	4,295	69.66	$y = -0.0021697x^2 + 18.6365x + 29633.9$
	2	3,171	66.85	$y = -0.0012877x^2 + 8.1661x + 53901.2$
	3	2,784	115.08	$y = -0.0012018x^2 - 6.3444x + 133621.3$
	4	11,429	128.48	$y = -0.0017477x^2 + 42.1141x - 124556.9$
Pink	1	2,090	68.56	$y = 0.0008697x^2 - 17.0057x + 85687.1$
	2	1,468	59.76	$y = 0.0023915x^2 - 26.7632x + 87860.6$
	3	1,914	55.36	$y = 0.0027547x^2 - 31.2736x + 102860.7$
	4	11,429	61.36	$y = -0.0010236x^2 + 22.9018x - 66679.0$
Chum	1	2,090	90.44	$y = 0.0021041x^2 - 30.4264x + 131387.8$
	2	1,468	46.05	$y = 0.0013544x^2 - 14.0749x + 62741.8$
	3	1,914	86.92	$y = 0.0039131x^2 - 46.5865x + 157327.0$
	4	11,429	145.72	$y = -0.0021899x^2 + 49.6381x - 135549.5$
Steelhead	1	2,090	66.40	$y = 0.0010953x^2 - 18.8777x + 86288.0$
	2	1,468	52.64	$y = 0.0018760x^2 - 21.7496x + 78459.0$
	3	1,914	60.72	$y = 0.0027547x^2 - 31.2736x + 102860.7$
	4	11,429	77.68	$y = -0.0013029x^2 + 29.2034x - 85901.3$

the greatest amount of spawnable area was available at a relatively low flow of 1,824 cfs.

6.4.5.3 Chum Salmon. The peak spawning discharges for chum salmon in Reference Reaches 1, 2, and 3 were 2,090, 1,468, and 1,914 cfs, respectively (Table 6.9 and Figs. 6.23 and 6.24). The mean peak spawning discharge for Reference Reaches 1-3 was 1,824 cfs. The peak spawning discharge at Reference Reach 4 was 11,429 cfs.

The 80 percent range of velocity for chum salmon had indicated that chum salmon preferred slower spawning velocities than those preferred by chinook or pink salmon. In the Skagit slower spawning velocities were enhanced by low discharges.

Field observations made in November 1975 and 1976 indicated the interacting effects of streamflow and spawning escapement on stream utilization. The mean monthly discharge from the Gorge Powerhouse in November 1975 was 7,081 cfs, while in November 1976, it was 3,692 cfs (USGS 1976 and 1977). The estimated spawning escapement (Table 5.3) for 1975 was 7,800 and for 1976 was 85,000. In November 1975 the chum salmon redds seen in the upper Skagit were mostly either in the side channels or next to the banks. Often these latter seemed to be located behind submerged stumps, boulders, and logs. These areas were apparently "preferred" by spawning chum salmon presumably because bottom velocities in other areas were too high. In November 1976, with the mean daily flows only about half those in November 1975 and with a spawning escapement about 11 times larger in 1976 than in 1975, large areas of chum salmon mass spawning were observed in the mainstem river away from the banks. The differences in the spawning areas utilized from 1 year to the next were dramatic and many of the areas spawned in November 1976 contained no spawning chums in November 1975. Some of the chum salmon spawning areas selected at the lower discharges during 1976 were the same ones that had been utilized by spawning chinook salmon 1 to 2 months.

6.4.5.4 Steelhead Trout. The peak spawning discharge for steelhead trout in Reference Reaches 1, 2, and 3 were 2,090, 1,468, and 1,914 cfs, respectively (Table 6.9, Figs. 6.25 and 6.26). The mean peak spawning discharge for Reference Reaches 1-3 was 1,824 cfs. The peak spawning discharge at Reference Reach 4 was 11,429 cfs.

The 80 percent ranges of depth and velocity for steelhead trout were similar to those for pink salmon. As with pinks the greatest amount of spawnable area was available at the relatively low flow of 1,824 cfs.

6.4.6 Potential Spawnable Area

The 20 sample transects that were investigated were spread over 37.7 river miles of the Skagit River and provided a systematic sample from which an average river width and spawnable width for the river were obtained. The spawnable width of a sample transect was defined as that part of the total river width that was within the 80 percent ranges of preferred depth and velocity for each species.

Spawnable width and river width were dependent on discharge. Discharge in the Skagit varied greatly so the sample transect investigations were confined to three discharge surveys within a subrange of the regulated flows that was most likely to be important to spawning Skagit River salmonids. This subrange of the regulated flows was derived from the mean daily natural flow of the Skagit at the Gorge Powerhouse for September and October and ranged from 900-6,025 cfs at that location. Natural flow was defined as the river flow if the reservoirs were not present.

Natural flows were used because regulation on the Skagit River is a recent phenomenon in an evolutionary time sense, and therefore Skagit River salmonid stocks have evolved under natural flow conditions except for the past 60 years. Natural flows for the river directly below Gorge Powerhouse were calculated on a daily basis by SCL and on a monthly basis by the USGS. The figures of both agencies agreed closely. Seattle City Light directly calculated natural flows from a combination of changes in water elevation levels of the three upstream reservoirs and known powerhouse and spillway discharges. The September and October flows were used because chinook and pink salmon spawned during those months. The peak spawning discharges for chum and steelhead were contained within this range of flows even though they spawn at different times of the year.

Thus, the mean daily natural flows of the Skagit for September and October directly below Gorge Powerhouse from 1961-1974 were ordered in terms of magnitude and the lowest and highest 2.5 percent were discarded to eliminate the extremes. The remaining discharges were then divided equally into three categories which were classified low, medium, and high (Table 6.10). Each of the 20 sample transects was then surveyed on three separate occasions at a low, medium, and high flow. For locations on the Skagit River downstream of Gorge Powerhouse, the inflows of the major tributaries were added to the natural flow at Gorge, thus extending the classification system to any point on the Skagit downstream to the Baker River (Table 6.10).

The results of the 60 depth and velocity surveys conducted over the 20 sample transects during a 2-year period are presented and discussed in the following sections (6.4.6.1-6.4.6.4) for chinook, pink, and chum salmon and steelhead trout. The discussion will deal with comparisons of several parameters to describe differences between various river sections. The basic parameters discussed include: 1) mean estimated spawnable width as calculated (in ft) and as percent of mean river width; 2) estimated spawnable area as calculated (in ft^2) and as percent of wetted area. In addition the estimated spawnable area for the various river sections are presented as percent of the total estimated spawnable area between Newhalem and Baker River, as well as the estimated spawnable area per acre of wetted area (ft^2/acre) and per river mile (ft^2/mi).

To facilitate the comparisons the sample transects were divided into two main groups: 1) those located above the Copper Creek Dam site; and 2) those below the Copper Creek Dam site. In addition the sample transects in these two main groups were further divided into four

Table 6.10 **Discharge classification system and sampling scheme for the 20 sample transects in the upper Skagit River.**

River section below or near:	Discharge ranges (cfs)		
	Low	Medium	High
Gorge Powerhouse Mean = 2200 cfs	900–1700	1700–2400	2400-6025
Newhalem Creek + 124 cfs	1024-1824	1824-2524	2524-6149
Goodell Creek + 172 cfs	1196-1996	1996-2696	2696-6321
USGS above Alma Creek + 348	1544-2344	2344-3044	3044-6669
Bacon Creek + 225 cfs	1769-2569	2569-3269	3269-6894
USGS Marblemount + 387 cfs	2156-2956	2956-3656	3656-7281
Cascade River + 755 cfs	2911-3711	3711-4411	4411-8036
Sauk River + 2753 cfs	5664-6464	6464-7164	7164-10789
Baker River + 2110 cfs	7774-8574	8574-9274	9274-12899

subgroups: 1) those located between Newhalem and the Copper Creek Dam site; 2) those between the Copper Creek Dam site and the Cascade River; 3) those between the Cascade River and the Sauk River; and 4) those between the Sauk River and the Baker River.

The method precludes making statements about the degree of significance of the numerical differences discussed. We observed some areas in our Skagit River reference reaches that were potentially spawnable based on depth and velocity but were not utilized by spawning fish. In an attempt to assign significance to numerical differences presented, these results were compared to available observed distribution data. The relative importance of the various river sections is discussed based on potential and observed distribution data.

For chum and steelhead comparisons were made for the sections between Newhalem and Baker River. For chinook and pink salmon comparisons were made for the sections between Newhalem and Sauk River with separate tables provided to facilitate the comparisons.

In the sections that follow for the individual species the maximum and minimum values for the parameters are usually discussed. In addition comparisons were made between sections upstream and downstream of Copper Creek Dam site. Comparisons and discussions were usually based on the one discharge classification (either low, medium, or high) that provided the highest overall value even though for a single river section a value may have been higher for a different discharge category. This follows from the idea that a river must be managed as a unit and cannot be managed to optimize conditions in individuals river sections when the sections have differing qualities.

6.4.6.1 Chinook Salmon. The mean spawnable width for chinook salmon was greatest at a medium flow for five of the six river sections listed in Table 6.11. The analysis in Reference Reaches 1-3 predicted a peak spawning discharge of 3,417 cfs. The mean natural flow directly below Gorge Powerhouse for September and October was 2,200 cfs which was in the medium category. By prorating 2,200 cfs downstream to include tributary inflow, the discharge increased to 3,456 cfs just above the Cascade River (near Reference Reach 3). The mean of 2,200 cfs and 3,456 cfs was 2,828 cfs (i.e., the mean discharge for the Skagit between Gorge Powerhouse and the Cascade River). This figure was 589 cfs less than the 3,417 cfs predicted by the reference reach analysis.

Between Newhalem and the Copper Creek Dam site the mean spawnable width for chinook salmon was 50 ft. This figure was the lowest one in any of the river sections listed in Table 6.11. The mean spawnable width was greatest at 139 ft in the river between the Copper Creek Dam site and the Cascade River.

Above the proposed dam site there was an estimated spawnable area for chinook salmon of 2,678 $ft^2 \times 10^3$ at a medium flow, and below the dam there were 15,379 $ft^2 \times 10^3$ (Table 6.12). This difference was due in part to the larger wetted area below the dam site, but in addition there was proportionately more of it that was potentially spawnable for chinook

Table 6.11 Mean spawnable widths for chinook, pink, and chum salmon in the Skagit River between Newhalem and the Baker River. Mean river width and the percentage of the mean river width suitable for spawning are listed.

River section	Discharge classification	Mean river width (ft)	Mean spawnable width for chinook (ft)	Percent of mean river width	Mean spawnable width for pink (ft)	Percent of mean river width	Mean spawnable width for chum (ft)	Percent of mean river width
Newhalem to Copper Creek Dam Site (10.2 mi)	Low	209	37	17	34	16	71	34
	Medium	233	50	21	37	16	74	32
	High	274	36	13	19	7	41	15
Copper Creek Dam Site to Cascade R. (5.9 mi)	Low	236	125	53	54	23	151	64
	Medium	249	139	56	45	18	103	41
	High	293	62	21	23	8	44	15
Cascade River to Sauk River (11.1 mi)	Low	317	57	18	32	10	162	51
	Medium	355	83	24	30	9	144	41
	High	378	53	14	32	8	69	18
Sauk River to Baker River (10.5 mi)	Low	431	84	20	65	15	150	35
	Medium	504	111	22	61	12	157	31
	High	527	144	27	73	14	184	35
Subtotal								
Copper Creek Dam Site to Baker R. (27.5 mi)	Low	343	82	24	49	14	155	45
	Medium	389	106	27	45	12	140	36
	High	417	90	22	45	11	108	26
Total								
Newhalem to Baker River (37.7 mi)	Low	307	70	23	45	15	132	43
	Medium	347	91	26	43	12	122	35
	High	378	75	20	38	10	90	24

salmon. While approximately 27 percent of the total wetted area below the proposed dam was classified as spawnable, 21 percent of the wetted area above the dam site was considered in this category (Table 6.12). This was partly because of the presence of a set of long, turbulent rapids above the dam site between RM 85.8 and RM 87.2 that provided very little spawnable area for salmon.

The Skagit between the dam site and the Cascade River had the largest percentage, or 56 percent of its wetted area available to spawning chinook salmon (Table 6.12). The other three sections had similar percentages, 21-24 percent, of their total wetted area classified as spawnable.

Table 6.13 compares the estimated chinook salmon spawnable area in each river section as a percentage of the total estimated spawnable area between Newhalem and the Baker River. The 10.2 mi of river between Newhalem and the Copper Creek Dam site contained a disproportionately small amount of estimated spawnable area than its length would indicate. This section contained 15 percent of the total chinook spawnable area while it comprised 27 percent of the river section length. Conversely, the sections between the Copper Creek Dam site and the Cascade River and between the Sauk River and Baker River contained a disproportionately large amount of estimated spawnable area than their lengths would indicate, 24 percent versus 16 percent and 34 percent versus 28 percent, respectively. The percentages for the remaining section, Cascade River to Sauk River, were similar.

Based upon the amount of estimated spawnable area per acre of wetted area available, the Skagit above the dam site averaged 9.3 $ft^2 \times 10^3$/acre while below the dam site it averaged 11.8 $ft^2 \times 10^3$/acre (Table 6.13).

Based upon the amount of spawnable area per river mile, the Skagit above the dam site averaged 263 $ft^2 \times 10^3$/mi compared to the river below the dam site which averaged 559 $ft^2 \times 10^3$/mi (Table 6.13). The river between the proposed dam site and the Cascade River contained the largest amount of spawnable area per river mile, 735 $ft^2 \times 10^3$/mi, compared to 479 $ft^2 \times 10^3$/mi, the mean value for the Skagit between Newhalem and the Baker River.

Another important comparison was between the percentage of the estimated spawnable area in the various river sections and the actual percentage of chinook salmon that spawned there based on the aerial photograph counts. It was previously stated that chinook redd counts were not made below the Sauk River because of the turbidity. If the sample transects below the Sauk River were excluded from the spawnable area analysis, then at a medium flow 23 percent of the total estimated chinook salmon spawnable area was located above the dam site (Table 6.14). In 1975 and 1976, 29.4 percent and 25.5 percent, respectively, of all the chinook salmon redds counted from aerial photographs were in this area (Table 6.5). The river section between the Copper Creek Dam site and the Cascade River contained 36 percent of the total chinook spawnable area above the Sauk; in 1975 and 1976, 35.3 percent and 45.8 percent, respectively, of the total chinook salmon redds were counted in this area.

Table 6.12 Estimated spawnable area for chinook, pink, and chum salmon in the Skagit River between Newhalem and the Baker River. Estimated wetted area and the percentage of the estimated wetted area spawnable are listed.

River section	Discharge classification	Estimated wetted area ($ft^2 x10^3$)	Estimated chinook spawnable area ($ft^2 x10^3$)	% of wetted area	Estimated pink spawnable area ($ft^2 x10^3$)	% of wetted area	Estimated chum spawnable area ($ft^2 x10^3$)	% of wetted area
Newhalem to Copper Creek Dam Site (10.2 mi)	Low	11,265	1,966	17	1,843	16	3,841	34
	Medium	12,558	2,678	21	1,985	16	3,991	32
	High	14,758	1,940	13	1,005	7	2,182	15
Copper Creek Dam Site to Cascade River (5.9 mi)	Low	7,339	3,887	53	1,678	23	4,693	64
	Medium	7,764	4,337	56	1,415	18	3,204	41
	High	9,127	1,926	21	722	8	1,384	15
Cascade River to Sauk River (11.1 mi)	Low	18,580	3,348	18	1,848	10	9,490	51
	Medium	20,779	4,880	24	1,783	9	8,421	41
	High	22,176	3,105	14	1,852	8	4,045	18
Sauk River to Baker River (10.5 mi)	Low	23,877	4,647	20	3,578	15	8,300	35
	Medium	27,959	6,162	22	3,360	12	8,718	31
	High	29,195	7,961	27	4,020	14	10,225	35
Subtotal Copper Creek Dam Site to Baker R. (27.5 mi)	Low	49,797	11,883	24	7,104	14	22,483	45
	Medium	56,502	15,379	27	6,558	12	20,343	36
	High	60,499	12,992	22	6,595	11	15,654	26
Total Newhalem to Baker River (37.7 mi)	Low	61,061	13,849	23	8,947	15	26,324	43
	Medium	69,060	18,057	26	8,543	12	24,334	35
	High	75,257	14,933	20	7,599	10	17,836	24

Table 6.13 Percentage of the total estimated spawnable area for chinook salmon in various sections of the Skagit River between Newhalem and the Baker River, compared to the percentage of the total river miles in each section. Spawnable area per acre of wetted area and spawnable area per river mile are also listed.

River section	Discharge classification	Estimated chinook spawnable area ($ft^2 x 10^3$)	% of total estimated chinook spawnable area	% of total river miles	Estimated chinook spawnable area per acre of wetted area ($ft^2 x 10^3$/acre)	Estimated chinook spawnable area per river mile ($ft^2 x 10^3$/mi)
Newhalem to Copper Creek Dam Site (10.2 mi)	Low	1,966	14	27	7.5	193
	Medium	2,678	15	27	9.3	263
	High	1,940	13	27	5.7	190
Copper Creek Dam Site to Cascade River (5.9 mi)	Low	3,887	28	16	23.1	659
	Medium	4,337	24	16	24.3	735
	High	1,926	13	16	9.2	326
Cascade River to Sauk River (11.1 mi)	Low	3,348	24	29	7.8	302
	Medium	4,880	27	29	10.2	440
	High	3,105	21	29	6.1	280
Sauk River to Baker River (10.5 mi)	Low	4,647	34	28	8.5	443
	Medium	6,162	34	28	9.6	587
	High	7,961	53	28	11.9	758
Subtotal Copper Creek Dam Site to Baker R. (27.5 mi)	Low	11,883	86	73	10.4	432
	Medium	15,379	85	73	11.8	559
	High	12,992	87	73	9.4	478
Total Newhalem to Baker River (37.7 mi)	Low	13,847	100	100	9.9	367
	Medium	18,057	100	100	11.4	479
	High	14,933	100	100	8.6	396

The river between the dam site and the Sauk River contained 77 percent of the chinook salmon spawnable area above the Sauk (Table 6.14) while in 1975 and 1976, respectively, 70.6 percent and 74.4 percent of the total chinook salmon redds were counted in this same area (Table 6.5).

The order of relative importance for the potential and observed distribution data for river sections between Newhalem and Sauk River was identical. The magnitudes of the percent distribution were in general agreement for the two sets of data.

6.4.6.2 Pink Salmon. The mean spawnable width for pink salmon was greatest at a low flow for the Skagit River between Newhalem and Baker River, although not strongly so (Table 6.11). The analysis in Reference Reaches 1-3 predicted a peak spawning discharge for pink salmon of 1,824 cfs. This figure was included in the low flow range for most of the river sections between the Gorge Powerhouse and the Cascade River (Table 6.10), which was also the area covered between Reference Reaches 1-3. The mean discharge of the low flow category for the area directly below the Gorge Powerhouse was 1,331 cfs. By prorating 1,331 cfs downstream to include tributary inflow, the discharge increased to 2,587 cfs just above the Cascade River. The mean of 1,331 cfs and 2,587 cfs was 1,959 cfs. This figure was only 135 cfs more than the 1,824 cfs predicted by the reference reach analysis.

The greatest mean spawnable width was 65 ft, and it occurred between the Sauk River and the Baker River (Table 6.11). The sections with the smaller mean spawnable widths for pink salmon were between the Cascade River and Sauk River and between Newhalem and Copper Creek Dam site with mean spawnable widths of 32 ft and 34 ft, respectively. Above the dam site there was an estimated spawnable area of 1,843 $ft^2 \times 10^3$ and below there was 7,104 $ft^2 \times 10^3$ (Table 6.12). The spawnable area above the dam site was 16 percent of the wetted area available while the spawnable area below the dam site comprised 14 percent of the wetted area.

Twenty-one percent of the estimated spawnable area was above the dam site, and the 10.2 river miles in question comprised 27 percent of the 37.7 mi of the Skagit studied (Table 6.15). Conversely, the other 79 percent of the estimated spawnable area was below the proposed dam.

Based upon the amount of estimated spawnable area per acre of wetted area available, the Skagit above the dam site averaged 7.1 $ft^2 \times 10^3$/acre, while below the proposed dam site it averaged 6.2 $ft^2 \times 10^3$/acre (Table 6.15).

However, based upon the amount of spawnable area per river mile, Skagit above the Copper Creek Dam site averaged 181 $ft^2 \times 10^3$/mi while from the Copper Creek site to the Baker River it averaged 258 $ft^2 \times 10^3$/mi (Table 6.15). The river section with the largest amount of estimated spawnable area per acre of wetted area was between Copper Creek Dam site and Cascade River (10.0 $ft^2 \times 10^3$/acre) and per river mile was between Sauk and Baker rivers (341 ft^2 10^3/mi). By comparison the Newhalem to Baker River section as a whole had 6.4 $ft^2 \times 10^3$/acre and 273 ft^2 10^3/mi.

Table 6.14 Percentage of the total estimated spawnable area for chinook salmon in various sections of the Skagit River between Newhalem and the Sauk River, compared to the percentage of the total river miles in each section.

River section	Discharge classification	Estimated chinook spawnable area ($ft^2 x 10^3$)	% of total estimated chinook spawnable area above Sauk R.	% of total river miles above Sauk R.
Newhalem to Copper Creek Dam Site (10.2 mi)	Low	1,966	21	38
	Medium	2,678	23	38
	High	1,940	28	38
Copper Creek Dam Site to Cascade R. (5.9 mi)	Low	3,887	42	22
	Medium	4,337	36	22
	High	1,926	28	22
Cascade River to Sauk River (11.1 mi)	Low	3,348	36	41
	Medium	4,886	41	41
	High	3,105	45	41
Subtotal Copper Creek Dam Site to Sauk R. (17.1 mi)	Low	7,236	79	63
	Medium	9,217	77	63
	High	5,031	72	63
Total Newhalem to Sauk River (27.2 mi)	Low	9,202	100	100
	Medium	11,895	100	100
	High	6,971	100	100

Table 6.15 Percentage of the total estimated spawnable area for pink salmon in various sections of the Skagit River between Newhalem and the Baker River, compared to the percentage of the total river miles in each section. Spawnable area per acre of wetted area and spawnable area per river mile are also listed.

River section	Discharge classification	Estimated pink spawnable area ($ft^2 x 10^3$)	% of total estimated pink spawnable area	% of total river miles	Estimated pink spawnable area per acre of wetted area ($ft^2 x 10^3$/acre)	Estimated pink spawnable area per river mile ($ft^2 x 10^3$/mi)
Newhalem to Copper Creek Dam Site (10.2 mi)	Low	1843	21	27	7.1	181
	Medium	1985	23	27	6.9	195
	High	1005	13	27	3.0	99
Copper Creek Dam Site to Cascade River (5.9 mi)	Low	1678	19	16	10.0	284
	Medium	1415	17	16	7.9	240
	High	722	10	16	3.4	122
Cascade River to Sauk River (11.1 mi)	Low	1848	21	29	4.3	166
	Medium	1783	21	29	3.7	161
	High	1852	24	29	3.7	167
Sauk River to Baker River (10.5 mi)	Low	3578	40	28	6.5	341
	Medium	3360	39	28	5.2	320
	High	4020	53	28	6.0	383
Subtotal Copper Creek Dam Site to Baker R. (27.5 mi)	Low	7104	79	73	6.2	258
	Medium	6558	77	73	5.1	238
	High	6595	87	73	4.7	240
Total Newhalem to Baker River (37.7 mi)	Low	8947	100	100	6.4	237
	Medium	8543	100	100	5.4	227
	High	7599	100	100	4.4	202

Comparisons were made between the estimated spawnable area for pink salmon in river sections between Newhalem and the Sauk River and the observed spawner distribution in those sections during 1977. Approximately one-third of the total estimated pink spawnable area was contained in each of the three sections between Newhalem and Sauk River (Table 6.16). The spawner distribution survey conducted in 1977 (Table 6.7) indicated that 39.5 percent of the spawned area was observed above the Copper Creek Dam site, 47.5 percent between Copper Creek Dam site and Cascade River, and 13.0 percent between Cascade and Sauk rivers. The order of relative importance for the sections between Newhalem and Sauk River were identical for both data sets. Agreement between the pairs of values was not good, however, but as indicated in Sec. 6.4.3.2 may relate to flow conditions during the incubation phase of the life cycle.

6.4.6.3 Chum Salmon. The mean spawnable width for chum salmon in the river as a whole was largest for the low discharge classification (Table 6.11).

The greatest mean spawnable width of 162 ft occurred in the Skagit between the Cascade and Sauk rivers (Table 6.11). The smallest mean spawnable width for chum salmon was 71 ft between Newhalem and the Copper Creek Dam site. Above the dam there was an estimated spawnable area of 3,841 $ft^2 \times 10^3$ and below there was 22,483 $ft^2 \times 10^3$ (Table 6.12). The spawnable area above the dam site was 34 percent of the total wetted area available while the spawnable area below the dam site comprised 45 percent of the total wetted area.

There was 14.8 $ft^2 \times 10^3$ of spawnable area per acre of wetted area above the dam site and 19.6 $ft^2 \times 10^3$ of spawnable area per acre of wetted area below the dam site (Table 6.17).

The total amount of chum salmon spawnable area might have been overestimated due to the wide 80 percent preferred spawning depth range mentioned in Sec. 6.4.1.5. However, the relative percentage of spawnable area in different sections of the Skagit would probably not have been affected.

Fifteen percent of the estimated spawnable area for chum salmon occurred above the proposed dam site, and the 10.2 mi of the Skagit in question represented 27 percent of the river miles studied (Table 6.17). This percentage was similar to the percentage of the estimated chinook salmon spawnable area above the dam site which ranged from 13 15 percent (Table 6.13).

The section predicted to be most important for chum salmon spawning was the 11.1 mi between the Cascade and Sauk rivers. In this stretch there were 855 $ft^2 \times 10^3$ of spawnable area per mile compared to 698 $ft^2 \times 10^3$ of spawnable area per mile for the entire Skagit between Newhalem and the Baker River (Table 6.17). From Newhalem to the proposed Copper Creek Dam site, the Skagit averaged 377 $ft^2 \times 10^3$ of spawnable area per mile for chum salmon, while from the Copper Creek site to the Baker River it averaged 818 $ft^2 \times 10^3$ of spawnable area per mile.

Table 6.16 Percentage of the total estimated spawnable area for pink salmon in various sections of the Skagit River between Newhalem and the Sauk River, compared to the percentage of the total river miles in each section.

River section	Discharge classification	Estimated pink spawnable area ($ft^2 x 10^3$)	% of total estimated pink spawnable area above Sauk R.	% of total river miles above Sauk R.
Newhalem to Copper Creek Dam Site (10.2 mi)	Low	1843	34	38
	Medium	1985	38	38
	High	1005	28	38
Copper Creek Dam Site to Cascade R. (5.9 mi)	Low	1678	31	22
	Medium	1415	27	22
	High	722	20	22
Cascade River to Sauk River (11.1 mi)	Low	1848	34	41
	Medium	1783	34	41
	High	1852	52	41
Subtotal Copper Creek Dam Site to Sauk R. (17.1 mi)	Low	3526	66	63
	Medium	3198	62	63
	High	2574	72	63
Total Newhalem to Sauk River (27.2 mi)	Low	5369	100	100
	Medium	5183	100	100
	High	3579	100	100

Table 6.17 **Percentage of the total estimated spawnable area for chum salmon in various sections of the Skagit River between Newhalem and the Baker River, compared to the percentage of the total river miles in each section. Spawnable area per acre of wetted area and spawnable area per river mile are also listed.**

River section	Discharge classification	Estimated chum spawnable area (ft^2x10^3)	% of total estimated chum spawnable area	% of total river miles	Estimated chum spawnable area per acre of wetted area (ft^2x10^3/acre)	Estimated chum spawnable area per river mile (ft^2x10^3/mi)
Newhalem to Copper	Low	3,841	15	27	14.8	377
Creek Dam Site	Medium	3,991	16	27	13.8	391
(10.2 mi)	High	2,182	12	27	6.4	214
Copper Creek Dam	Low	4,693	18	16	27.9	795
Site to Cascade	Medium	3,204	13	16	18.0	543
River (5.9 mi)	High	1,384	8	16	6.6	235
Cascade River to	Low	9,490	36	29	22.3	855
Sauk River	Medium	8,421	35	29	17.6	759
(11.1 mi)	High	4,045	23	29	7.9	365
Sauk River to	Low	8,300	32	28	15.2	790
Baker River	Medium	8,718	36	28	13.6	830
(10.5 mi)	High	10,225	57	28	15.2	974
Subtotal						
Copper Creek Dam	Low	22,483	85	73	19.6	818
Site to Baker R.	Medium	20,343	84	73	15.8	740
(27.5 mi)	High	15,654	88	73	11.3	569
Total						
Newhalem to	Low	26,324	100	100	18.8	698
Baker River	Medium	24,334	100	100	15.3	645
(37.7 mi)	High	17,836	100	100	10.3	473

The river section with the highest potential and observed utilization (Table 5.17 and Sec. 6.4.3.3, respectively) was between the Cascade and Sauk rivers, but it was more heavily utilized than predicted (36 percent versus 65.6 percent). Overall, the sections upstream of Cascade River were less utilized than predicted but direct comparisons could not be made because the divisions between sections was at Copper Creek Dam site (RM 84.0) for potential and "canyon" (RM 89) for observed. The section between Sauk and Baker rivers was also less utilized than predicted.

6.4.6.4 Steelhead Trout. The mean spawnable width for steelhead trout in the river as a whole was largest for the low discharge classification (Table 6.18).

The greatest mean spawnable width of 76 ft occurred in the Skagit between the Copper Creek Dam site and the Cascade River. Above the dam site, there was an estimated spawnable area of 1,224 $ft^2 \times 10^3$ and below there was 8,375 $ft^2 \times 10^3$ (Table 6.18). The spawnable area above the dam site was 11 percent of the total wetted area available while the spawnable area below the dam site was 17 percent of the total wetted area. There were 4.7 $ft^2 \times 10^3$ of spawnable area per acre of wetted area above the dam site and 7.3 $ft^2 \times 10^3$ of spawnable area per acre of wetted area below the dam site (Table 6.19).

Thirteen percent of the estimated spawnable area for steelhead trout occurred above the proposed dam site, and the 10.2 mi of the Skagit in question represented 27 percent of the river miles studied (Table 6.19). This percentage was similar to the percentage of the estimated chinook spawnable area, 13-15 percent, and chum spawnable area, 12-16 percent, above the dam site (Tables 6.13 and 6.17, respectively).

The river section predicted to be most important for steelhead trout spawning was the 5.9 mi between the Copper Creek Dam site and the Cascade River whereas the highest observed utilization was in the Cascade to Sauk section (Sec. 6.4.3.4). Between the project site and the Cascade River there were 399 $ft^2 \times 10^3$ of spawnable area per mile, compared to 255 $ft^2 \times 10^3$ of spawnable area per mile for the entire Skagit between Newhalem and the Baker River (Table 6.19). From Newhalem to the proposed Copper Creek Dam site, the Skagit averaged 120 $ft^2 \times 10^3$ of spawnable area per mile for steelhead trout, whereas from the Copper Creek site to the Baker River it averaged 305 $ft^2 \times 10^3$ of spawnable area per mile (Table 6.19).

A comparison was made between the percentage of the estimated spawnable area for steelhead trout in each river section above the Baker River (Table 6.19) and the percentage of steelhead redds observed on the aerial survey counts (Table 6.4). Thirteen percent of the total estimated spawnable area for steelhead was located above the proposed dam site, while between 1975 and 1978, 2 percent of the steelhead redds (peak counts) were located between Newhalem and Bacon Creek (1.1 mi below the dam site). The river section between Copper Creek Dam site and the Cascade River contained 25 percent of the total steelhead spawnable area above the Sauk; between 1975 and 1978, 20 percent of the steelhead trout redds were observed between Bacon Creek and the Cascade River. The river

Table 6.18 Mean spawnable width and estimated spawnable area for steelhead trout in the Skagit River between Newhalem and the Baker River. Mean river width, estimated wetted area, and the percentage of the mean river width and estimated wetted area suitable for spawning are listed.

River section	Discharge classification	Mean river width (ft)	Mean spawnable width for steelhead (ft)	Percent of mean river width	Estimated wetted area ($ft^2 x10^3$)	Estimated steelhead spawnable area ($ft^2 x10^3$)	Percent of wetted area
Newhalem to Copper	Low	209	23	11	11,265	1,224	11
Creek Dam Site	Medium	233	32	14	12,558	1,715	14
(10.2 mi)	High	274	18	7	14,758	973	7
Copper Creek Dam	Low	236	76	32	7,339	2,356	32
Site to Cascade R.	Medium	249	48	19	7,764	1,478	19
(5.9 mi)	High	293	22	8	9,127	690	8
Cascade River to	Low	317	43	14	18,580	2,543	14
Sauk River	Medium	355	26	7	20,779	1,542	7
(11.1 mi)	High	378	27	7	22,176	1,593	7
Sauk River to	Low	431	63	14	23,877	3,475	14
Baker River	Medium	504	59	12	27,959	3,244	12
(10.5 mi)	High	527	100	19	29,195	5,517	19
Subtotal							
Copper Creek Dam	Low	343	58	17	49,797	8,375	17
Site to Baker R.	Medium	389	43	11	56,502	6,264	11
(27.5 mi)	High	417	54	13	60,499	7,806	13
Total							
Newhalem to Baker	Low	307	48	16	61,061	9,599	16
River	Medium	347	40	12	69,060	7,979	12
(37.7 mi)	High	378	44	12	75,257	8,773	12

Table 6.19 Percentage of the total estimated spawnable area for steelhead trout in various sections of the Skagit River between Newhalem and the Baker River, compared to the percentage of the total river miles in each section. Spawnable area per acre of wetted area and spawnable area per river mile are also listed.

River section	Discharge classification	Estimated steelhead spawnable area ($ft^2 x 10^3$)	% of total estimated steelhead spawnable area	% of total river miles	Estimated steelhead spawnable area per acre of wetted area ($ft^2 x 10^3$/acre)	Estimated steelhead spawnable area per river mile ($ft^2 x 10^3$/mi)
Newhalem to Copper Creek Dam Site (10.2 mi)	Low	1224	13	27	4.7	120
	Medium	1715	22	27	5.9	168
	High	973	11	27	2.9	95
Copper Creek Dam Site to Cascade River (5.9 mi)	Low	2356	25	16	14.0	399
	Medium	1478	19	16	8.3	251
	High	690	8	16	3.3	117
Cascade River to Sauk River (11.1 mi)	Low	2543	27	29	6.0	229
	Medium	1542	19	29	3.2	139
	High	1593	18	29	3.1	144
Sauk River to Baker River (10.5 mi)	Low	3475	36	28	6.4	331
	Medium	3244	41	28	5.1	309
	High	5517	63	28	8.2	525
Subtotal						
Copper Creek Dam Site to Baker R. (27.5 mi)	Low	8375	87	73	7.3	305
	Medium	6264	79	73	4.8	228
	High	7800	89	73	5.6	284
Total						
Newhalem to Baker River (37.7 mi)	Low	9599	100	100	6.8	255
	Medium	7979	100	100	5.1	212
	High	8773	100	100	5.1	233

between the dam site and the Baker River contained 87 percent of the steelhead trout spawnable area above the Baker River (Table 6.19), while between 1975 and 1978, 98 percent of the steelhead trout redds were counted between Bacon Creek and the Baker River.

The order of relative importance of river sections between Newhalem and Baker River based on potential and observed distribution data was dissimilar. Agreement between the pairs of values was poor except for the section between Copper Creek Dam site and Cascade River.

6.4.6.5 Potential Spawnable Area and Escapement. Over the entire range of discharges occurring during the 1976 chinook, pink, and chum salmon spawning seasons, no more than 6 percent for chinook, 23 percent for pink, and 14 percent for chum salmon of the total estimated spawnable area in the reference reaches was ever actually utilized. A report by the WDF (Ames and Phinney 1977) stated: "Escapement goals for chinook salmon have been based on both historical escapements and the amout of available spawning area. In most cases, the spawning area available to chinook greatly exceeds the amount needed to support rational spawning escapements." This statement probably held true for pink and chum salmon as well. That was because all the spawnable areas discussed in this report were potential spawnable areas, and this meant salmon would find these areas suitable for spawning based solely on depth and velocity. Only a portion of these areas was ever actually utilized. Thus, an optimum or even reasonable salmonid escapement estimate could not be obtained by simply taking the amount of potential spawnable area estimated in this study and dividing by the average spawning pair territory or redd size.

7.0 INCUBATION AND EMERGENCE

7.1 Introduction

Water temperatures in the Skagit River have been altered by the completion of Ross, Diablo, and Gorge dams. Burt (1973) has estimated that the effect of the three reservoirs has been to elevate the river temperature above predam conditions during all times of the year, but more so during late fall and winter when salmon eggs are incubating in the gravels of the river bottom (Fig. 7.1). A similar conclusion was reached for the fall and early winter period by assuming that the Sauk and Cascade rivers are models of predam temperature conditions (Fig. 2.25). Since the incubation period of salmon is controlled by the accumulation of temperature units (TU's) (cumulative degree-days above 32 ^{o}F)[1] to hatch and complete yolk absorption, an increase in water temperature will accelerate embryonic development.

The situation for steelhead trout is not so clearcut. Burt (1973) estimated higher temperature throughout the steelhead incubation period, March-August (Fig. 7.1), while comparisons between Skagit and Sauk-Cascade temperature were mixed during that period (Fig. 2.25).

The change in thermal regime suggested that salmon eggs and alevins incubating in the upper Skagit must be exposed to higher temperatures than under predam conditions. Although yolk absorption was believed to occur earlier at higher temperatures, it has been inferred that chinook fry may spend a longer period of time in the gravel between yolk absorption and emergence. If this latter behavior prevents or inhibits feeding, emerging chinook fry could be in poorer condition than in the natural situation, thus affecting survival. If, as a result of elevated temperature, salmon fry emerged earlier than in the natural situation they may be exposed to less favorable environmental conditions, again, possibly affecting their survival.

The objectives of these studies were to assess the effects of the present temperature pattern on salmonid egg incubation and timing of fry emergence and to predict the potential survival effects of different emergence timings resulting from different temperature regimes. Preliminary analysis indicated that river temperature changes predicted for Ross High Dam might have the greatest potential effect on eggs and alevins of chinook salmon. Chinook salmon were the primary focus of our field studies through mid-1977 and so the major portion of this section concerns them. Additional field studies extending into 1978 were initiated for pink, chum, and coho salmon. Results from these studies will be presented in our yearend report.

---

[1]Centrigrade temperature units = Fahrenheit temperature units x 5/9.

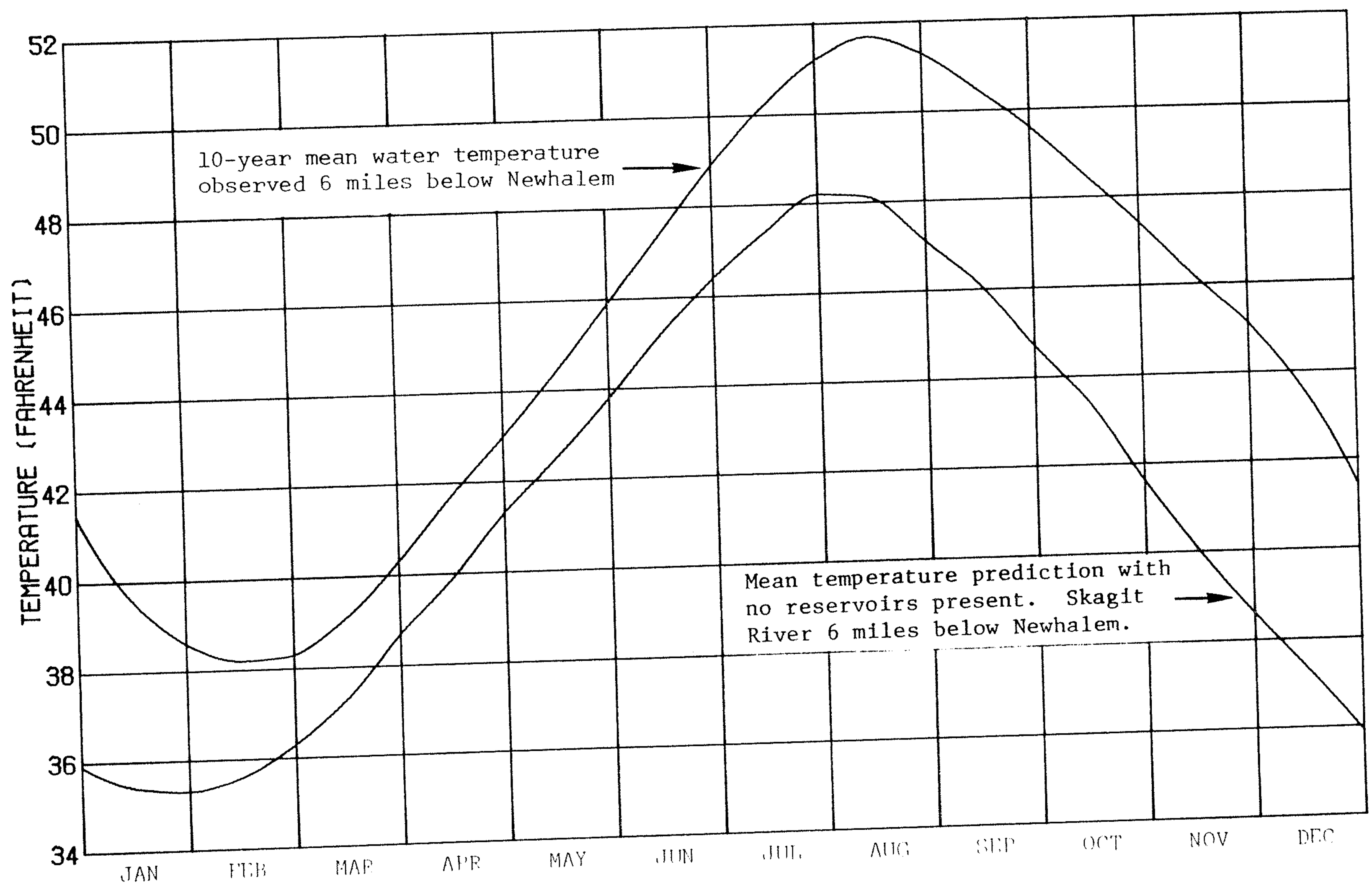

Fig. 7.1 Observed and forecast water temperatures for Skagit River (taken from Burt 1971, 1973).

7.2 Literature Review

There is little information in the literature on the temperature requirements of chinook salmon eggs to hatching, and more importantly, to emergence under natural conditions. Some measurements have been taken of TU's required to hatching under hatchery conditions. Most of this work has been done using constant temperatures. A notable exception is Seymour (1956) who exposed Sacramento, Entiat, Skagit, and Green rivers chinook salmon eggs to varying temperature regimes, simulating the natural pattern by beginning exposure on high but decreasing temperature as would be found in a river during the fall, then bottoming out at about 39 °F to represent winter conditions, and finally increasing temperatures to simulate spring conditions.

In one lot, Seymour subjected Skagit chinook eggs to a temperature regime averaging 49.4 °F which is close to the 47 °F experienced by Skagit chinook eggs in 1974. Seymour found that 974 TU's were required to 50 percent hatching of Skagit River chinooks under that temperature regime. Seymour concluded that the rate of development of Skagit eggs was intermediate between the faster developing Sacramento River chinook eggs and the slower developing Entiat River eggs.

Published literature on TU's to emergence proved difficult to find. Hatchery information was not applicable because most hatchery managers only note the most obvious stages of development, hatching and "swim-up." When alevins are incubated in substrate, "swim-up" coincides with yolk absorption, but under hatchery conditions it usually does not (Brannon 1974). The literature information concerning timing of the early life history of summer-fall chinook salmon is summarized in Table 7.1. Published studies of timing of the early life history of chinook under natural conditions are limited to Johnson (1974), Gebhards (1961), Wales and Coots (1954), Reimers and Loeffel (1967) and the reports of the Washington Department of Fisheries (WDF) on Columbia River spawning channels.

Skagit River chinook eggs experimentally incubated at the Marblemount Salmon Hatchery by WDF were estimated to require 1,700 TU's to yolk absorption (Johnson 1974).

Gebhards (1961) sampled a natural redd of a chinook salmon in the Lemhi River, Idaho, to determine development timing. He marked the redd in late August close to the peak spawning time of September 1, 1957. He states, "On December 12, a small section of gravel was dug from the spawning riffle and 34 sac fry (nine of them dead) were collected." It was his belief that hatching had occurred in early December. After placing a trap over the redd on January 21, 1958, he captured the first emergents from the redd on February 15 and the greatest number on February 19. The last fry to emerge did so on March 4.

Reimers and Loeffel (1967) calculated a mean egg deposition date, incubation period, hatching time and emergence date for fall chinooks in five selected tributaries of the Columbia River. Their calculations were

Table 7.1 Summary of literature information on the timing of the early life history of summer-fall chinooks under natural conditions.

Location	Peak spawning	Peak hatching	Peak emergence	Temperature units required to emergence	Author
Lemhi River, Idaho	Early September	Early December -	Mid-February		Gebhards (1961)
Klaskanine River, Washington	Mid-September	Mid-November -	Early February		Reimers and Loeffel (1967)
Fall Creek, California	Late September-end October[1]	--	January 1-April 1[1]		Wales and Coots (1954)
McNary Spawning Channel, Columbia River	Late September	--	December	1,800	Chambers (1963)
Wells Summer Chinook Spawning Channel, Columbia R.	Late October	--	Mid-February	1,600	Allen, Turner and Moore (1969-1972)
Skagit incubated at Marblemount Hatchery		--	--	1,700[2]	Johnson[3]

[1]No peak estimate was available.

[2]1974 estimate of temperature units required to yolk absorption at Marblemount Salmon Hatchery, Washington State Department of Fisheries.

[3]Personal communication.

made with TU information which they received through personal communication and not from data they collected. They mention that the TU requirements they used were for summer chinook, but they do not mention the exact number of TU's or from which stock they were derived. Of the five rivers they examined, the one which came closest (in timing of early life history) to approximating the Skagit was the Klaskanine River. Their estimate of peak spawning in this river was mid-September, peak hatching mid-November and peak emergence in early February. They report using monthly records of U.S. Geological Survey (USGS) data but they fail to give the exact temperatures used.

Wales and Coots (1954) studying the efficiency of chinook spawning in Fall Creek, California, found spawning to occur over approximately 1 month from late September to the end of October. No estimate of hatching time or the temperatures to which the eggs were exposed was given. However, trapping of downstream migrants showed emergence to occur from about January 1 to April 1.

Reports by WDF on Columbia River chinook salmon spawning channels also provide data on the early life history timing of chinooks. Chambers (1963), in his summary report of the McNary Dam Experimental Spawning Channel, reports that two races of chinook spawned in the channels--an upriver race and a local race. The upriver race could have been a mix of many different populations, and therefore, will not be considered here. The local race of chinooks began spawning in mid-September and peaked in late September-early October. Emergence peaked in December when fry had accumulated approximately 1,800 TU's.

Work done in 1968-1969 at Wells Summer Chinook Salmon Spawning Channel (Allen, et al. 1969) is of interest. Eggs of summer chinook which had historically spawned in the Wells Dam vicinity were planted on October 22 in the spawning channel. Samples removed periodically showed that between February 13 and February 27, all alevins had absorbed their yolks. Development to this point required approximately 1,600 TU's.

Because of the limited amount of published work on development rates of chinook salmon eggs and alevins at different temperature regimes, was necessary that we conduct further studies specific to the Skagit salmon population and river temperature conditions to determine the effects of altered temperature regimes on embryonic development, emergence timing and survival.

7.3 Study Area

These studies were conducted in the mainstem Skagit River between Newhalem and Rockport and in the lower Cascade and Sauk rivers (Fig. 7.2). Four study stations were established in the Skagit River:

Station 1--1/4 mi below Newhalem
Station 2--8 mi below Newhalem

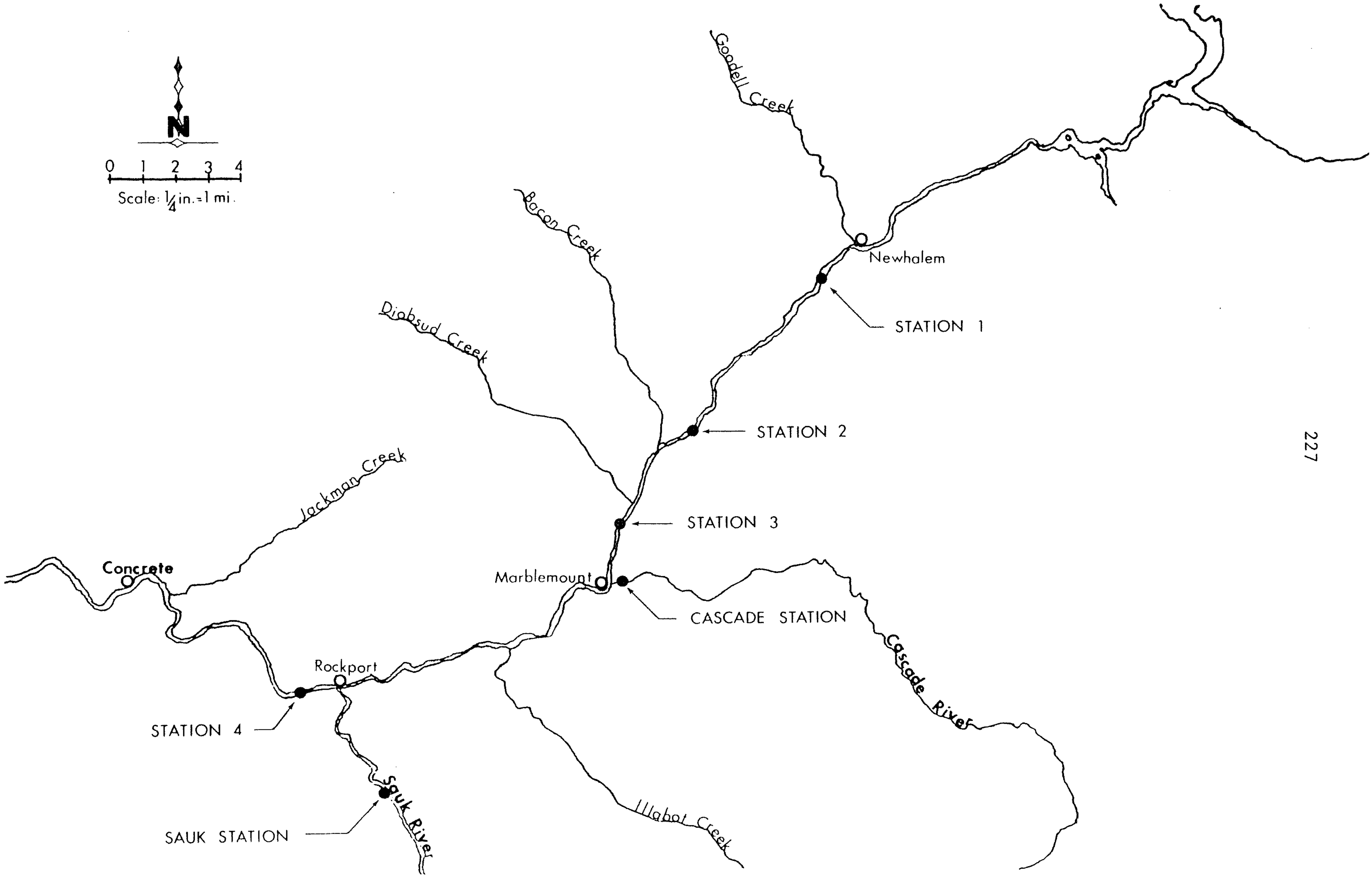

Fig. 7.2 Study stations on the Skagit, Sauk, and Cascade rivers.

Station 3--1 mi above the confluence of the Cascade
Station 4--1/2 mi below the confluence of the Sauk

One study station each was established in the Cascade River about 1/2 mile from its mouth and in the Sauk River about 5 mi from its mouth. Because it would be most affected by any dam-related temperature changes, major emphasis was given to the river immediately downstream from the present dam sites between Newhalem and the confluence of the Cascade. This area was characterized by pools and riffles with a predominantly gravel riverbed and was used to varying extents by spawning chinook, pink, and chum salmon and steelhead trout (Sec. 6.4.3).

7.4 Materials and Methods

7.4.1 Embryonic Development

Adult chinook salmon were netted out of the Skagit River near Marblemount during the 1974, 1975, and 1976 spawning seasons and transported to the Marblemount Hatchery. With the assistance of personnel from the hatchery, 1,000 to 3,500 eggs were removed from "ripe" females and fertilized with milt from chinook males. The procedure used was as follows:

1. Eggs stripped from female.
2. Milt added to eggs, mixed throughly and allowed to stand for about 5 min.
3. Eggs rinsed several times to remove excess sperm, blood clots, etc.
4. Let stand for 30-45 min. to water harden.
5. Transferred to appropriate size container and packed in cooler for transporting to incubation site.

Eggs from individual female chinook salmon were taken and fertilized on September 16, 1974, and September 3, 1975. Eggs were taken from four females over the course of the spawning season in 1976 and fertilization dates were September 8 and 16, and October 6 and 12.

Egg diameter and egg weight were determined after water hardening from samples of approximately 35 eggs from each female in 1976. Individual egg diameter was determined by measuring the total length of an egg sample as they lay in a groove and dividing by number of eggs. The weight of the total sample, determined using a top-loading Mettler balance (to 0.01 g), was divided by the number of eggs to determine individual egg weight.

In 1974 fertilized eggs were held overnight at the Marblemount Hatchery and planted the following day while in 1975 and 1976 they were transported immediately to the incubation sites for placement.

At the river incubation sites 50-80 eggs were placed in each of 6-12 perforated plastic containers (17-ounce capacity) containing gravel substrate. These, in turn, were placed in performated incubation boxes which rested on top of the river bottom and were secured to stable objects on the bank by a cable. In 1974 and 1975, 17- x 25- x 4-inch plywood incubation boxes were used which accommodated 12 plastic containers. Spaces between the containers were filled with rocks to prevent them from shifting, to break up and reduce the flow entering the boxes and flowing through the baffles, and to help hold down the boxes. In 1974, two incubation boxes were placed at each of four stations in the Skagit, while in 1975, one was placed at each of the three upstream stations in the Skagit and one each at the Cascade and Sauk stations.

To improve the sturdiness and durability, boxes of similar dimensions were constructed in 1976, using "expanded metal" for bottom, sides, and baffles, and with a hinged plywood lid to reduce light penetration. Four incubation boxes were placed at the Newhalem site (Station 1) for the Skagit, and one each in the Sauk and Cascade rivers for 1976.

Incubation boxes were monitored periodically during the incubation periods. The sampling schedule in 1974 and 1975 was to take samples every 200 TU's after blastopore formation, which requires 250-300 TU's, to monitor embryonic development. However, flow conditions dictated when containers could be removed and the original schedule could not be strictly followed in 1974.

Station 1, near Newhalem, proved to be the most successful incubation site because of its close proximity to the dams. Flow regulation by Gorge Powerhouse protected the site from flooding conditions and because much of the silt settles out in the upstream reservoirs, siltation in the egg containers was not a major problem as it had been at the downstream sites. In 1975, after losing one box to vandalism in late October, the others were destroyed by flooding in early December (Fig. 2.4). Based on the experience and information gained in 1974 and 1975, Station 1 was the only Skagit site used in 1976, and sampling was commenced just prior to the anticipated time for hatching and yolk asbsorption.

Sample size was varied at the individual sites depending on egg and/or alevin mortality to insure that enough organisms would be available for the entire sampling period. Lengths of individual fish were measured and fish were weighed in 5-mm length groups and condition factor was calculated at a later time. Specimens were preserved in Stockard's Solution in 1974 for later inspection to determine developmental stage. To determine time of hatching in 1976, specimens were removed, counted (hatched versus not hatched), and returned to the incubation boxes. Specimens to determine time of yolk absorption were preserved in 10 percent formalin and examined at a later time for the presence or absence of yolk.

The USGS recording thermometer, approximately 6 mi below Newhalem near Alma Creek, provided average daily temperature for the Skagit River in addition to Ryan 30-day continuous recording thermographs owned by Seattle City Light (SCL), located in the Sauk and Cascade rivers.

Chinook eggs were transported to the College of Fisheries Hatchery in Seattle for incubation studies in 1976. These eggs were also placed in perforated plastic containers containing gravel substrate, but were suspended in hatchery incubation troughs. The water temperature was controlled and maintained approximately 5 °F higher than measured in the Skagit near Newhalem. Samples were collected and preserved as indicated above for the 1976 river studies.

Temperature data were obtained from a Ryan 30-day continuous recording thermograph placed in the hatchery trough.

Specimens were examined to determine time to hatching and time to yolk absorption. For hatching it was simply noted whether the eggs were hatched or not hatched. The percentage of hatched fish was calculated for each sample and the date when 50 percent of the eggs had hatched was considered the mean hatching date. The presence or absence of yolk was determined by examining the body cavity of the fish by dissection. Yolk absorption was said to be completed when no yolk could be found. When 50 percent of the fish had absorbed their yolks, the mean yolk absorption date had been reached.

By summing the daily TU's over the period from fertilization to mean hatching and mean yolk absorption the respective TU requirements were obtained.

Based on TU requirement and the date of peak spawning determined in these studies for Skagit chinook, the theoretical timing to mean yolk absorption was determined for various temperature regimes. These included temperature regimes for the past several years in the Skagit; the mean, 1953-1977, Skagit River regime; recent and long-term temperature regimes for the Cascade and Sauk rivers; and the predicted regime assuming Copper Creek Dam was present. Similar comparisons were made for pink and chum salmon, and steelhead trout based on their spawning times and estimates of their TU requirements.

7.4.2 Timing of Emergence

Eggs from the same lot as those planted in the incubation boxes were buried in manmade redds on September 17, 1974. Two hundred eggs were buried at each of four stations in areas where natural spawning was observed. These "artificial" redds were then covered with 5- x 8-ft fry emergent nets, similar to the one described by Phillips and Koski (1969). The purpose of burying these eggs was to determine when fry of a known age would emerge from the gravel and this would provide information on whether chinook fry delay emergence after yolk absorption.

To determine when fry from naturally spawned eggs emerged from the gravel a natural redd at each station was marked on September 20, 1974, and it was noted that spawning had ceased on all four redds. Station 4 was subjected to a freshet in November (primarily caused by flooding of the Sauk) which obliterated the marked redd there, thus preventing it from being covered with an emergent net. The other three natural redds were covered with emergent nets like those used on the "artificial" redds, only larger--8 x 10 ft. Portions of the samples of captured fry were measured for length and weight, preserved, and later checked for remaining yolk.

Emergent nets were placed over manmade and natural redds in the fall of 1975 and 1976 to obtain further information about timing of emergence. High streamflow during early December 1975 and early January 1977 (Fig. 2.4 and 2.6, respectively), rendered them unusable and the studies were terminated.

By applying the TU requirement for yolk absorption to a chinook spawning curve, an emergence curve was constructed for the upper river (Newhalem to the Cascade River). "Theoretical emergence" was assumed to occur when 50 percent of the fish in a sample from incubation box studies had absorbed their yolks. The emergence data of fry from redds built on each day were calculated by summing the number of TU's from each day of spawning until eggs deposited on that day had accumulated the theoretical number of TU's required for emergence. In this way a curve showing the emergence period and the relative number of emerging fry was constructed. The information used for timing of chinook spawning in the upper Skagit River was obtained from spawning observations (number of new redds per day) obtained during 1976 (Sec. 6.4.2.1, Fig. 6.14).

A portion of the chinook eggs fertilized on October 12, 1976, was incubated in gravel substrate at the College of Fisheries Hatchery to determine the timing of emergence and associated TU's under the warmer hatchery conditions. Two hundred and fifty eggs were buried in gravel substrate in each of two compartments (26 x 12 x 6 inches) in a hatchery incubation trough. This was the same trough used for embryonic development studies described earlier and so was under the same temperature regime.

The compartments immediately downstream of the ones containing gravel and eggs were without gravel and were separated from the gravel compartment by a baffle with a 1-inch space at the bottom. The compartments without gravel were covered with black plastic to provide cover for newly emerged fry while the ones with gravel were left uncovered. Fry could, thus, emerge from the gravel at their own volition and move downstream into the nongravel compartment. The experiment was checked approximately daily and the fish in the nongravel compartment were removed, measured for length and weight, preserved, and later checked for remaining yolk.

7.5 Results

7.5.1 Embryonic Development

7.5.1.1 Chinook Salmon. Eggs taken from five female chinook salmon (one from the 1974 run and four from the 1976 run) were incubated in the Skagit River near Newhalem to determine date to mean hatching and to mean yolk absorption. In general, the temperature regime during the 1974-1975 incubation period was similar to that of the 23-year average, while in 1976-1977 it was warmer (Fig. 2.29).

The results of these studies are summarized in Table 7.2. Hatching probably began in mid-November 1974 when the eggs had accumulated about 940 °F TU's (Fig. 7.3), although this was not specifically determined because of inadequate sampling frequency. The date to mean yolk absorption was February 28, 1975. By summing TU's for the period September 16, 1974 to February 28, 1975, it was determined that chinook in the incubation boxes required approximately 1,913 °F TU's to yolk absorp- tion (Fig. 7.3).

For the 1976-1977 cycle the range of dates to mean hatching was November 5 to December 16, 1976 (Table 7.2). The range of TU's required was 968 to 1,000 TU's and the mean was 981 TU's (SD = 14). On the average it took 61 days from fertilization to hatching.

The range of dates to mean yolk absorption for the 1976-1977 cycle was February 6 to March 13, 1977 (Table 7.2). The number of TU's required ranged from 1,769 to 2,153 (Fig. 7.4). The mean number required from both years' data was 1,929 °F TU's (SD = 153). On the average 151 days passed between fertilization and yolk absorption. The range was from 139 to 165 days.

Comparisons were made between number of TU's required and mean incubation temperature and between number of TU's required and egg size to determine the relative influence of these two factors on developmental rate. For eggs from different females (Table 7.2) the correlation coefficient for TU's to hatching versus mean temperature was r = .66 and for TU's to yolk absorption versus mean temperature was r = .71. While not strongly correlated, developmental rate for eggs from different females appeared to be influenced by mean temperature during incubation. However, alevins from Females #1-76 and #2-76 incubated under similar mean temperatures, 46.0 and 45.9 °F, differed markedly in TU's to yolk absorption, 160 TU's. Alevins from Females #1-74 and #4-76 where mean temperature was 43.6 and 43.9 °F, respectively, differed in TU's to yolk absorption by about 100 TU's. In this case the eggs incubated at cooler mean temperature required more TU's than those incubated at warmer mean temperature. Weight and diameter were not measured for eggs from Female #1-74.

Individual egg diameter and egg weight were determined for eggs from each of the four female chinook salmon taken in 1976 (Table 7.3). Both diameter and weight were highly correlated to number of TU's required to mean yolk absorption with correlation coefficients (r) of .97 and 1.00, respectively. They were not well correlated, however, with numbers of TU's to mean hatching (r = .28 and .43, respectively).

Eggs from chinook Female #3-76 were incubated in the Cascade and Sauk rivers and at the College of Fisheries Hatchery in Seattle, as well as in the Skagit River at Newhalem during the 1976-1977 cycle. The water temperature was lower in the Cascade and Sauk rivers from mid-October 1976

Table 7.2 Summary of incubation studies for 1974-75 and 1976-77 cycles for eggs from Skagit River chinook salmon incubated near Newhalem. Shows dates, temperature units, number of days and mean temperature to mean hatching and to mean yolk absorption.

		To mean hatching				To mean yolk absorption			
Female	Date fertilized	Date	TU's (°F)	# of days	Mean temp. (°F)	Date	TU's (°F)	# of days	Mean temp. (°F)
#1-74	9-16-74	Not specifically determined				2-28-75	1913	165	43.6
#1-76	9- 8-76	11- 5-76	979	58	48.9	2- 9-77	2153	154	46.0
#2-76	9-16-76	11-13-76	968	58	48.7	2- 6-77	1994	143	45.9
#3-76	10- 6-76	12- 7-76	975	62	47.7	2-22-77	1769	139	44.7
#4-76	10-12-76	12-16-76	1000	65	47.4	3-13-77	1814	152	43.9
	Mean		981	61			1929	151	
	Standard deviation		14				153		

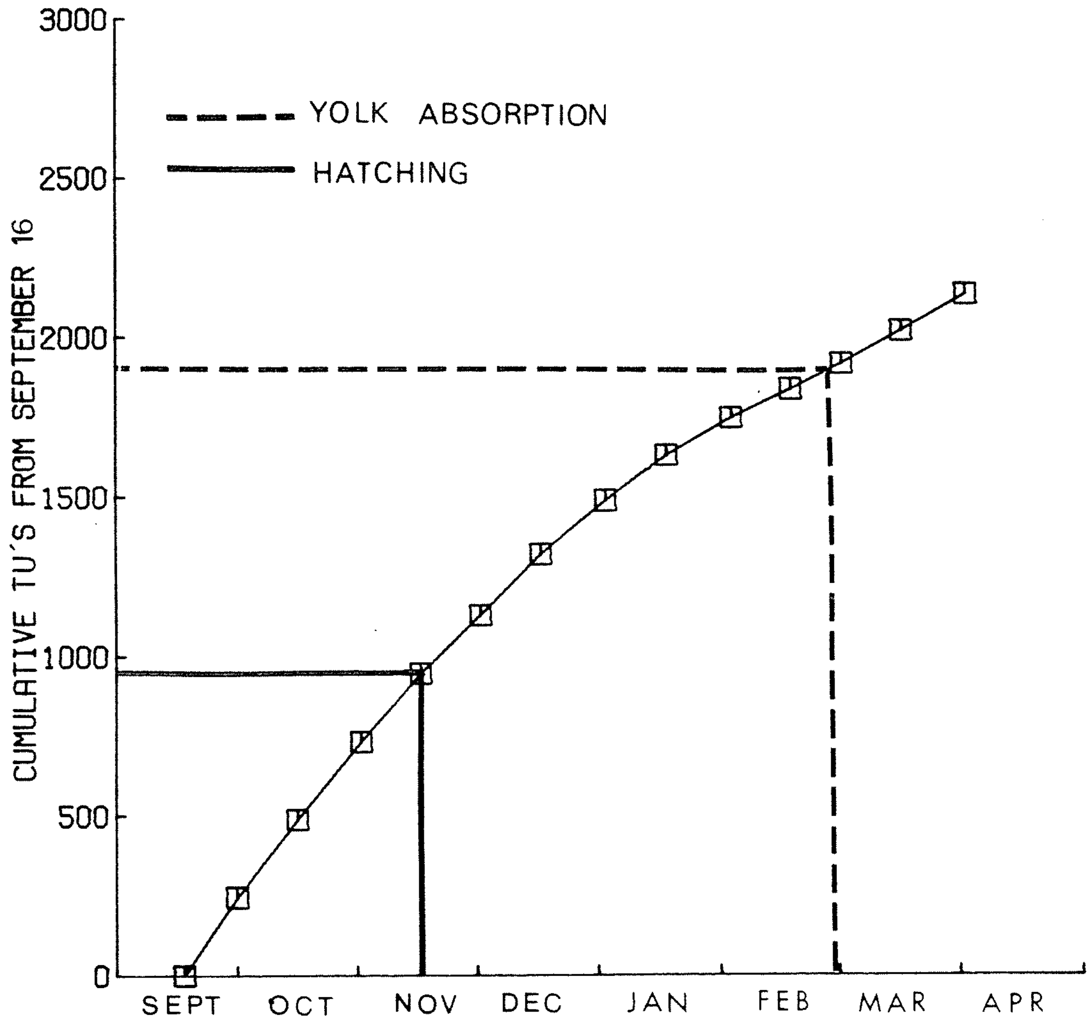

Figure 7.3 Cumulative temperature units (Fahrenheit) experienced by Skagit River chinook eggs in the Station 1 incubation box, commencing September 16, 1974.

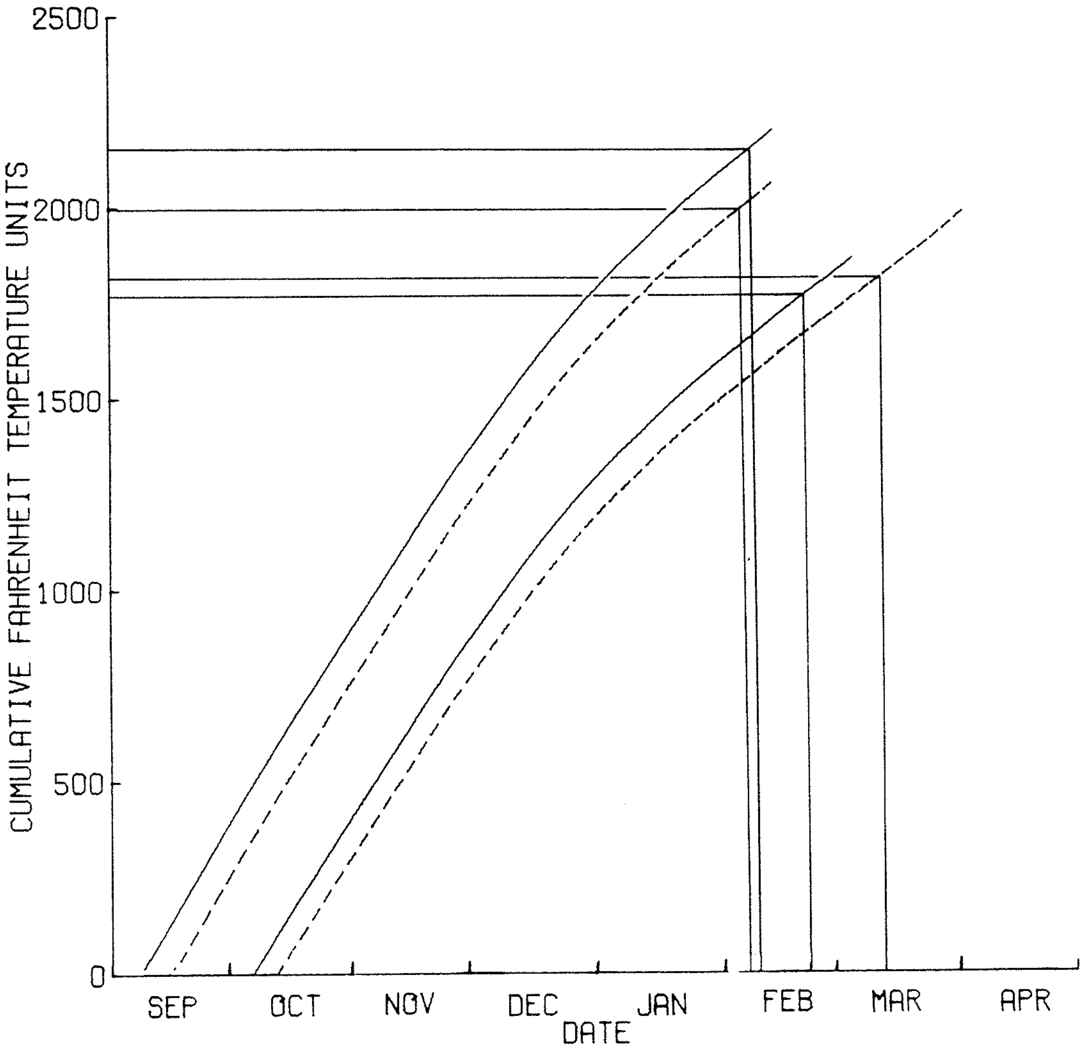

Fig. 7.4 Cumulative temperature units (Fahrenheit) experienced by Skagit River chinook eggs in the Station 1 incubation boxes, commencing September 8 and 16, and October 6 and 12, 1976. Observed dates and associated TU requirements of mean yolk absorption are shown.

Table 7.3 Egg weight, egg diameter, number of temperature units required to mean yolk absorption and to mean hatching, and mean incubation temperature to yolk absorption, for eggs taken from four chinook females in 1976.

Female No.	Egg weight (g)	Egg diameter (mm)	TU's to hatching (°F)	TU's to yolk absorption (°F)	Mean incubation temperature to yolk absorption (°F)
1-76	0.441	9.16	979	2153	46.0
2-76	0.383	8.77	968	1994	45.9
3-76	0.278	7.43	975	1769	44.7
4-76	0.287	7.96	1000	1814	43.9

to early February 1977 than it was in the Skagit, while at the University of Washington Hatchery it was maintained at about 5-6 ^{o}F higher (Fig. 7.5). It was assumed that egg diameter and weight were not variables in this experiment since the eggs were from an individual female and were presumably of similar size at the various sites.

The results of this experiment are presented in Table 7.4. Compared to the Skagit where mean hatching occurred December 7, the effect of the cooler Cascade and Sauk rivers was to retard development by about 40 days so that mean hatching occurred in mid-January 1977. The effect of the warmer conditions at the University of Washington Hatchery was to accelerate development by 15 days and mean hatching occurred on November 22, 1976. The average number of TU's required to mean hatching was 958 TU's.

These same trends were observed to mean yolk absorption also. Overall, the date to mean yolk absorption was delayed from February 22, in the Skagit to April 19 and 14 in the Cascade and Sauk, respectively (Fig. 7.6). This amounted to a delay of 56 days in the Cascade and 51 days in the Sauk. Development at the University of Washington Hatchery was accelerated and date of mean yolk absorption was advanced by 32 days from February 22 to January 21, 1977 (Fig. 7.6).

Eggs from Female #3-76 incubated under the cooler temperature regimes of the Cascade and Sauk rivers required less TU's, 1,710 and 1,662 TU's, respectively, than eggs from the same female incubated in the Skagit River with 1,769 TU's (Table 7.4). The converse was true and to a greater extent for eggs from the same female incubated under the warmer temperature regime at the University of Washington Hatchery at 2,069 TU's. This suggests that the developmental rate was altered by a compensating mechanism, probably physico-biochemical, and thus, the effects of the warmer and cooler temperature regimes on eggs from a single Skagit chinook female were dampened. The compensation was only partial, however, but the shift was toward the Skagit condition in all three cases. If eggs at the other sites had required the same number of TU's as at the Skagit site, namely, 1,769 TU's, then yolk absorption would theoretically have occurred on April 25 and 24, in the Cascade and Sauk, respectively, and on January 2, at the University of Washington Hatchery (Fig. 7.6, dashed vertical lines). Thus, the date to mean yolk absorption was shifted 6 days (10 percent) in the Cascade, 10 days (16 percent) in the Sauk, and 19 days (37 percent) at the University of Washington Hatchery from the respective theoretical dates of mean yolk absorption toward the date to mean yolk absorption for the Skagit. The greatest shift occurred for the warmer condition than for the cooler ones. However, the temperature differential was also greater between Skagit and University of Washington Hatchery, at 6.6 ^{o}F than between Skagit and cooler regimes; for Cascade River 3.9 ^{o}F, and for Sauk River 4.0 ^{o}F (Table 7.4).

The results of incubation studies conducted at the University of Washington Hatchery for the 1976-1977 cycle are presented in Table 7.5. The 6-day difference between fertilization date for eggs from Females #3-76 and #4-76 was maintained to mean hatching which occurred on November 22 and 28, 1976, respectively. Both required about 1,000 TU's.

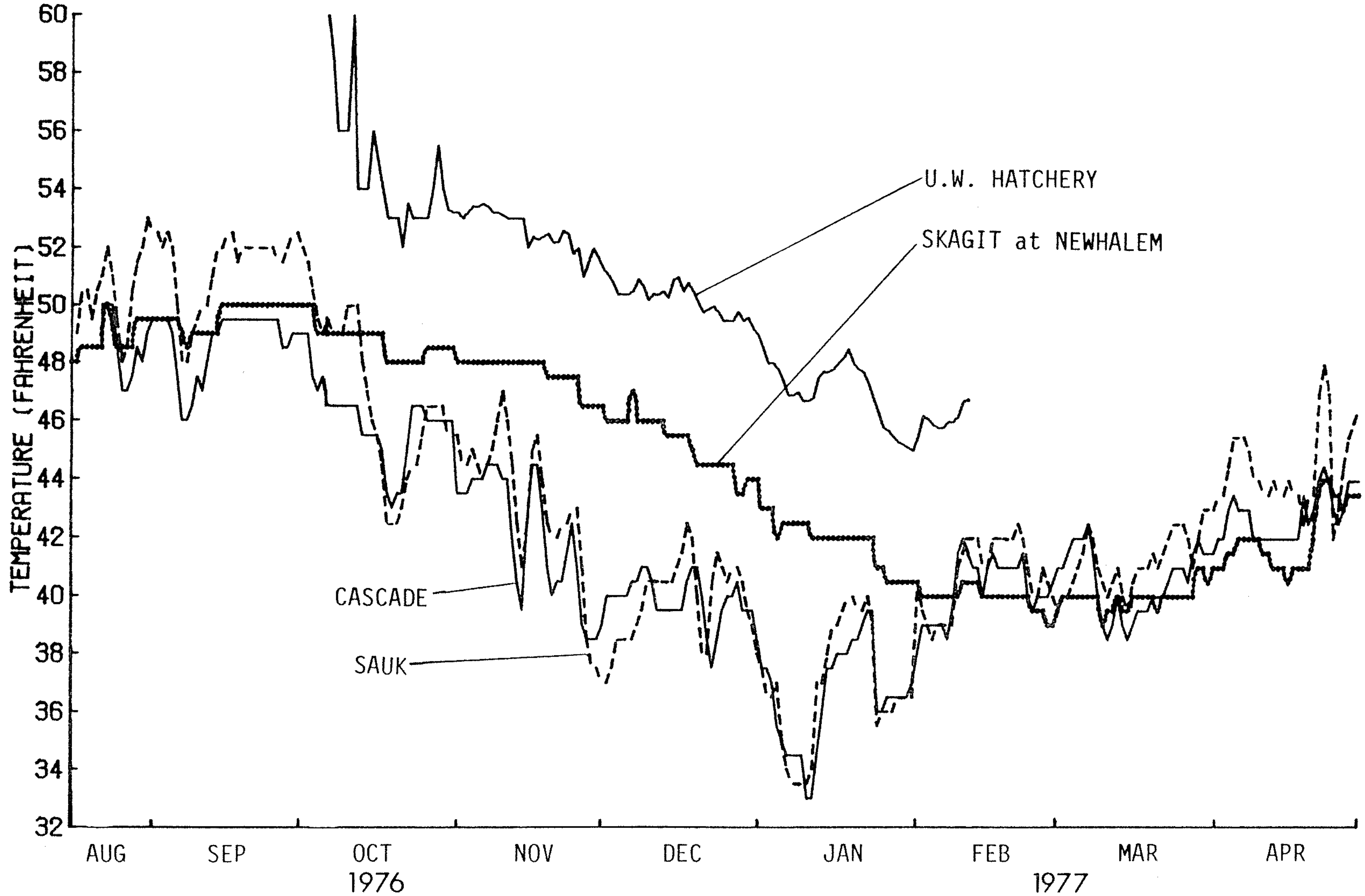

Fig. 7.5 Daily temperatures in degrees Fahrenheit for the Skagit (near Newhalem), Sauk, and Cascade rivers and University of Washington Hatchery from August 1976 to April 1977.

Table 7.4 Summary of incubation studies using eggs from chinook female #3-76 fertilized on October 6, 1976 and incubated at four sites. Shows location, dates, temperature units, number of days and mean temperature to mean hatching and to mean yolk absorption.

Location	To mean hatching				To mean yolk absorption			
	Date	TU's (°F)	# of days	Mean temp. (°F)	Date	TU's (°F)	# of days	Mean temp. (°F)
Skagit River	12- 7-76	975	62	47.7	2-22-77	1769	139	44.7
Cascade River	1-18-77	949	104	41.1	4-19-77	1710	195	40.8
Sauk River	1-15-77	888	101	40.8	4-14-77	1662	190	40.7
U.W. Hatchery	11-22-76	1019	47	53.7	1-21-77	2069	107	51.3
Mean		958				1803		
Standard deviation		55				183		

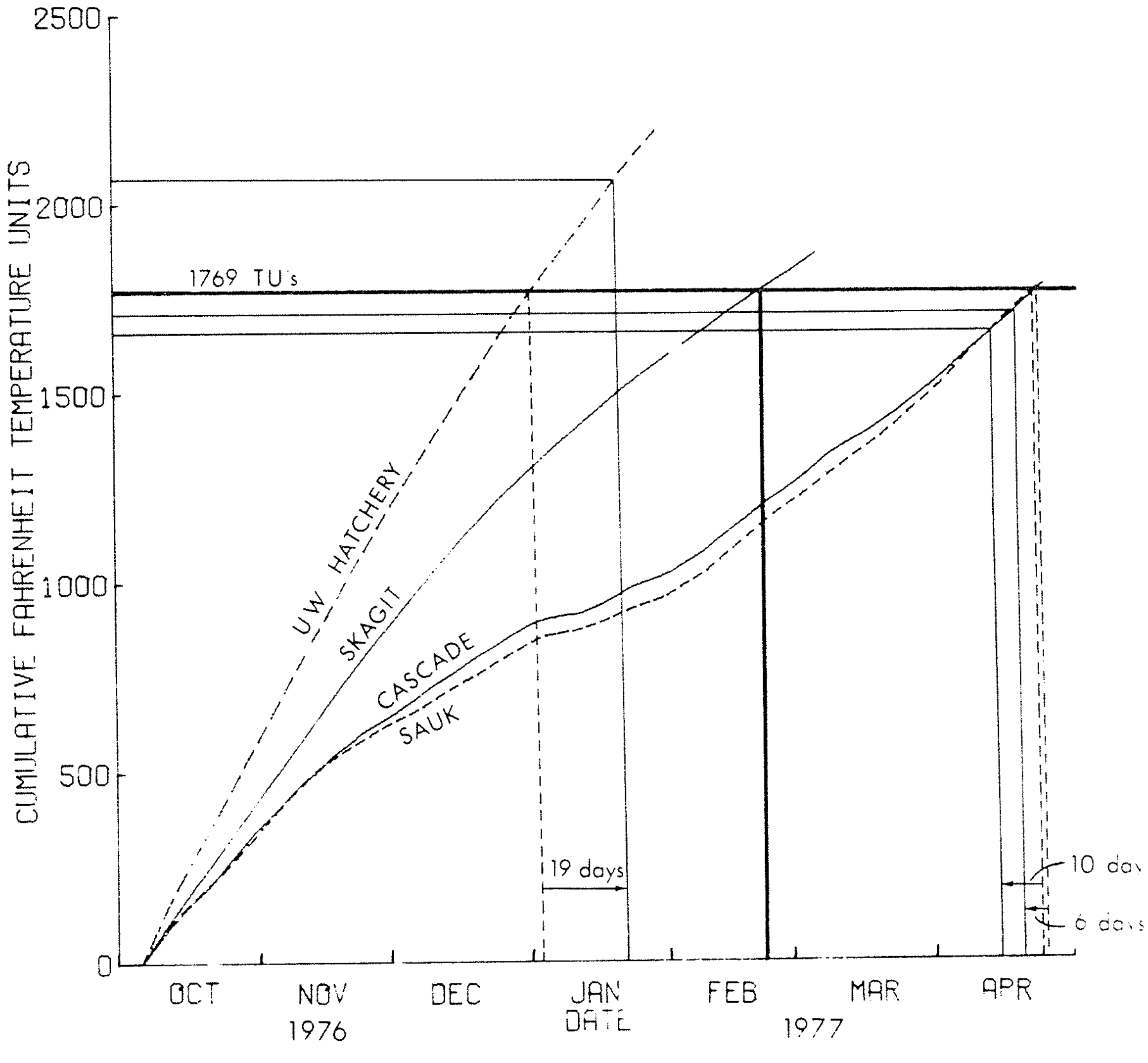

Fig. 7.6 Cumulative temperature units (Fahrenheit) experienced by chinook eggs from female # 3-76 at selected sites, commencing October 6, 1976. Observed dates and associated TU requirements of mean yolk absorption are indicated by vertical and horizontal solid lines. Theorectical dates to mean yolk absorption assuming 1769 TU are indicated by vertical dashed lines.

Table 7.5 Summary of incubation studies for eggs from Skagit River chinook salmon incubated at the University of Washington Hatchery for 1976-77 cycle. Shows dates, temperature units, number of days and mean temperature to mean hatching and to mean yolk absorption.

Female	Date fertilized	To mean hatching: Date	TU's (°F)	# of days	Mean temp. (°F)	To mean yolk absorption: Date	TU's (°F)	# of days	Mean temp. (°F)
#3-76	10- 6-76	11-22-76	1019	47	53.7	1-21-77	2069	107	51.3
#4-76	10-12-76	11-28-76	990	47	53.1	1-29-77	2032	109	50.6

The dates to mean yolk absorption were January 21 and 29, 1977, a difference of 8 days and about 2,050 TU's were required (Table 7.5 and Fig. 7.7). At a higher mean temperature (51.3 ^{o}F) eggs from Female #3-76 required about 40 TU's more than eggs from Female #4-76 incubated at a lower temperature (50.6 ^{o}F). Contrary to results presented in Table 7.3, more TU's were required to yolk absorption by the smaller eggs from Female #3-76 and less were required by the larger eggs from Female #4-76.

In summary, the developmental rate and TU requirements to hatching and yolk absorption were shown to be influenced by mean incubation temperature and egg size which when taken together sometimes showed confounding effects. Eggs from a single female, and presumably of similar size, clearly showed different TU requirements to yolk absorption when incubated at mean temperatures differing by from 4.0 to 10.6 ^{o}F (Table 7.4). TU requirements to yolk absorption for eggs from four females which ranged in weight from 0.441-0.287 g and in diameter from 9.16 to 7.96 mm were shown to be highly correlated to egg weight and diameter (Table 7.3). Thus, changes in developmental rate appeared to be controlled by mean incubation temperature when it was sufficiently different and egg size was similar. Conversely, changes in developmental rate appeared to be controlled by egg size when it was sufficiently different and mean incubation temperature was similar. The relative degree of influence for each of these two factors probably depended on the relative amount of difference for each factor. The factor showing the greater difference would probably have the greater influence on changing the developmental rate. If both factors were sufficiently different at the same time then presumably the influences could be additive or in opposition. Contradictory results were more likely when factor differences were small.

Length and weight were determined for alevins (yolk remaining) and fry (yolk absorbed) taken from the incubation boxes. Measurements were usually taken over the period from several weeks prior to mean yolk absorption to several weeks after. From the length and weight measurements, condition factor was calculated according to the formula:

$$\text{Condition factor} = \frac{\text{Weight (g)} \times 10^5}{\text{Length (mm)}^3} .$$

Yolk, when it was present in the fish, was included in the weight measurement and, therefore, was included in the calculation of condition factor. <u>See</u> Sec. 8.0 for a more detailed discussion of condition factor.

Length, weight, and condition factor data are presented in Table 7.6 for juvenile chinook salmon sampled from the incubation box located near Newhalem during 1975 and in Tables 7.7, 7.8, and 7.9 for juveniles from the four females and sampled during 1976-1977 at the various incubation sites. As a general rule the mean length increased slightly over the first several sampling periods then remained fairly constant through the

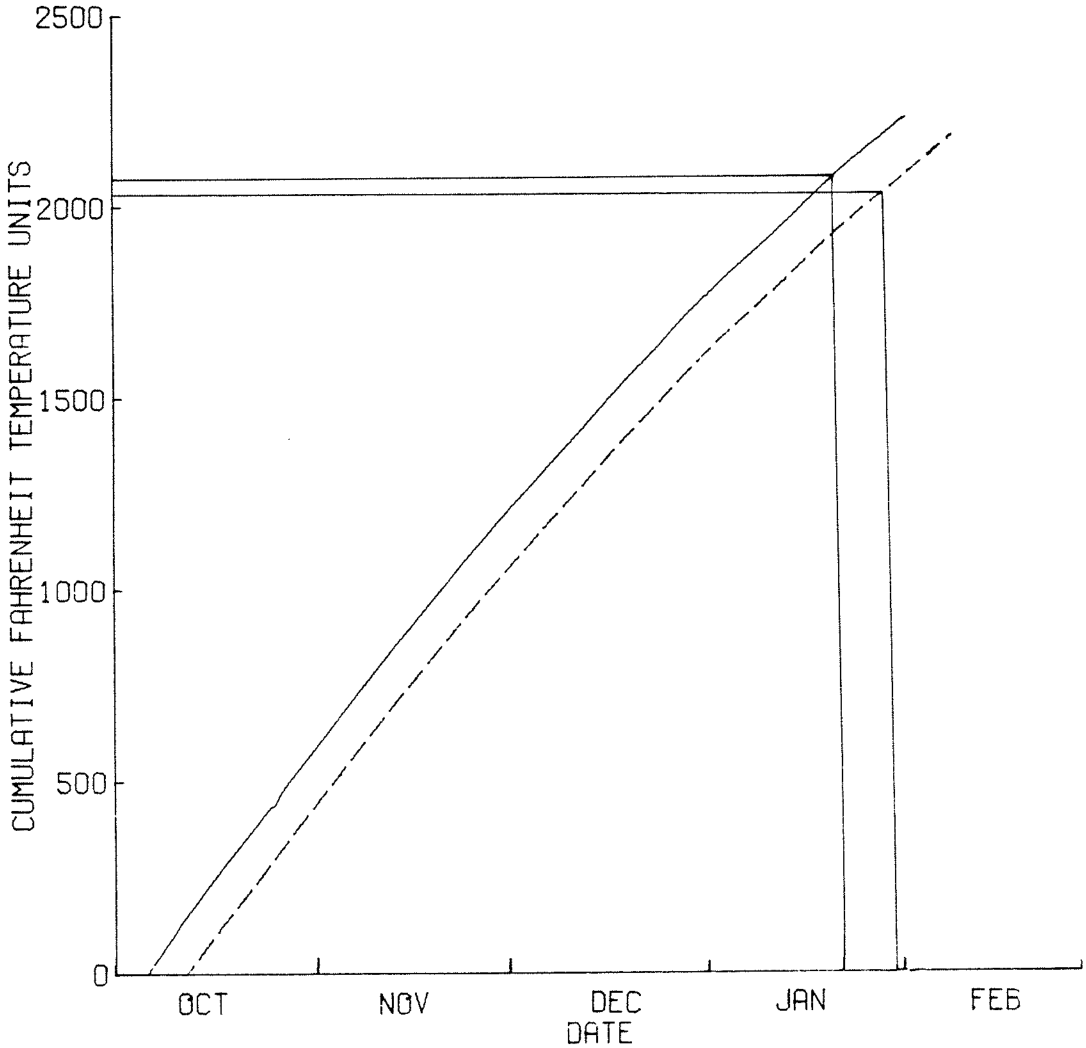

Fig. 7.7 Cumulative temperature units (Fahrenheit) experienced by Skagit River chinook eggs at the U.W. Hatchery, commencing October 6 and 12, 1976. Observed dates and associated TU requirements of mean yolk absorption are shown.

Table 7.6 Length, weight, and condition factor, of juvenile chinook salmon from one female and sampled from incubation box located in Skagit River near Newhalem, 1974-75.

Date	Sample size	Mean length (mm)	Mean weight (g)	Condition factor
1975				
1- 8	25	37.4	.47	.91
2- 4	7	40.0	.58	.91
2-11	18	39.9	.52	.81
2-18	36	40.9	.54	.78
3- 4	29	41.7	.52	.72
3-11	27	40.8	.51	.72
3-18	47	41.0	.51	.73
4- 1	36	40.8	.50	.73
4- 8	20	41.1	.44	.64
4-22	41	40.3	.41	.63
Mean		40.5	.49	.74

Table 7.7 Length, weight, and condition factor of juvenile chinook salmon from four females and sampled from incubation boxes located in Skagit River near Newhalem, 1976-77.

Date	Sample size	Mean length (mm)	Mean weight (g)	Condition factor	Sample size	Mean length (mm)	Mean weight (g)	Condition factor
1976	Female #1-76				Female #2-76			
12-17	46	38.8	0.539	0.923				
12-23	44	39.4	0.542	0.886				
12-29	36	40.2	0.544	0.837				
1977								
1-4	30	40.9	0.564	0.824				
1-10	21	41.5	0.576	0.806				
1-14	43	41.7	0.572	0.789				
1-19	31	41.6	0.553	0.768				
1-24	43	41.9	0.560	0.761	16	40.1	0.494	0.766
1-28	46	42.2	0.568	0.756	15	40.8	0.507	0.746
2-2	15	41.9	0.542	0.737	15	40.5	0.479	0.721
2-7	20	41.8	0.531	0.727	15	40.7	0.482	0.715
2-11					19	40.2	0.451	0.694
Mean		40.9	0.554	0.811		40.4	0.481	0.727
1977	Female #3-76				Female #4-76			
1-28	49	35.1	0.315	0.728				
2-2					14	36.3	0.360	0.753
2-24	49	36.4	0.309	0.641				
2-28	25	36.7	0.311	0.629	25	38.4	0.390	0.689
3-2	25	36.8	0.310	0.622	25	37.9	0.379	0.696
3-4	40	36.9	0.306	0.609	33	38.2	0.369	0.662
3-7	44	36.4	0.301	0.624	28	38.4	0.373	0.659
3-10	34	36.8	0.306	0.614	21	38.1	0.380	0.687
3-14					25	38.5	0.368	0.645
3-17					26	37.9	0.352	0.647
3-21					25	38.5	0.364	0.638
3-24					25	38.2	0.358	0.642
3-28					25	38.5	0.347	0.608
Mean		36.4	0.308	0.624		38.2	0.367	0.662

Table 7.8 Length, weight, and condition factor of juvenile chinook salmon from female #3-76 and sampled from incubation boxes located in Cascade and Sauk rivers, 1976-77.

Date	Cascade River				Sauk River			
	Sample size	Mean length (mm)	Mean weight (g)	Condition factor	Sample size	Mean length (mm)	Mean weight (g)	Condition factor
1977								
3-21					10	35.1	0.277	0.641
4-4					10	35.7	0.316	0.695
4-7	10	36.0	0.311	0.667	25	36.3	0.339	0.709
4-11	10	36.2	0.319	0.672	25	36.2	0.318	0.670
4-14	10	36.3	0.315	0.659	25	36.1	0.311	0.661
4-18	15	36.3	0.311	0.650	25	36.4	0.309	0.641
4-22	15	36.2	0.296	0.624	19	36.5	0.293	0.603
4-26	15	36.2	0.285	0.601	22	36.0	0.288	0.617
Mean		36.2	0.304	0.641		36.1	0.309	0.655

Table 7.9 Length, weight, and condition factor of juvenile chinook salmon from two females and sampled from incubation boxes located at University of Washington Hatchery, 1976-77.

Date	Female #3-76				Female #4-76			
	Sample size	Mean length (mm)	Mean weight (g)	Condition factor	Sample size	Mean length (mm)	Mean weight (g)	Condition factor
1976								
12-27	49	34.7	0.301	0.723				
12-31	46	35.8	0.310	0.675				
1977								
1-6	48	36.3	0.318	0.669	36	36.3	0.360	0.750
1-10	46	36.5	0.322	0.661	50	37.0	0.393	0.775
1-14	49	36.4	0.318	0.662	37	37.2	0.376	0.733
1-18	47	36.4	0.312	0.646				
1-19					47	37.8	0.371	0.690
1-22	42	36.5	0.302	0.619				
1-23					49	37.8	0.376	0.698
1-28	45	36.2	0.305	0.646	49	37.5	0.363	0.689
2-2	46	35.8	0.266	0.583	44	37.2	0.360	0.697
2-7					48	37.1	0.342	0.672
2-11					29	36.9	0.317	0.631
Mean		36.1	0.306	0.654		37.2	0.364	0.706

remainder of the sampling period, but sometimes decreased slightly for the last couple of samples. The mean weight typically remained fairly constant through the first half of the sampling period or increased slightly, while during the latter half, it usually decreased.

The general trend for condition factor was to decrease through the sampling period. At or near the time of mean yolk absorption the condition factors for fish from Females #3-76 and #4-76 ranged from about .62 to .69 at the various incubation sites. For fish from Females #1-74, #1-76, and #2-76 condition factors were in the vicinity of .72.

Overall mean length, weight, and condition factor of alevins and fry resulting from incubation of eggs from four chinook females appeared to be related to egg diameter and weight (Tables 7.3 and 7.7). The larger (9.16 mm) and heavier (0.441 g) eggs produced longer (40.9 mm) and heavier (0.554 g) juvenile chinook salmon with higher condition factor (0.811) while the smaller (7.43 mm) and lighter (0.278 g) eggs produced shorter (36.4 mm) and lighter (0.308 g) juveniles with lower condition factor (0.624). Intermediate sized eggs produced intermediate sized juveniles.

Eggs from individual Females, #3-76 and #4-76, produced juveniles of similar overall mean length, weight and condition factor at each of the various incubation sites. These factors are shown in Tables 7.7, 7.8, and 7.9 for juveniles from Female #3-76 and in Tables 7.7 and 7.9 for juveniles from Female #4-76. These results indicated that juvenile size at or near mean yolk absorption was primarily influenced by egg size and little affected by incubation temperature. Presumably the relationship was that the larger eggs contained more yolk material to be converted to body tissue.

7.5.1.2 Theoretical Timing to Yolk Absorption. The timing to mean yolk absorption under various temperature regimes was calculated for chinook (summer-fall), pink, and chum salmon, and steelhead trout. These calculations do not assume a compensatory shift in developmental rate which if acting might tend to dampen the variation. The timing of spawning, including the peaks, was based on observations by Fisheries Research Institute (FRI) during the 1975, 1976, and 1977 spawning seasons described in Sec. 6.4.2. The TU requirement for Skagit chinook salmon was determined from FRI studies reported in Sec. 7.5.1.1. TU requirements for pink, chum, and steelhead were based on information from other systems, since specific incubation characteristics were not known for Skagit River populations.

The calculated dates to mean yolk absorption for chinook, pink, and chum salmon are shown in Table 7.10 for recent and long-term temperature regimes measured for the Skagit River at Alma Creek (USGS) and the predicted predam regime for Skagit River at Alma Creek (Burt 1973). In general, the water temperatures during the incubation periods for these species were above average during 1976-1977, below average during 1975-1976, and near average during 1974-1975.

Table 7.10 Comparison of calculated dates to mean yolk absorption for chinook, pink, and chum salmon, based on temperature records for Skagit River at Alma Creek (USGS) and Burt's predicted pre-dam regime for Skagit River at Alma Creek.

	Temperature regime	Chinook (summer-fall)	Pink	Chum
Date of peak spawning		Sep 7	Oct 7	Dec 7
Temperature unit requirement		1,930	1,690	1,350
	1974-75	Feb 4	Mar 16	May 16
	1975-76	Feb 18	Mar 31	May 22
	1976-77	Jan 18	Feb 26	May 1
	Mean (1953 to 1977)	Feb 6	Mar 21	May 16
	Burt's pre-dam	May 24	Jun 6	Jun 22

For chinook salmon the calculated peak dates of mean yolk absorption showed a 4-week variation (January 18-February 18) between warmer and cooler temperature regimes with the peak expected on February 6, based on the long-term temperature regime. Projections based on the total spawning period for Skagit chinooks (late August through October) indicated that under average temperature conditions, completion of yolk absorption would be expected to occur from early January to late May. Based on Burt's (1973) predicted predam regime, mean yolk absorption would be expected on May 24.

Pink and chum salmon showed a 5- and 3-week variation, respectively, for estimated peak yolk absorption over the past three incubation periods. Under average temperature conditions completion of yolk absorption would be expected to occur from mid-February to mid-April with the peak on March 21 for pinks, and from early April through May, with the peak on May 16, for chum. Mean yolk absorption would be expected on June 6 and June 22 for pink and chum, respectively, under Burt's (1973) predicted predam regime.

Timing to mean yolk absorption was calculated for steelhead trout for recent and long-term temperature regimes (Table 7.11) for the Skagit River at Alma Creek (USGS). The water temperature during the expected incubation period for steelhead was, in general, below average in 1975 and 1976, while it was above average in 1977. The spawning period for steelhead trout is not well defined, and as indicated in Sec. 6.4.2.5, the time of peak spawning can vary. Based on the temperature regimes of the past 3 years, the time to mean yolk absorption showed a 2- to 3-week variation between years. Steelhead eggs spawned as early as March 15, and as late as May 15, would be expected to complete yolk absorption on June 22 and July 26, respectively, under average temperature conditions. For steelhead eggs spawned on March 15, April 15, and May 15, mean yolk absorption would be expected on July 3, 17, and August 14, respectively, under Burt's (1973) predicted predam regime.

Since salmon eggs usually incubated during a period when temperatures are falling (Fig. 2.25), the length of the yolk absorption period (i.e., from beginning to end) was usually longer than the length of the spawning period. This resulted from the earlier spawned eggs accumulating TU's faster because of generally higher water temperatures than subsequently spawned eggs.

The disparity was greatest for chinook and pink salmon for which the length of the period for the completion of yolk absorption was approximately twice as long as the spawning period. The lengths of the two periods were nearly equal for chum salmon because the first part of their incubation period occurred during a period of decreasing temperatures while the latter part occurred under increasing temperature.

These relationships were reversed for steelehad trout because their egg incubation occurred during a period of increasing temperatures. As a result the period of completion of yolk absorption was compressed and was approximately one-half the length of the spawning period. Like salmon,

Table 7.11 Comparison of calculated mean dates of completion of yolk absorption for steelhead trout based on temperature records for Skagit River at Alma Creek (USGS) and Burt's predicted pre-dam regime for Skagit River at Alma Creek.

	Temperature regime	Steelhead trout		
Date of spawning		Mar 15	Apr 15	May 15
Temperature unit requirement		1,100	1,100	1,100
	1975	Jun 29	Jul 13	Jul 31
	1976	Jun 29	Jul 17	Aug 2
	1977	Jun 13	Jun 28	Jul 17
	Mean (1953 to 1977)	Jun 22	Jul 8	Jul 26
	Burt's pre-dam	Jul 3	Jul 17	Aug 4

however, steelhead development was accelerated by warmer temperature, and yolk absorption would be expected to occur on an earlier date.

The dates to mean yolk absorption were calcualted for chinook, pink, and chum salmon, and steelhead trout, using recent and average temperature regimes from the Cascade and Sauk rivers. The rationale for this was based on the assumption that these systems served as reasonable models of Skagit predam conditions (Sec. 2.2). Therefore, they may reflect the developmental timing of these species in the predam Skagit River. Again, these calculations do not account for a compensatory shift in developmental timing.

The theoretical dates of mean yolk absorption for the Sauk and Cascade rivers are shown in Tables 7.12 and 7.13, respectively, for chinook, pink, and chum salmon. Based on the average regimes development to yolk absorption would be delayed 43 days for chinooks, 31 days for pink, and 1 day for chums, under Sauk River conditions (Table 7.12), compared to Skagit at Alma Creek conditions (Table 7.10). Since Cascade River temperatures were generally lower than Sauk River temperatures, there would be an additional delay of 11 days for chinook, 7 days for pink, and 6 days for chum salmon (Table 7.13).

For steelhead trout development to yolk absorption under the average regimes would be advanced 8, 5, and 2 days for those females spawning on March 15, April 15, and May 15, respectively, in the Sauk (Table 7.14) compared to the Skagit at Alma Creek (Table 7.11). The difference in timing was 1 day or less when comparing Cascade River (Table 7.15) to Skagit at Alma Creek (Table 7.11) under average conditions.

7.5.2 Timing of Emergence

The fry emergent nets over the "artificial" redds located at each station were checked twice weekly after they were installed in 1974. By late May 1975, no fry had been observed in the nets and it was assumed that the eggs had either died or fry had emerged without being detected. Consequently, no data were obtained from this experiment.

At Stations 1 and 2 the emergent nets placed on natural redds marked on September 20, 1974, caught fry. The net at Station 3 caught no fry and may have been placed on a false redd. It was removed in late May. At Station 1 fry were first observed in the net on January 18, 1975, and 17 of the 24 fish caught had completed yolk absorption (Table 7.16). The net was checked 3 days later and 121 fish were removed. Of the 18 fry examined for yolk, 10 fry had absorbed their yolks. The net at Station 1 was removed on January 21.

Between September 20 and January 18, these fry had been exposed to approximately 1,601 TU's. It is not known how much earlier than September 20 the eggs from which the fry developed had been spawned; however, if they required approximately 1,930 TU's to yolk absorption and emergence they would have been placed in the gravel about September 2.

Table 7.12 Comparison of calculated mean dates of completion of yolk absorption for chinook, pink, and chum salmon based on temperature records for Sauk River (USGS and SCL).

	Temperature regime	Chinook (summer-fall)	Pink	Chum
Date of peak spawning		Sep 7	Oct 7	Dec 7
Temperature unit requirement		1,930	1,690	1,350
	1974-75[1]	Mar 17[2]	Apr 20[2]	May 21[2]
	1975-76[1]	Mar 21[2]	Apr 21[2]	May 16[2]
	1976-77[1]	Mar 2[2]	Apr 7[2]	May 8[2]
	Mean (1970 to 1977)[3]	Mar 21	Apr 21	May 17

[1]SCL temperature data containing some gaps.

[2]Calculation made using 1970-77 mean temperature data for gaps.

[3]USGS temperature data from Mar 1970 to Apr 1971 and SCL temperature data from Feb 1972 to May 1977.

Table 7.13 Comparison of calculated mean dates of completion of yolk absorption for chinook, pink, and chum salmon based on temperature records for Cascade River (USGS and SCL).

	Temperature regime	Chinook (summer-fall)	Pink	Chum
Date of peak spawning		Sep 7	Oct 7	Dec 7
Temperature unit requirement		1,930	1,690	1,350
	1976-77[1]	Mar 25	Apr 19	May 18
	Mean (1952 to 1973)[2]	Apr 1	Apr 28	May 23

[1]SCL temperature data.

[2]USGS temperature data.

Table 7.14 Comparison of calculated mean dates of completion of yolk absorption for steelhead trout based on temperature records for Sauk River (USGS and SCL).

	Temperature regime	Steelhead trout		
Date of spawning		Mar 15	Apr 15	May 15
Temperature units required		1,100	1,100	1,100
	1975[1]	Jun 17[2]	Jul 6[2]	Jul 26[2]
	1976[3]	Jun 14	Jul 3	Jul 27
	1977[3]	Jun 8	Jun 26	Jul 17
	Mean (1970 to 1977)[4]	Jun 14	Jul 3	Jul 24

[1] SCL temperature data containing some gaps.

[2] Calculation made using 1970-77 mean temperature data for gaps.

[3] SCL temperature data.

[4] USGS temperature data from Mar 1970 to Apr 1971 and SCL temperature data from Feb 1972 to May 1977.

Table 7.15 Comparison of calculated mean dates of completion of yolk absorption for steelhead trout based on temperature records for Cascade River (USGS and SCL).

	Temperature regime	Steelhead trout		
Date of spawning		Mar 15	Apr 15	May 15
Temperature units required		1,100	1,100	1,100
	1976[1]			Aug 9
	1977[1]	Jun 18	Jul 4	Jul 23
	Mean (1952 to 1973)[2]	Jun 22	Jul 9	Jul 27

[1]SCL temperature data.

[2]USGS temperature data.

Table 7.16 Data on fry captured in emergent nets over natural redds, 1975.

Station	Date of emergence	No. of fish	Number for development	Number measured	Average length (mm)	Average weight (g)	Wet weight condition factor	Percent without yolk
1	Jan 18	24	24	0				71
	Jan 21	121	18	62	39.9	0.64	1.00	56
2	Jan 25	359	22	19	41.5	0.58	0.90	95

At Station 2, 359 fry were removed from the net on January 25, 1975, and all but one of the 22 fry analyzed had absorbed their yolks. By the time these fish had become fry, they had been exposed to approximately 1,631 TU's from September 20, and if they required 1,930 TU's to emergence, the eggs would have been spawned on September 4. The emergent net was removed on January 25, 1975.

The 1976 chinook spawning curve showing number of new redds per day (Fig. 6.14) was assumed to be representative of chinook spawning above the confluence of the Cascade River in 1974. Using the spawning curve (smoothed by threes), an emergence curve was calculated by summing TU's from each day of spawning until the number of TU's required for "theoretical" emergence was accumulated (1,930 TU's). Fig. 7.8 shows the estimated relative number of emerging fry in the upper Skagit. Calculated emergence began in early Janaury and increased gradually until it peaked in early February. Most of the fry emerged from late January to mid-March, but emergence continued into mid-May. Fry availability data obtained by electroshocking (Sec. 8.4.1.1) substantiate early January emergence since fry were captured as early as January 7, 1975, the first sampling date.

For the 1976-1977 incubation cycle the timing of expected emergence was calculated from the timing of spawning and the TU requirement for Skagit chinook salmon (Fig. 7.9). The timing of spawning is presented in the form of a histogram with intervals 5 days in width and height shown in percentage. A "histogram" of expected emergence was constructed by summing the TU's for each 5-day interval until 1,930 TU's had been accumulated. This "histogram" of expected emergence is not of the usual form and requires special interpretation. Each column in the emergence histogram was derived from a column in the spawning histogram. The height of the column represents the relative proportion emerged given in percentage and is the same height as the corresponding column in the spawning histogram. The width of the column indicates the length of the emergence period resulting from the corresponding 5-day spawning interval.

The timing of theoretical emergence for 1976-1977 (Fig. 7.9) was somewhat advanced compared to theoretical emergence for 1974-1975 (Fig. 7.8). Calculated emergence began in mid-December 1976, reached a peak in mid-January 1977, and continued to late April 1977. Electroshocking data confirmed an earlier emergence date with fry being captured in early December 1976.

The emergence pattern for chinook eggs fertilized on October 12, 1976, and incubated in gravel substrate at the University of Washington Hatchery is shown in Fig. 7.10. Emergence extended from about December 17, 1976, to January 14, 1977. Peak emergence for both compartments combined occurred on December 29, 1976, when 1,558 TU's had been accumulated. Individually there was a difference of 2 days to peak emergence between the compartments, December 28 and 30, 1976.

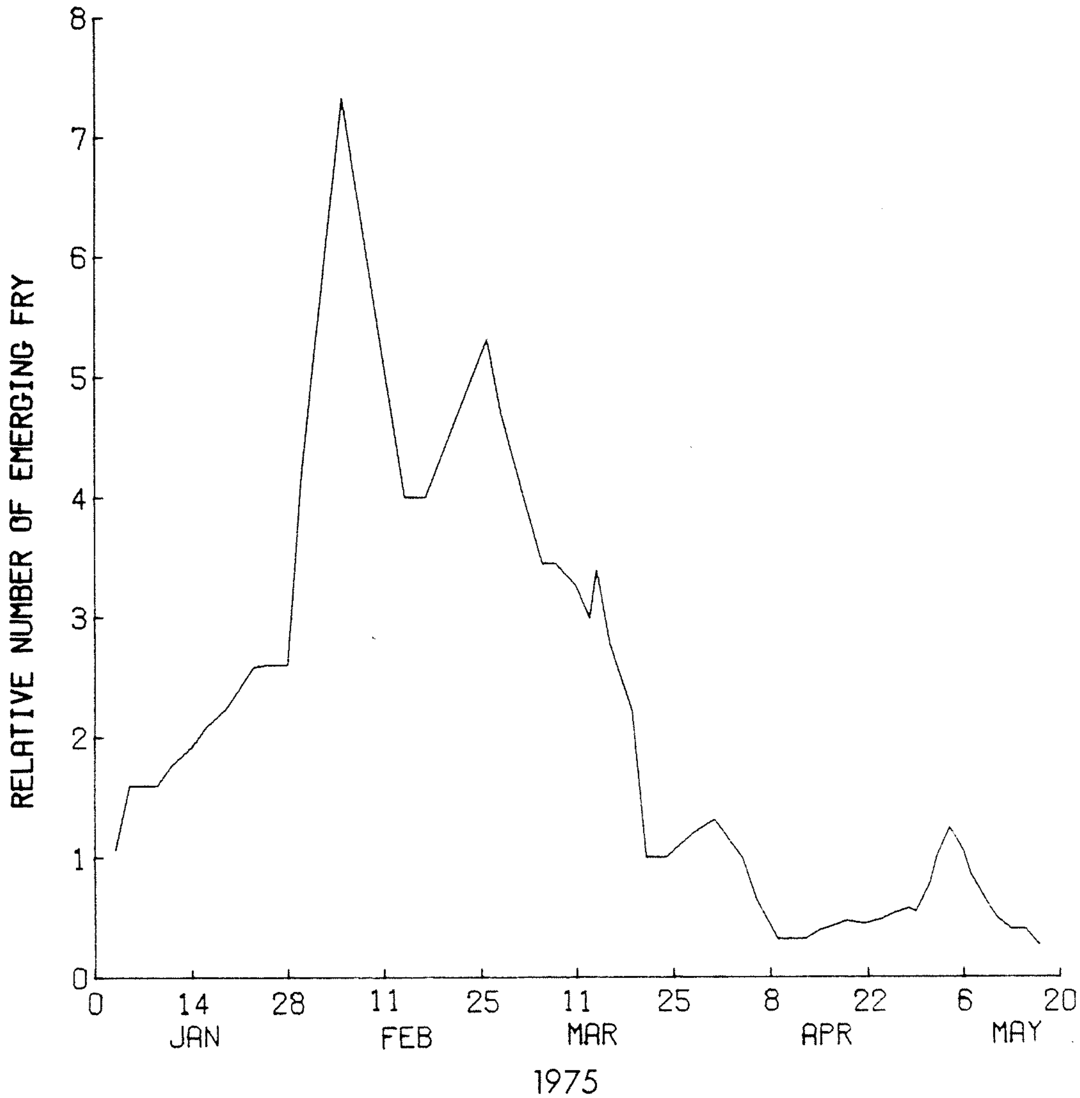

Fig. 7.8 Estimated emergence curve of 1974 chinook salmon fry assuming 1930 temperature units to emergence and peak spawning to be September 9th.

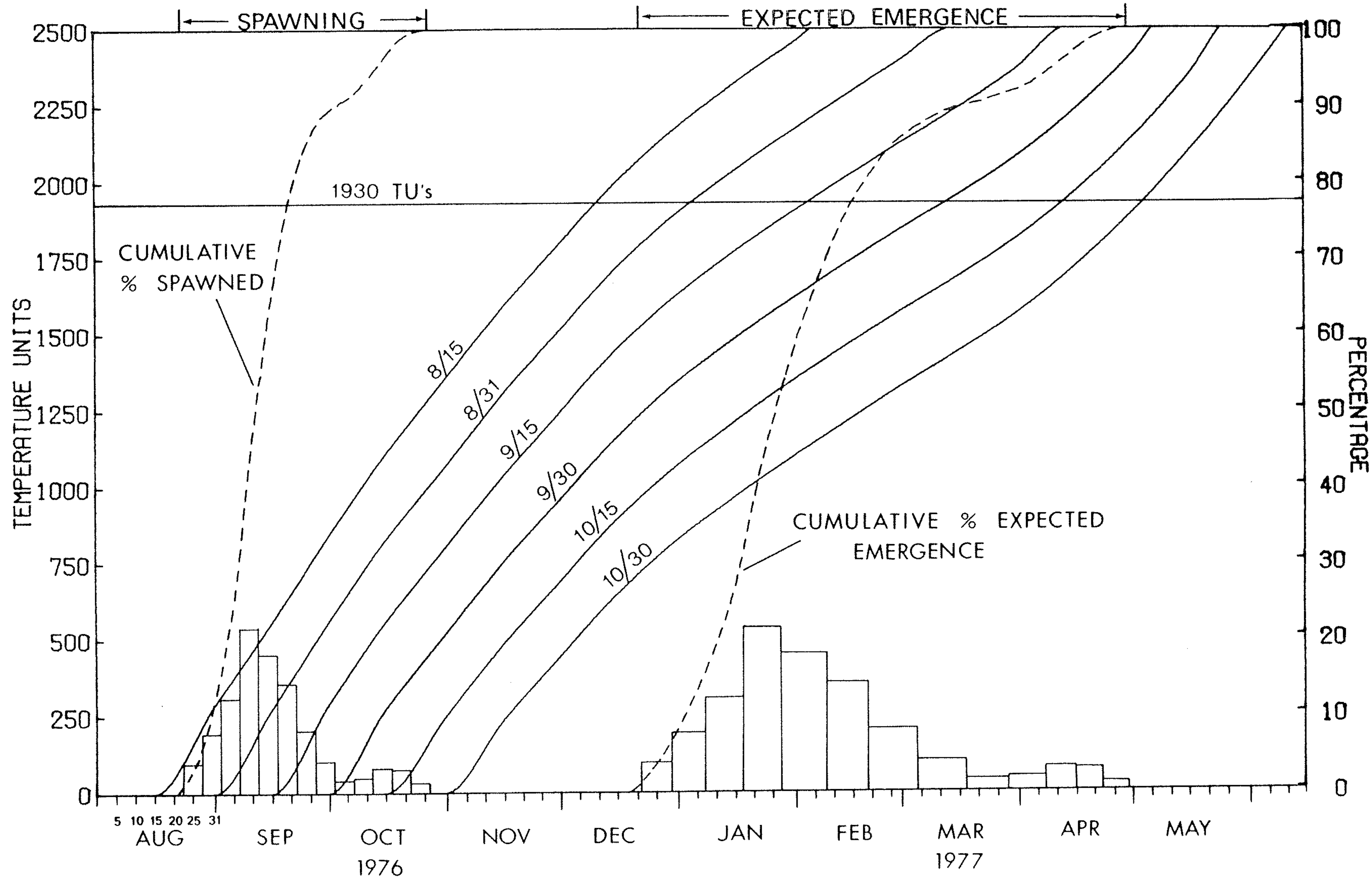

Fig. 7.9 Timing and relative magnitude of chinook spawning and expected emergence for 1976-1977 based on the accumulation of 1930 temperature units. Cumulative percent spawning and cumulative percent expected emergence are shown.

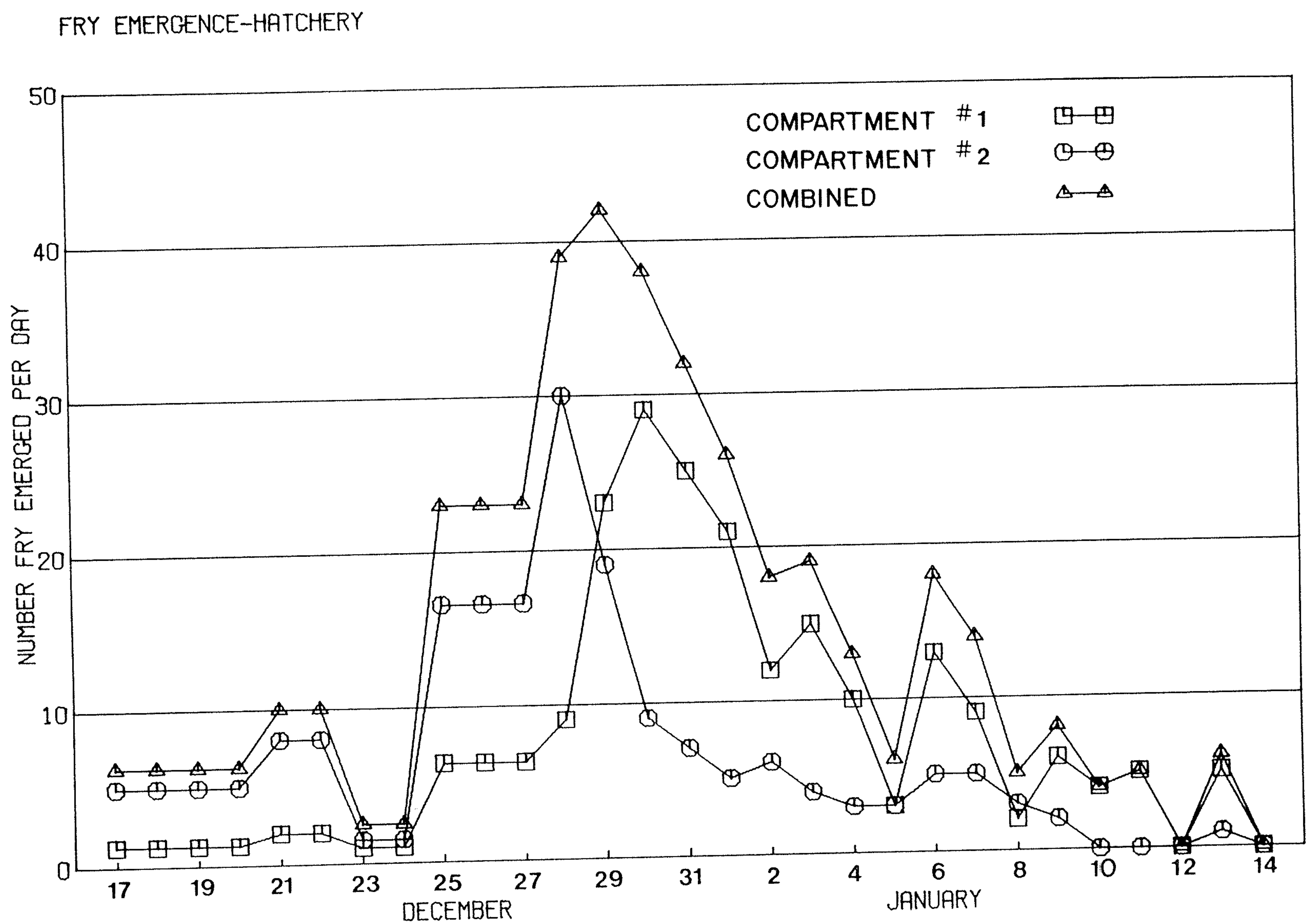

Fig. 7.10 Number of chinook fry emerged per day when incubated in gravel substrate at University of Washington Hatchery during 1976-1977.

Egg to fry survival was excellent for this emergence experiment. From the 500 eggs initially planted, 477 live fry were recovered, or 95 percent survival.

All emerged fry from this experiment were examined for absence or presence of yolk and none was found to have completed yolk absorption.

7.5.3 Fry Condition at Emergence

The physical condition of fry held in the Station 1 incubation box past yolk absorption during early 1975 was compared with the physical condition of Skagit fry. Condition data for fry captured in the Skagit system are presented in detail in Sec. 8.4.1.2. When incubation box fry were compared with fry caught by electroshocking, in all cases natural fry weighed more and their condition factors were larger (Table 7.17). The percent that natural fry were greater in weight than incubation box fry rose from 8 percent on March 4 to 71 percent on April 22, when the last sample was removed from the box. The condition factor of natural fry also rose from 11 percent greater than incubation box fry on March 11 to 51 percent greater on April 22.

Very little, if any, food was available to the incubation box fry. This is supported by the fact that five stomachs from each sample were examined and none of them contained food. (See Sec. 8.4.1.3 for results of chinook diet studies.) Also, as the number of weeks from yolk absorption increased, the average weight, length, and condition factor generally decreased (Table 7.17). In contrast, the average weight, length, and condition factor of natural fry generally increased (Table 8.11) and food was found in stomachs taken on all dates during 1975 except March 4, when no stomach samples were taken.

The physical condition of fry taken from the emergent net at Station 1 on January 21 is also shown in Table 7.17. Sixty-two fry were 4 percent shorter, 21 percent heavier, and their condition factor was higher than incubation box fry on March 4, the date closest to "theoretical" yolk absorption.

The length, weight, and condition factor of chinook fry from Female #4-76 emerging from gravel substrate at University of Washington Hatchery are presented in Table 7.18. These fry, emerging at their own volition, showed a general increase in length from about 34 to 38 mm, an increase in weight from about 0.33 to 0.41 g, and the resulting decrease in condition factor from about 0.86 to 0.68. This general increase in length and weight was not observed for juvenile chinook from Female #4-76 sampled from incubation boxes located at University of Washington Hatchery (Table 7.9). By comparison the emerging alevins overall were slightly shorter, similar in weight, and had slightly higher condition factor.

Table 7.17 Comparison of fry held in incubation box after yolk absorption and natural fry captured by electrofishing, 1975.

Date	Fry from incubation boxes: Sample size	Average length (mm)	Average wet weight (g)	Wet weight cond. factor	Date	Natural fry captured on same or comparable dates: Sample size	Average length (mm)	Average wet weight (g)	Wet weight cond. factor	Percent natural fry are greater than incubation box fry: Average length	Average wet weight	Wet weight cond. factor
3-4	29	41.7	0.52	0.72	3-4	30	40.9	.57	.83		8	14
3-11	27	40.7	0.51	0.72	3-11	30	41.5	.58	.80	2	18	11
3-18	47	40.7	0.51	0.73	3-25	26	40.6	.64	.95		21	22
4-1	36	40.8	0.50	0.73	4-1	42	40.1	.63	.89		29	24
4-8	20	41.0	0.44	0.64	4-8	56	42.6	.69	.93	4	57	45
4-22	41	40.3	0.41	0.63	4-22	66	41.6	.70	.95	3	71	51
	Fry from natural redd Station 1											
1-21	62	39.9	0.64	1.00								

Table 7.18 Length, weight, and condition factor of chinook alevins emerging from gravel substrate at University of Washington Hatchery, 1976-77.

Date	Number emerged	Mean length (mm)	Mean weight (g)	Condition factor
1976				
12-16	62	33.8	0.334	0.862
12-20	25	34.5	0.345	0.839
12-22	20	35.1	0.348	0.805
12-24	5	36.2	0.366	0.772
12-27	69	36.6	0.373	0.761
12-28	39	36.8	0.373	0.745
12-29	42	37.0	0.377	0.741
12-30	38	37.8	0.376	0.725
12-31	32	37.7	0.377	0.702
1977				
1-1	26	37.5	0.374	0.709
1-2	18	37.3	0.370	0.714
1-3	19	37.9	0.380	0.698
1-4	13	37.8	0.383	0.711
1-5	6	37.8	0.373	0.689
1-6	18	38.3	0.382	0.681
1-7	14	37.1	0.381	0.744
1-8	5	38.2	0.376	0.675
1-9	8	38.3	0.384	0.686
1-10	4	38.5	0.385	0.675
1-11	5	38.0	0.412	0.751
1-12	0	-	-	-
1-13	6	38.7	0.392	0.678
1-17	3	38.3	0.390	0.693
Mean		36.7	0.368	0.753

7.6 Discussion

7.6.1 Hatching

The estimated number of TU's required to hatching for chinook salmon eggs incubated in the Skagit River showed little variation between different females when incubated at similar mean water temperature. More variability was encountered when comparing TU requirements to hatching for eggs from the same female incubated under warmer and cooler temperature regimes. Temperature Units to hatching did not appear to be related to egg size.

The estimated number of TU's that Skagit River chinooks required to hatching as determined by these studies for eggs from four females was quite similar to those that Seymour (1956) found for Skagit chinooks in his experiments (981 at mean temperatures ranging from 47.4 to 48.9 °F compared with 974 at 49.4 °F, mean temperature). Wild summer chinook eggs spawned at the Marblemount Hatchery on September 16, 1974 were estimated by the hatchery manager to have begun hatching on November 20, when they had accumulated 1,070 TU's. They were exposed to an intermediate average temperature (48 °F) compared to eggs from four females incubated in the Skagit River near Newhalem (Table 7.2).

7.6.2 Yolk Absorption and Emergence

Completion of yolk absorption and emergence are not necessarily synonymous. Under hatchery conditions juvenile chinook from Skagit River stock and incubated in trays containing gravel substrate were observed to reach peak emergence approximately 3 weeks before the first juveniles completed yolk absorption in other fish from the same stock. Under natural conditions, however, the timing to yolk absorption and to emergence appeared to be similar.

Burgner (1974), in his testimony before the Federal Power Commission in regard to raising Ross Dam, calculated that yolk absorption of summer chinook salmon in the upper Skagit River would, on the average, be completed by mid-December, but was under the impression that fry do not emerge from the gravel for at least 2.5 months beyond mid-December, rather, in early March. Johnson (1974), of WDF, concurred with Burgner's view and added that the emergence time was determined by electrofishing. Both Johnson and Burgner based their statements on a peak spawning date of September 1 and a requirement of 1,700 TU's to yolk absorption.

The results of these studies indicated that in 1975, 1976, and 1977, emergence was not delayed. Based on a peak spawning date of September 7, and a requirement of 1,930 TU's to yolk absorption, time of completion of yolk absorption peaked in early February, mid-February, and mid-January, respectively, and not mid-December. It began in January or December depending on temperature. Electroshocking in these years showed some fry had emerged from the gravel as early as January 7, 1975; January 5, 1976; and December 2, 1976.

If fry were delaying in the gravel after yolk absorption they would have to rely on body tissues and energy reserves for nourishment. This would be reflected in emerged fry having poor physical condition. As reported in Sec. 6.5.3 fry held in the Station 1 incubation box past yolk absorption simulated this condition and it was found that in every case natural fry weighed more and had a higher condition factor. This suggests that natural fry were not exposed to starvation conditions. Fry were caught in the emergent nets over natural redds at Stations 1 and 2, 1.5 months before Johnson's estimate of peak emergence. A sample of 42 fish from the net at Station 1 showed that about 30 percent still had yolk remaining in their bodies, while 5 percent of a sample of 22 fish from the net at Station 2 still had yolk remaining. Juvenile chinook with yolk remaining at emergence would indicate that they are not delaying in the gravel.

Since the timing to yolk absorption and to emergence appeared to be similar under natural conditions, completion of yolk absorption and calculations made from yolk absorption data will be considered to approximate emergence.

7.6.3 Temperature Unit Compensation

The estimated number of TU's required to yolk absorption by chinook salmon eggs from different females incubated in the Skagit River showed similar variation to the number of TU's required by eggs from the same female incubated under warmer and cooler temperature regimes. For the former case, the variation was primarily due to egg size since it was shown that the TU requirement was highly correlated to egg size. Presumably, the larger the eggs, the more yolk material they contained, and more time would be required for that yolk to be absorbed. The results were confounded by differences in mean incubation temperature but the magnitude of the differences did not appear great enough to be the overriding factor.

In the latter case, where egg size was not a factor, the TU requirements were shown to be highly correlated to mean temperature during the incubation period. This suggests that the developmental rate was altered by a compensating mechanism so that at higher temperature more TU's were required and at lower temperature fewer TU's were required. According to E. Brannon (personal communication) sockeye and pink salmon have a physico-biochemical compensating mechanism which in effect compensates their TU requirements under different regimes, i.e., requiring fewer TU's in years of colder water and more TU's in years of warmer water.

By this mechanism the fish possess some degree of adaptability to counteract year-to-year variation in environmental conditions. Such a mechanism would presumably improve fish survival by tending to maintain their emergence at a specific time of year when environmental conditions, food resources, etc., are more favorable.

For chinook eggs from a single female incubated in warmer and cooler water temperature during 1976-1977, the shift in timing was toward the timing of eggs incubated in the Skagit River in both cases. The amount of compensation was 59 and 107 TU's for temperatures 3.9 and 4.0 °F cooler which resulted in a 10 and 16 percent shift in timing toward the Skagit condition while it was 300 TU's for temperatures 6.6 °F warmer which resulted in a 37 percent shift in timing.

7.6.4 Fry Condition at Emergence

According to Brannon (1974), "The trend from hatching to yolk absorption is a consistent reduction in condition factor from approximately 2.65 to 0.76, with some variation because of racial differences among chinook salmon. When condition factor reaches 0.75, weight loss of the alevins will have started from starvation."

The condition factors at mean yolk absorption were approximately 0.72 for fry from Skagit chinook females taken during the first half of September and were, therefore, similar to Brannon's minimum value, 0.76. For fry from females taken in October the condition factors at mean yolk absorption were approximately 0.64. This difference may indicate racially different stocks in the Skagit River, the former derived from stocks that Orrell (1976) considered to be the native "summer" chinook and the latter considered to be hatchery-derived "fall" chinook. These possible stocks could not be separated on the basis of spawning timing, however (Sec. 6.4.2.1).

The WDF (Allen and Moser 1963-1969, and Allen et al. 1969-1972) reported the following condition factors for fry egressing from two of their Columbia River spawning channels:

1. Rocky Reach: 1962-1964, 1966-1968. January-June: condition factor ranged from 0.62 to 1.28.
2. Wells: 1967-1968. April-May: condition factor ranged from 0.74 to 0.89.

These fry included those captured soon after emerging as well as those which had resided in the spawning channel for an unknown period. In comparison, the minimum condition factors observed in Columbia River channels (0.62 and 0.74) were similar to those observed to mean yolk absorption in our incubation studies (0.64 to 0.72).

7.6.5 Effects of Altered Temperature Regimes

7.6.5.1 Chinook Salmon. The Skagit River temperature regime has undergone a change as a result of dam construction, primarily Ross Dam, but the magnitude of the change is not precisely known and can only be estimated. Burt (1973) estimated that predam temperature regime was in general cooler than the present regime. A more conservative estimate was to consider the Sauk and Cascade regimes as models of predam conditions in the Skagit.

Upon examination of WDF spawning ground records back to 1952, we found no evidence that the spawning timing for Skagit summer-fall chinook has undergone a change.

In comparison with other chinook populations in other systems (Table 7.1), it appears that the timing of spawning and estimated emergence for Skagit River chinook salmon is similar. From the available data, only the peak spawning time described by Wales and Coots (1954) and Allen et al. (1969-1972), differed markedly from that of chinook spawning in the Skagit. The other three estimates fall within or coincide closely with Skagit River chinook spawning.

Estimates of emergence by Reimers and Loeffel (1967) and Gebhards (1961) agree closely with the estimate for chinook in the Skagit, as does emergence at Wells Spawning Channel. The estimate by Wales and Coots (1954) spans approximately the same emergence period as the chinook in the Skagit; however, no peak estimate was reported. Only Chambers′ (1963) estimate of peak emergence differs significantly and this may be due to spawning channel temperatures being different from predam Columbia River temperatures.

The spawning patterns of chinook in the Sauk and Cascade rivers provide additional information for comparison with Skagit River chinook spawning. Spawning time in the Sauk coincided with Skagit River timing for the early portion of the run (Orrell 1976) and Cascade chinook spawn within the same time period as Skagit chinook (R. Orrell, personal communication). Since the spawning times in the upper Skagit, Sauk, and Cascade rivers appear to be similar, it does not appear that chinook spawners in the Skagit River have reacted to increased water temperatures in the river by spawning later. However, there have been only seven or eight generations of chinook which have spawned in the Skagit since 1948 (the estimated initial time of temperature changes in the Skagit). This may or may not have been enough generations to show selection for later spawners. The timing of initiation and peak spawning were observed to be similar for the 1975 and 1976 chinook runs and the postpeak spawning pattern was similar in all 3 years of observation, 1975-1977 (Sec. 6.4.2.1). However, the spawning pattern and timing of Skagit River chinook may be influenced by the releases of "fall" chinook from the Marblemount Hatchery. These releases were quite large, 3-5 million fingerlings, in the early 1970′s. From 1974 (1973 brood) to 1976, no "fall" chinook were released in the upper Skagit system. This termination may affect the future spawning timing, particularly for the later part of the run.

Chinook incubation at McNary Dam Spawning Channel required 1,800 TU′s to emergence at an average temperature of 52 °F (Chambers 1963) while chinook at Wells Spawning Channel required only 1,600 TU′s at an average temperature of 45.5 °F. In both instances the number of TU′s required was less than the average 1,930 TU′s found in these studies at an average temperature ranging from 44 to 47 °F, even though the McNary population experienced a higher average temperature and the Wells population experienced a similar average temperature. These data appear to be in conflict, insofar as one would expect to see more TU's required with a warmer average temperature. However, the differences between McNary, Wells, and Skagit chinook are probably attributable to the requirements of different racial stocks of salmon, as indicated by Seymour's (1956) study.

If Burt's (1973) predam estimated temperatures are correct, then chinook emergence would have occurred in May (Table 7.10). However, it appears that predam temperatures in the Skagit may have approximated those now observed in the Sauk and Cascade because spawning times in the Skagit, Sauk, and Cascade are so similar. Sheridan (1962) showed a correlation between spawning time of pink salmon and stream temperatures. He found that in streams with warmer temperature regimes spawning time began later and that streams with similar temperatures showed similar spawning times. Conversely, similar spawning times could possibly indicate similar temperature regimes and if this were the case, it would appear that Burt's estimate may be low.

It does not appear that TU adjustment with higher temperature has been sufficient to shift emergence timing of Skagit River chinook to that under predam conditions since the first appearance of Skagit River chinook fry precedes that of Sauk and Cascade river fry by about 1 month (Sec. 8.4.1.1). It is likely, however, that by TU adjustment the effect of temperature increases resulting from dam construction on the Skagit River has been dampened.

7.6.5.2 Pink and Chum Salmon and Steelhead Trout. Specific TU data are not yet available for Skagit River pink and chum salmon. Analysis is in progress for incubation studies still in progress as of July 31, 1978, for these two species plus coho salmon. In lieu of these data and using those from other systems, predictions were made of the effect of altered temperature regimes for Skagit pink and chum salmon.

Based on the calculated timing to mean yolk absorption, the postdam elevated temperature regime has probably shortened the time to emergence by 4-11 weeks for pink salmon depending upon which predam temperature regime (Burt or Sauk-Cascade) is used for comparison. For Skagit chums this comparison ranged from essentially no change (using Cascade) to 5 weeks shorter (using Burt).

Similar comparisons for steelhead indicated that the present time to emergence may have been shortened by about 10 days from predam conditions based on Burt's prediction, lengthened by 2-8 days using Sauk River mean regime as a model, and essentially unchanged using Cascade River mean regime.

It seems likely that Skagit pink and chum salmon also possess a compensating mechanism to adjust TU requirements according to water temperature. The existence and magnitude of such a mechanism if present should be indicated by the 1977-1978 incubation studies.

7.6.6 Potential Effects of Copper Creek Dam

The range of potential effects of Copper Creek Dam on the downstream temperature regime was predicted and is presented in Sec. 2.2.2. Based on the maximum potential effect the dates to mean yolk absorption were calculated for chinook, pink, and chum salmon, and steelhead trout (Table 7.19). Note the general agreement between dates to mean yolk absorption for Gorge Dam intake from SCL data (Table 7.19) and for Skagit River at Alma Creek from USGS data (Tables 7.10 and 7.11, mean temperature regimes).

The predicted change in dates to mean yolk absorption was greatest for summer-fall chinook and pink salmon where the expected delay in timing was 14 and 13 days, respectively. The dates to mean yolk absorption under the two regimes were similar for chum salmon and steelhead trout with a trend to shorten slightly the incubation period.

As indicated in Sec. 2.2.2 for temperature the shift in timing was considered the maximum and could range to little or no effect depending on physical and operational factors as yet unknown or undetermined. This maximum shift was in general toward predicted predam conditions.

Table 7.19 Comparison of calculated dates to mean yolk absorption for chinook, pink, and chum salmon, and steelhead trout, based on temperature records for Gorge intake (SCL, 1971 to 1977), and the estimated temperature at Copper Creek Dam intake.

	Temperature regime	Chinook (Sum/Fall)	Pink	Chum	Steelhead		
Date of spawning		Sep 7	Oct 7	Dec 7	Mar 15	Apr 15	May 15
Temperature unit requirement		1,930	1,690	1,350	1,100	1,100	1,100
	Gorge Dam intake	Feb 3	Mar 16	May 14	Jun 20	Jul 7	Jul 27
	Copper Cr Dam intake	Feb 17	Mar 29	May 13	Jun 18	Jul 4	Jul 24

8.0 FRY REARING

8.1 Introduction

8.1.1 Fry Availability, Growth, and Feeding

Fry of five salmonid species--chinook salmon (*Oncorhynchus tshawytscha*), pink salmon (*O. gorbuscha*), chum salmon (*O. keta*), coho salmon (*O. kisutch*), and rainbow-steelhead trout (*Salmo gairdneri*)--reside in the Skagit River system for varying periods after emergence before migrating downstream to saltwater.

Electrofishing has been the primary means to detect the presence and relative abundance of salmon and trout fry and to collect fry for diet analysis and for size and condition measurements in the Skagit system. In 1973, Washington Department of Fisheries (WDF) personnel sampled 200-ft sections of Marblemount, Sutter Creek, and Rockport bars on the Skagit River on eight occasions from March 2 through May 21 to assess availability of chinook, chum, and coho fry to potential stranding flows (Phinney 1974a). The chinook fry length data indicated a prolonged emergence. In 1974, WDF collected samples of chinook, coho, chum, and pink fry at the same three locations as well as at additional locations extending downstream to tidal influence and in the Sauk and Suiattle rivers (Orrell 1976). Sampling was conducted at intervals over the period March 4 - May 22, inclusive. Both beach seine and backpack Smith-Root Mark V electrofishing unit were used. Most samples in the upper Skagit and Sauk were taken by electrofishing. Measurement of the growth rate of chinook fry was found impossible because of prolonged emergence from the gravel and continual migration downstream. There was no significant difference found in chinook fry condition factor between sampling locations.

Fisheries Research Institute (FRI) began studies of salmon and rainbow-steelhead fry availability and condition after emergence in 1974. Fry of chinook, pink, chum, and coho salmon, and rainbow-steelhead trout were collected from four sites on the Skagit River and from five unregulated tributaries to determine the timing of emergence from the gravel and length of residency in the study area, and to monitor changes in abundance, length, weight, and condition factor during the period of their residency. These measurements were used to help determine the effects of temperature regimes and flow patterns modified by hydroelectric operations.

Comparative studies of chinook fry diet in the Skagit River and two tributaries were initiated by FRI in 1975. In 1976 and 1977, the other species of salmon and rainbow-steelhead trout were also collected for stomach analysis.

Fry diet was studied to determine if there were any differences in fry diet in the dam-regulated Skagit River compared to the unregulated Cascade and Sauk rivers, and, if so, whether these changes could be related to a modified benthic community structure in the Skagit, the presence of zooplankton released from the reservoirs, and changes in fry length, weight, and condition factor.

8.1.2 Fry Stranding

The Skagit and Baker rivers differ from other rivers in the watershed because of power-production-related flow fluctuations introduced at Gorge Powerhouse and Baker Dam. Flow fluctuations have resulted in salmonid fry stranding mortalities in previous years. The major concern is over chinook fry, although pink, chum, and coho salmon, and steelhead trout have been affected at times.

WDF conducted investigations on salmon fry stranding in the Skagit River in March and April 1970 (Thompson 1970) to determine whether flow changes resulting from power production caused stranding, and if so, what measures were necessary to alleviate the problem. These studies resulted in the recommendation that a minimum flow of 2,800 cfs be maintained in the Skagit River at Marblemount (river mile--RM--78.2) during the time when it was felt that salmon fry were abundant. A minimum discharge was then developed for Gorge Powerhouse (RM 94.3) based on fry emergence and migration data and on normal trubutary inflow between Gorge Powerhouse and Marblemount. The minimum discharges and dates recommended were 2,300 cfs from February 1 to April 15; 2,000 cfs from April 15 to May 1; and 1,700 cfs from May 1 to May 15. The Federal Power Commission (FPC) licensed minimum flow of 1,000 cfs was to remain in effect the rest of the year.

In March 1973 at the request of Seattle City Light (SCL), personnel from WDF and FRI conducted additional studies on the stranding problem (Phinney 1974a). The 1973 study re-emphasized the earlier findings that substantial salmon fry mortalities could occur under certain conditions. Phinney recommended that a reduction in the minimum flows outlined by Thompson (1970) was not acceptable if flows were fluctuating.

In their studies, Thompson (1970) and Phinney (1974a) discussed the probable factors involved in fry stranding as:

1. The seasonal abundance of each of the different species in the shallow water areas.
2. The magnitude and rate of flow fluctuation, particularly the level and duration of the low flow when proportional larger areas of river bar are exposed.
3. The time of day of flow fluctuation, as it may affect fry distribution and behavior.
4. Trubutary inflow, as it contributes to the discharge at Gorge Dam and affects total flow levels.
5. The topography of the river channel, including the slope and substrate composition at different locations.

Total estimates of fry kill in the Skagit River between Marblemount and Baker River were made in the March 1973 experiments. These estimates were based on enumeration of dead fry found per unit area in the area exposed by flow fluctuation on four bars in the Skagit River between Rockport and Newhalem. These estimates were extrapolated to kill per linear foot of each of the four bars and further extrapolated to total linear feet of bar in the river area from Newhalem to the Sauk River mouth and from the Sauk River mouth to Baker River, based on measurements from aerial photos. Bars in the latter river stretch were not sampled.

Estimates of total kill were as follows:

Date	Flow reduction (Newhalem)	Mortality	
		Newhalem-Sauk	Sauk-Baker
March 17	~5,000 cfs to 2,304 cfs	17,900	15,600
March 18	~5,000 cfs to 2,304 cfs	22,400	19,500
March 18	2,304 cfs to 1,088 cfs	105,300	91,900

Some aspects of the estimates could be challenged, and there is certainly question as to whether experiments on other dates would have provided larger or smaller mortality estimates. The 1973 experiment did show, however, that substantial mortality can occur as a result of flow fluctuation, and that schedules such as proposed by WDF need to be applied insofar as feasible to minimize this source of mortality. This, in fact, has been accomplished by informal agreement between WDF and SCL.

Phinney (1974b) estimated that roughly 3 percent of the total potential number of chinook fry produced in the Skagit River between Newhalem and the sauk river were killed in the scheduled severe flow reduction of March 18. Obviously, if fluctuations this extreme were repeated periodically, the cumulative mortality could be severe. However, it could be speculated, with some justification, that rearing area is limited and that as a result remaining fry may have a higher survival rate, at least partially compensating for mortality caused by stranding, or that the weaker fry tend to be the ones killed by stranding. However, adequate proof of these possibilities is still lacking. An effort was made to determine success of brood year classes subjected to favorable and unfavorable flow-fluctuation water years by examining escapement-return data. However, it was determined that the accuracy of available escapement data, the difficulties of assigning chinook catches in the various fisheries to river of origin, and the relatively low variation in the estimates of escapement from year to year precluded correlating return per spawner to possible flow fluctuation conditions encountered by the brood year fry.

Studies were conducted by FRI personnel during the winter and early spring of 1976 and 1977 to determine the extent of losses due to fry stranding in the Skagit River between Newhalem and the Sauk River under the present operational regime and estimate the probable effects of flow regulations which may be potentially proposed by fisheries agencies for relicensing or which may be potentially provided by Copper Creek Dam. the previously described studies of Thompson (1970) and Phinney (1974a) were conducted during scheduled flow reductions where the rate of reduction (ramping rate) was near or greatly exceeded, in the case of Thompson's studies, the maximum ramping rate of the usual operational policy of SCL. The data on stranded fry was further used to compare the condition factors of stranded and non-stranded fry in an effort to determine if stranding was size selective.

Additional investigations were undertaken in 1978 to better understand some of the factors which may influence fry susceptibility to stranding. These investigations were carried out in an experimental channel where the timing and magnitude of the flow reduction and the fry population could be controlled.

8.2 Study Sites

8.2.1 Fry Electrofishing Sampling Stations

The stations for collection of salmonid fry for food habit studies and for size and condition measurements are shown in Fig. 8.1. For the most part, the stations in the mainstem Skagit are the same stations sampled with the plankton pump as described in Sec. 4.2.

The County Line Station was on the gently sloping cobble-covered bar at the Whatcom-Skagit County line at RM 89.2. At flows above about 2500 cfs, the bar was separated from the right bank by a back channel that was also sampled for fry.

The Talc Mine Station was at the island near the left bank at RM 84.3 near the site of the proposed Copper Creek Dam. This station included areas with rapidly flowing water over cobbles on the river side of the island, quiet sandy habitats below the island, and muddy, brushy areas with overhanging vegetation in the back channel.

The Marblemount Station was on the left bank above the mouth of the Cascade River near the Marblemount Bridge at RM 78.3. This site had strong currents and deep water (about 2 ft/sec and 2 ft, respectively) fairly close to shore and a cobble and gravel bottom. There was a small quiet pool used as a boat launch and a submerged brush pile under the bridge.

The Rockport Station was at a sand and rock bar downstream of the town of Rockport and upstream of the mouth of the Sauk River at RM 67.0. There were some brushy areas in the back channel on the right bank. At flows above 11,000 cfs, the Rockport Bar was inundated so samples were taken in the park at the town of Rockport in fairly slow-flowing water with submerged roots and undercut banks in May 1976 and April 1977.

The Concrete Station was added above the mouth of the Baker River at RM 56.7 in April 1977, to sample fry condition and diet in conjunction with plankton drift sampling (Sec. 4.0) as far downstream as possible without the confounding influence of possible limnoplankton releases from reservoirs on the Baker River. This area included shallow sandy riffles, pools with submerged logs, and deeper riffles with cobble and gravel substrate.

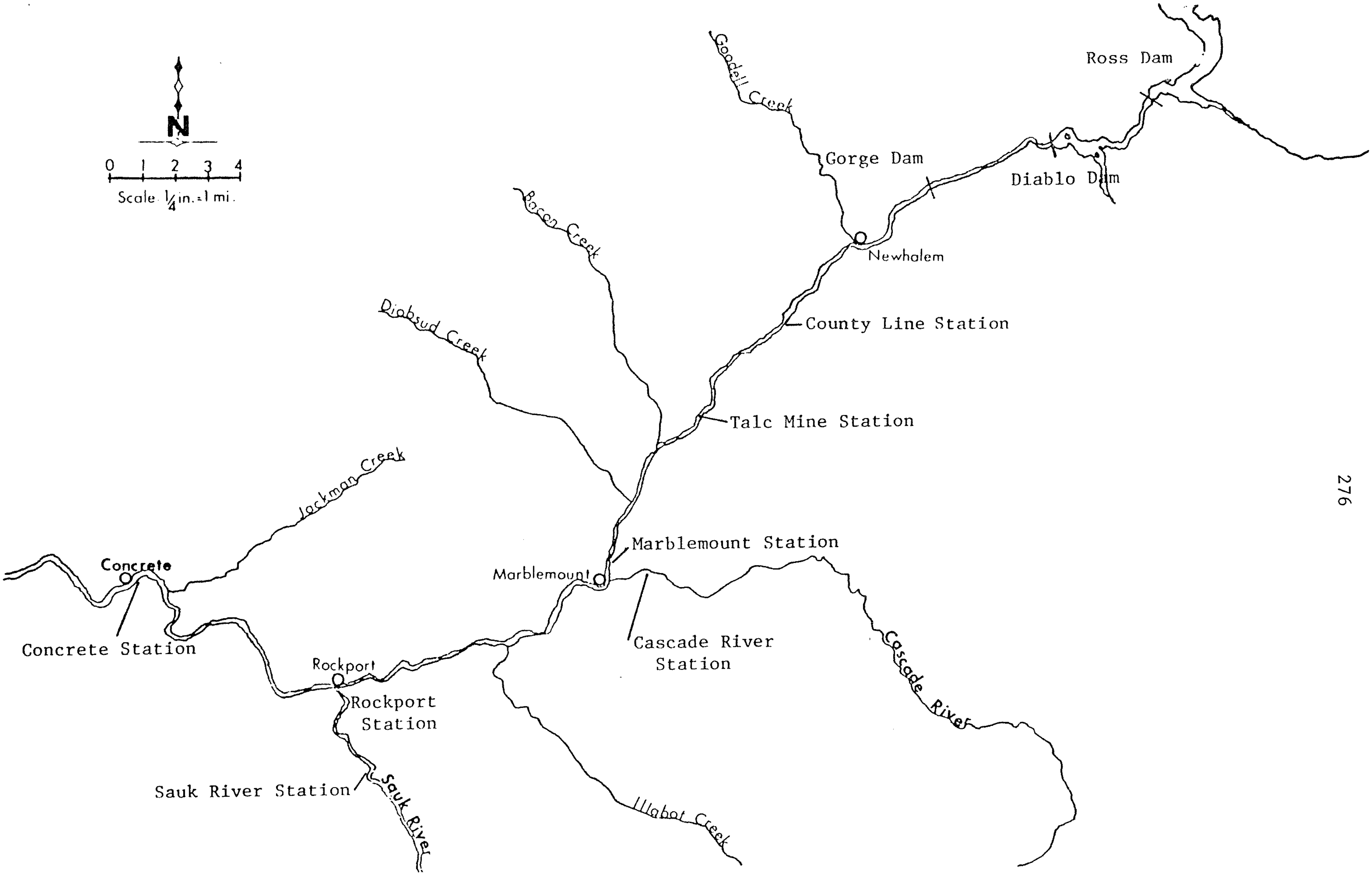

Fig. 8.1 Electrofishing stations for stomach and condition samples, Skagit Basin, Washington.

Fry from two major Skagit tributaries were also sampled for condition and stomach content analysis. The Cascade River was sampled on the left bank near the highway bridge (RM 0.9) upstream from the Marblemount Hatchery. This area included some fast, deep areas with a few stumps. Sometimes the small back channel to the left of the main channel upstream from the bridge was also sampled. The Sauk River was sampled for fry on the right bank at the county road bridge (RM 7.0). There were gravel beaches and submerged stumps and roots here.

Three minor Skagit tributaries were also sampled for fry. Goodell Creek, which enters the Skagit River at RM 92.9, was sampled near the highway bridge that crosses the creek 0.1 mi upstream from the Skagit River. Bacon Creek, which enters the Skagit at RM 82.9, was sampled upstream of the campground above the highway bridge 0.2 mi from the Skagit River. Diobsud Creek, which enters the Skagit at approximately RM 80.7, was sampled near the highway bridge 0.2 mi from the Skagit River. Bacon Creek is the largest of these minor tributaries, with a 7-year average discharge of 429 cfs, and Diobsud Creek is the smallest.

Sites of fry collection in the Skagit River were sometimes varied to seek out different fry habitats or because of the occasional unavailability of the boat for transportation to the usual sampling stations.

8.3 Materials and Methods

8.3.1 Electroshocking for Fry

A Smith-Root type backpack electrofisher was the primary collection device used for capturing salmon and rainbow-steelhead trout fry for (1) availability assessment, (2) size and condition factor analysis, and (3) diet analysis. Open gravel bars, back channels, and undercut banks were shocked from depths of less than 1 inch to over 3 ft in an effort to sample different rearing habitats. Generally, electrofishing was done by a crew of two: One person carried and operated the electrofisher while the other person helped collect the stunned fry and kept count of the catch.

In 1974, chinook, pink, chum, and coho salmon and rainbow-steelhead trout fry were sampled at the upper three Skagit sites, the Sauk River, the Cascade River, Diobsud Creek, Bacon Creek, and Goodell Creek. The Skagit River sites were first sampled on February 14-15, the Cascade River and Sauk River were first sampled on February 21-22, while the creeks were added in March or April. Generally, weekly to biweekly samples were taken through June 13, with occasional sampling in July, August, and September 1974. Limited sampling was conducted with fyke nets in Diobsud, Bacon, and Goodell creeks. Samples were collected for assessment of seasonal availability of the fry and for analysis of changes in lengths, weights, and condition factors.

In 1975, chinook fry were sampled from the upper three Skagit River sites, the Sauk River, and the Cascade River on a weekly to biweekly basis from early January to late August. From 1 to 55 fry were taken but an attempt was made to obtain at least ten fish for analysis of lengths, weights, and condition factors at each sampling. Usually five chinook fry were preserved from these collections for diet analysis from January 18 to June 16 in the Skagit River, from March 11 to June 16 in the Cascade River, and from February 11 to June 16 in the Sauk River.

Sampling began again in December 1975 at four stations on the Skagit above the Sauk, and at stations on the Sauk and Cascade rivers. Goodell, Diobsud, and Bacon creeks were also sampled. Additional sampling was done on the Skagit River near Concrete beginning in April 1977. Chinook, pink, chum, coho, and rainbow-steelhead fry were collected for assessment of availability and for analysis of length, weight, and condition factor changes. An attempt was made to collect 25 specimens of each available species for each sample from the Skagit, Sauk, and Cascade river sites, while a limit of 10 specimens of each species was usually observed in the three minor tributaries. This sampling was continued year-round through 1976 on a weekly basis for about the first half of the year, and then every two weeks. Weekly electrofishing was resumed in December 1976 and continued to May 1977 when sampling was done every two weeks. Sampling in the creeks was terminated in August 1977. Sampling at the remaining stations was monthly from September through December 1977. In 1978, monthly samples continued to be collected at the stations on the Sauk and Cascade rivers, and at the Talc Mine Station on the Skagit River through April while weekly samples were collected into June at the County Line, Marblemount, and Rockport stations on the Skagit River.

Monthly samples of five fry from each of the five species (except pink salmon which were scarce) were obtained when available for analysis of stomach contents from the stations on the Skagit, Cascade, and Sauk rivers beginning February 1976. In April 1977, the monthly sample size was increased to ten fish of each available species from each river site and a station at Concrete upstream from the mouth of the Baker River which was added to coincide with plankton sampling at this site. This sampling was continued through April 1978.

In late January 1976, attempts were initiated to make the monitoring of chinook fry availability more quantitative by standardizing electrofishing as to location, distance and area covered, and time expended. Two 50-ft passes with the backpack electrofisher were made parallel to the shore. During the downstream pass, the band from the shore to 10 ft out was covered. During the upstream pass, the band from 10 ft out to 20 ft from shore was covered. One thousand ft^2 were covered in the two passes. Fry were captured by the electrofisher operator or a helper and counted at the end of each pass. Fry that escaped capture during the two passes were also counted. In 1976, quantitative sampling of chinook fry was conducted weekly to biweekly from January 26 to May 19 at the County Line Station (RM 89.2) and from January 23 to April 22 at the Rockport Station (RM 67.0). In 1977, the Marblemount Station (RM 78.3) was added as a quantitative sampling site and chum fry availability was also monitored. The transect shocking in 1977 began on January 26 and continued weekly to biweekly through June 6, 1977.

8.3.2 Analysis of Fry Samples

8.3.2.1 Fry Availability. Total fry catches at Skagit Basin sampling sites using electrofishing were tabulated by species and dates. However, these catches were not from standardized effort, but were the total catch of fry for size and condition and for diet studies for each sampling period. To achieve the desired sample size more effort was required early and late in the rearing season for a particular species than during mid-season. Surplus fish in mid-season were often passed over without being counted. While not strictly quantitative, these data can give a general picture of fry abundance during the sampling period. Fry catch tables also indicate the earliest and latest dates fry were available. Fry densities at Skagit River sites were calculated from the standardized electrofishing effort for chinook fry in 1976 and 1977 and for chum fry in 1977. These data were plotted over time to show seasonal changes in fry density.

8.3.2.2 Fry Size and Condition. Fry for size and condition factor analysis were generally brought alive in jars of water to the laboratory in Newhalem. Fry were anesthetized with MS-222, drained in a wire strainer, measured from tip of snout with jaw closed to fork of tail to the nearest millimeter, and sorted into 5-mm length groups.

In 1974 and 1975, wet weights of each length group were measured to the nearest tenth of a gram (0.1 g) on an Ohaus triple beam balance. In 1975, some fry were frozen until they could be transported to Seattle were fry were dried in a Stable Therm laboratory oven at 60°C. Dried fry were weighed by length groups to the nearest ten thousandth of a gram (0.0001 g) on a type H & T Mettler balance.

Beginning December 1975, wet weights of each 5-mm length group were obtained to the nearest hundredth of a gram (0.01 g) on a top-loading Mettler balance (PN 1210).

Condition factors were computed using the formula:

$$\text{Condition factor} = \frac{(\text{Average weight in g}) \times 10^5}{(\text{Average length in mm})^3}$$

A condition factor was computed for each 5-mm length group. Then the mean condition factor, weighted by the number of fish in each length group, was computed for each sample.

8.3.2.3 Fry Diet. Fry for diet analysis were preserved in 10 percent formalin at the time of collection in 1975. For the first 3 months of 1976, fish for diet analysis were brought alive into the laboratory at Newhalem to be weighed and measured along with fish used for condition sampling. This treatment resulted in poor preservation of some stomach contents. Starting in May 1976, the catch was subsampled in the field and fry used for stomach analysis were preserved in 10 percent formalin. Size and condition of these fish were assumed to be similar to fish sampled for condition at the same station and time. Lengths were recorded at time of dissection. Year classes were separated by length frequency.

Stomachs were dissected and contents of each were identified, classified, and enumerated. Intestines were not examined.

8.3.3 Fry Stranding

8.3.3.1 Mortality Due to Stranding. In 1976, observations for fry stranding were made by FRI personnel along the main channel of the Skagit River at County Line Bar (right bank at RM 89.2), Marblemount Reference Reach (left bank at RM 79.4), and Rockport Bar (right bank at RM 67.0). In 1977 the same areas were studied except for Marblemount which was sampled downriver in the vicinity of the Marblemount Bridge (left bank at RM 78.3). The observations were made to obtain data comparable with those obtained by WDF in 1973 (Phinney 1974a). Two additional sites (Bacon Creek Bar, RM 82.8 and Sutter Creek Bar, RM 70.9) examined by WDF in 1973 were not studied by FRI because of the limited bar exposure under normal operating conditions. It was found in 1976 that effective observations could not be made on days when the exposed substrate was frozen. This restricted the times in early season when observations could be taken. Times selected for observations of fry stranding under normal operating conditions were times when flow reduction was sufficient to expose considerable river bar area.

In 1977, improved communication with the SCL Power Control Center facilitated the sampling effort by helping predict when such flow reductions were likely to occur. If the flow reduction occurred during daylight hours, the survey team was present at the study site as the flow receded. These measures were taken to minimize scavenging of the stranded fry by birds.

Fry stranding surveys were not possible after late-April 1977 because flow control exercised by SCL until late-October 1977 virtually eliminated flow fluctuations and the resulting stranding mortalities for that period. Transecting methods were essentially the same as those described by Phinney (1974a). The upper layer of substrate was removed to maximize the detection of stranded fry. Fry mortality per unit area and per linear length of exposed bar was calculated for the days when surveys were conducted in 1976 and 1977. The estimate of linear feet where stranding might occur between Gorge Powerhouse and the Sauk River (27.7 river miles) was obtained by outlining the shorelines and perimeters of bars where conditions approximated those of the study sites on a set of aerial photographs with a scale of one inch equals one hundred feet. The outlined areas were measured with a map measuring instrument and converted to feet by multiplying by 100. This distance was used in the calculations of total mortalites for the days when surveys were conducted.

The potential fry mortality from stranding for 1977 was estimated by expanding the mortality estimates calculated for the days in 1977 when surveys were conducted. The hourly flow records from January 1 to

April 21, 1977 were analyzed. This included the period when fry were available but not necessarily in peak numbers until the non-fluctuating flow regime was implemented by SCL. The flow reductions in excess of approximately one foot were classified according to the minimum elevation reached at the Newhalem gage (U.S. Geological Survey--USGS) and to the number of feet dropped. Based on this classification the proportion of flow fluctuations surveyed to the total number of flow fluctuations for the period was calculated and used to project the potential seasonal fry mortality due to stranding.

8.3.3.2 Stranding Selectivity. Length, weight, and condition factors were calculated for four groups of stranded chinook fry from 1976 and one group from 1977 to compare with length, weight, and condition factors of unstranded fry (electroshocking samples) from the same locations.

In addition, a group of rainbow-steelhead trout fry were captured in August 1977 and treated like a stranded fry sample to determine if stranding and subsequent handling caused changes in lengths, weights, or condition factors. The stranded fry are different from the electroshocked samples in that they have been dead for several hours before they are brought back to the laboratory for measuring and weighing while the electroshocked samples were normally alive just prior to measuring. The trout fry were brought back to the laboratory alive, killed, weighed, and measured, just like a normal electroshocked sample. The fry were then placed on a bed of wet gravel for two hours, simulating stranding conditions, and finally placed in a jar of water for one hour, simulating the trip from the field to the laboratory. The fry were remeasured, reweighed, and condition factors were calculated.

The changes in lengths and weights were applied to the original samples of stranded chinook fry for another comparison with the unstranded fry. All comparisons were made using the Wilcoxon matched-pairs signed-ranks test.

8.3.3.3 Ramping Rates. Fry stranding data from our 1976 and 1977 studies were combined with that of Phinney (1974a) to describe the relationship between stranding mortality and ramping rate. Stranding mortality for sites common to both studies (County Line and Marblemount bars) was plotted against ramping rate. Regression analysis was performed and correlation coefficients were calculated.

8.3.3.4 Experimental Studies. A section of spawning channel at the Big Beef Creek Research Station on Hood Canal was altered to simulate flow and substrate conditions on the Skagit River. The channel was formed by two 3-ft high and 6-inch thick concrete walls and was 50 ft long (Fig. 8.2). A river bar was simulated by placing a single layer of large rock (minimum diameter 2 inches) on a substrate of mixed sand and gravel. The 8-ft wide bar was sloped gently (1 to 15) to one side where there was an 18-inch wide channel for minimum flow. The fry were contained within the "bar" area by two screens made of 1/8-inch nylon net stretched over a wooden frame. The downstream screen had a 6-x 12-inch opening into the

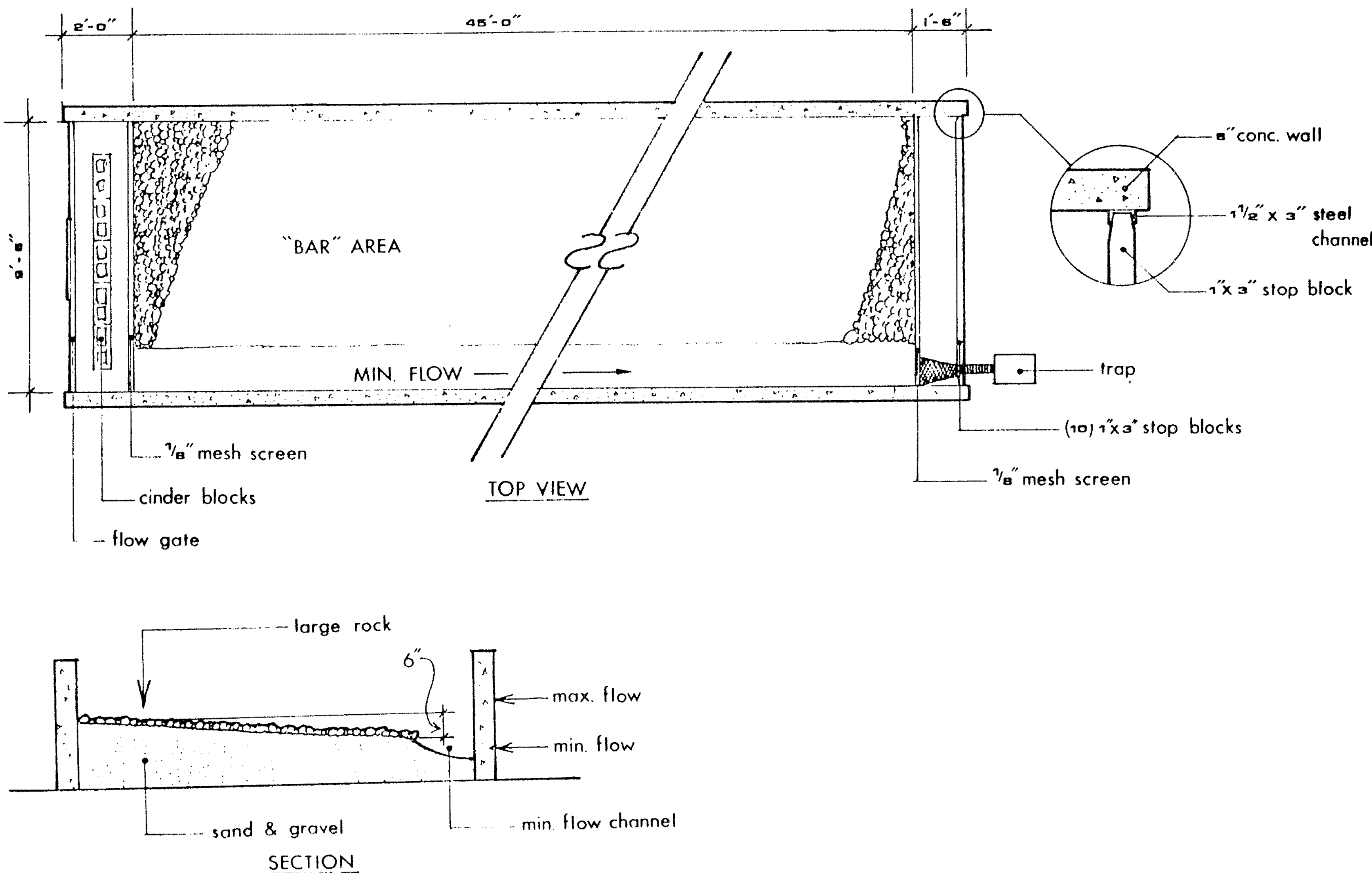

Fig. 8.2 Experimental stranding channel at Big Beef Creek Research Station.

minimum flow channel. The opening had a bag net and trap which were used to remove the fish after each trial. The water level in the channel was controlled by a stack of 10 1-x 3-inch boards just below the lower screen. During a trial six boards were removed, one every 10 min, to simulate a river drop of 6 inches per hr (actual rates in the Skagit River vary up to about 18 inches per hr). The water flow rate was controlled just upstream of the upper screen by a 2-x 3-ft gate. As each board was removed the gate was closed a predetermined amount to maintain the flow rate near 1 ft/sec to simulate typical Skagit River flow rates. To divert and dissipate the strong current of water entering the channel, there was a stack of cinder blocks between the gate and upper screen.

Prior to use in the experimental channel all fry were held in an adjacent channel in one of two 5-x 5-ft pens made with the same 1/8-inch netting as the screens. The water level and flow rates were constant. The second 5-x 5-ft pen held the "used" fry, which had experienced the channel.

Chinook fry were collected at the Skagit River by electroshocker and transported to Big Beef on February 16, March 9, and March 29, 1978, (Groups I, II, and III, respectively). Additional chinook fry were collected at the Lewis River with a stick seine on April 21, 1978, (Group IV).

The following routine was used for each trial in the experimental channel:

- Gravel on "bar" was raked to distribute it evenly.
- Trap was disconnected and cover was placed over opening in lower screen.
- Stop blocks put in position and flow gate opened-level raised to maximum.
- Sample of 100 fry released at midchannel.
- Fry were allowed to acclimate for either 16 or 64 hrs.
- Beginning at 8:00 a.m., one stop block was removed every 10 min. As each block was removed the flow gate was closed a predetermined amount.
- When the flow reduction had uncovered the bar, 6 blocks and 60 min later, the remaining 4 blocks were removed.
- The trap was positioned and the lower screen opening uncovered.
- The nonstranded fry were collected in the trap and the stranded fry were recovered by sorting through the gravel.

- The channel was completely drained and those fry which avoided the trap were hand-netted out of the minimum flow channel.

The variables tested were: stability of flow prior to reduction; fry learning; and fry age and/or size. The effect of prior flow was examined by running overnight and weekend trials with 16 and 64 hrs, respectively, of steady flow prior to the reduction. Fry learning was examined by running the same sample of fry twice and comparing the stranding mortality between the first and second trials. Fry age and size were examined by comparing the differences in stranding mortality between the fry sampled on February 16; March 9; March 29; and April 21, 1978.

The general schedule was to run the weekend trials from Friday afternoon to Monday morning. Following the trial, these fish were put in the "used fry" pen to be returned to the river. The first run fry were put in either Monday or Wednesday afternoon and recovered Tuesday or Thursday morning, respectively. While the channel was prepared for their second run the fry were held in a large bucket. The turnaround time for the channel was about 6 hrs. Following the second run, on Wednesday or Friday morning, the recovered fry were then put in the "used fry" pen. Because of early difficulties in recovering the first run fish, the sample was often too reduced to make a second run.

8.4 Results and Discussion

8.4.1 Chinook Salmon Fry

8.4.1.1 Chinook Salmon Fry Availability. In the initial years of sampling, it was believed that summer-fall chinook fry did not begin emergence until late February. Overall, catches by WDF on the first sampling date, March 2, 1973, were much lower than on subsequent sampling dates, and catches were highest from the latter half of March to mid-May (Phinney 1974). In 1974, catches by WDF in March were lowest on the first of the four sampling dates (Orrell 1976). However, embryonic development studies and electrofishing in 1975 established that chinook fry emergence in the Skagit above the Cascade River began in early January and extended into May, with peak emergence possibly occurring from late January to early February (Sec. 7.0).

In 1976, chinook fry from the 1975 brood were first encountered by electrofishing in the Skagit River on January 5, and were present in subsequent weekly samples (Table 8.1). In the more quantitative sampling beginning January 23, 1976, chinook fry were present at the County Line and Rockport stations and increased in abundance to mid-March (Fig. 8.3). At the County Line Station, catches were highest on April 13, then declined to low abundance by May 19. At Rockport Station, fry densities were highest in late March and remained rather constant to April 22.

The 1976 brood was first encountered by electrofishing on December 2, 1976 (Table 8.2). The chinook fry catch reached maximums at the Marblemount Station on February 25, 1977, and at the County Line Station on March 8 (Fig. 8.3). Catches were lower at Rockport and reached a less

Table 8.1 Chinook fry catches at Skagit Basin sampling sites using electrofisher, 1975 brood.

Date	Skagit River at County Line	Skagit River at Talc Mine	Skagit River at Marble-mount	Skagit River at Rock-port	Cascade River	Sauk River	Goodell Creek	Bacon Creek	Diobsud Creek
1975									
12/19-1/3	-		-		-	-			
1976									
1/4 -1/10	2	-	13		-	-			
1/11 -1/17	6	-	23		-	-			
1/18 -1/24	17	7	31	10	-	1			
1/25 -1/31	30	1	25		-	-		-	
2/1 -2/7	28	28	45	30	-	11			
2/8 -2/14	36	35	39		10	23			
2/15 -2/21	28	11	49	42	24	8			
2/22 -2/28	41	23	26	46	33	20	-	3	-
2/29 -3/6	38	34	37	62	29	28			-
3/7 -3/13	49	28	113		42	25	-	26	
3/14 -3/20	141	29	36	53	28	26	-	30	-
3/21 -3/27	110	30	60	54	25	26	1	23	25
3/28 -4/3	56	25	25	26	26	26	-	25	-
4/4 -4/10	44	32	32	27	29	19	2	30	9
4/11 -4/17	152	28	25	43	26	16	2	30	1
4/18 -4/24	25	28	24	46	34	20	-	27	5
4/25 -5/1	48	25	27	33	35	6	-	28	1
5/2 -5/8	36	22	42	28	29	3	-	29	1
5/9 -5/15	25	12	27	24	19	-		39	-
5/16 -5/22	15	10	25	27	38	7	-	25	5
5/23 -5/29	25	25	29	43	17	3	-	26	-
5/30 -6/5	31	16	38	30	7	9			
6/6 -6/12	16	29	30	32	13	-	-	24	-
6/13 -6/19	35	54	27	11	5	8	-	30	
6/20 -6/26	42	34	29	32	4	11	-	14	-
6/27 -7/3	17	11	19	-	2	1	-	17	-
7/4 -7/10	28	21	11		-	1	-	-	
7/11 -7/17	3	-	2		1	1	-	1	-
7/18 -7/24	-		3	8	-	-	-	-	-
7/25 -7/31	1		1	-	1	-	-	-	-
8/1 -8/7	-		-	-	-	-	-	-	-

Note: dash (-) signifies catch was zero.
blank signifies sampling not conducted.

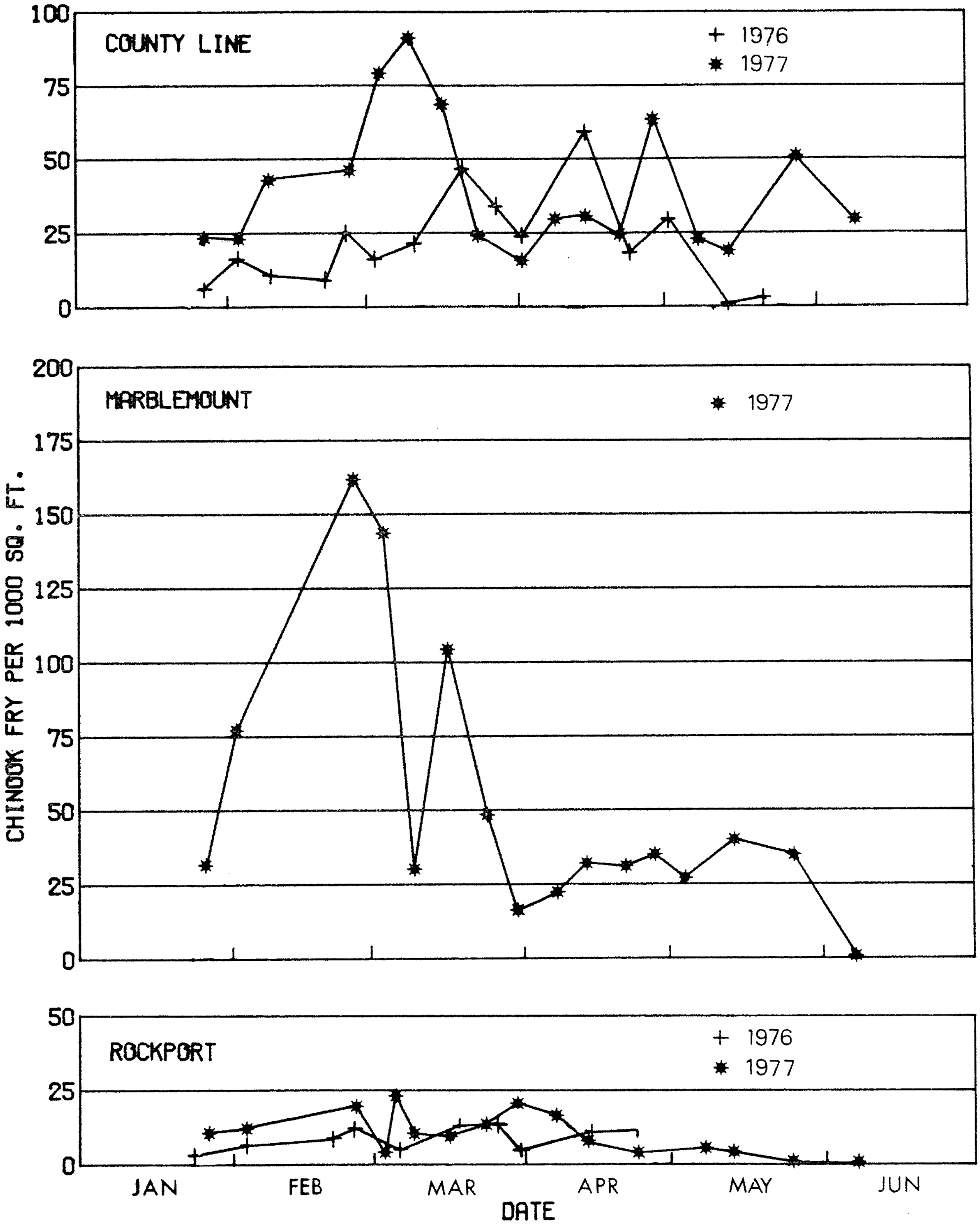

Fig. 8.3 Chinook fry availability at Skagit River sampling sites from standardized electrofishing effort, 1976 and 1977.

Table 8.2 Chinook fry catches at Skagit Basin sampling sites using electrofisher, 1976 brood.

Date	Skagit River at County Line	Skagit River at Talc Mine	Skagit River at Marble-mount	Skagit River at Rock-port	Cascade River	Sauk River	Goodell Creek	Bacon Creek	Diobsud Creek
1976									
11/7 -11/20	-	-	-	-	-	-	-	-	-
11/21-12/4	1	-	1	-	-	5	-	-	-
12/5 -12/11	1	-	2	4	-	2	-	1	-
12/12-12/18	4	2	13	14	-	8	-	-	-
12/19-12/25	9	5	15	15	-	15	-	-	-
12/26-1/1	19	19	11	18	-	29	-	-	-
1977									
1/2 -1/8	35	19	34	29	1	33	-	-	-
1/9 -1/15	27	18	33	32	-	26	-	-	-
1/16 -1/22	22	26	32	26	-	31	1	4	9
1/23 -1/29	9	12	30	28	4	26	-	5	4
1/30 -2/5	54	23	77	35	11	33	-	8	30
2/6 -2/12	25	25	27	25	16	27	-	11	11
2/13 -2/19	33	28	27	22	23	30			
2/20 -2/26	111	31	162	70	32	45	-	12	10
2/27 -3/5	197		144	109	43	38	-	12	13
3/6 -3/12	186	28	27	38	25	28	-	10	10
3/13 -3/19	129	13	105	36	25	26	-	12	16
3/20 -3/26	73	26	48	51	31	27	6	14	27
3/27 -4/2	31	28	26	79	31	32	10	11	27
4/3 -4/9	62	35	37	69	38	84	9	13	27
4/10 -4/16	63	39	32	33	29	34	5	11	11
4/17 -4/23	51	13	31	18	31	34	12	12	20
4/24 -4/30	139	69	35	36	33	38	12	19	12
5/1 -5/7	55		32	24	30	26	2	10	19
5/8 -5/21	46	32	40	24	37	24	7	13	20
5/22 -6/4	95	38	35	33	33	12	2	-	30
6/5 -6/18	69	13	5	1	2	18	1	2	23
6/19 -7/2	27	4	29	2	5	7	-	-	11
7/3 -7/16	57	2	32	-	6	1	-	2	13
7/17 -7/30	44	-	1	-	2	-	-	-	1
7/31 -8/13	16	-	-	-	-	15	-	-	-
8/14 -8/27	1	-	-	-	-	10	-	-	-

Note: dash (-) signifies catch was zero.
blank signifies sampling not conducted.

distinct peak on March 4. The earlier emergence timing of the 1976 brood was to a large extent the result of warmer incubation temperatures in 1976-1977 (Sec. 7.0).

First appearance of chinook fry was later in the tributaries than in the mainstem Skagit. In 1976, fry apppeared in the mainstem on January 5, in the Sauk River on January 21 (1 fish), in the Cascade River on February 11, in Bacon Creek on February 27, in Goodell Creek on March 25 (one fish), and in Diobsud Creek on March 25 (Table 8.1). The later emergence in tributaries is related primarily to lower mean development temperatures. In 1977, first emergence was earlier, but the pattern of later initiation of emergence in tributaries was repeated, except that emergence began as early in the Sauk River as in the mainstem Skagit above the Sauk. The first fry appeared during mid-January in the three creeks except for one precocious fry in Bacon Creek (Table 8.2).

In 1976, chinook fry catches in Goodell and Diobsud creeks were small. First appearance was later and last catches were earlier than at any other sampling station (Table 8.1). In 1977, the catches in these two creeks were larger and extended over a longer period.

The timing of downriver and seaward migration of summer-fall chinook fry is not well defined. In 1974 sampling conducted by WDF showed that chinook fry had reached the lower river by the first sampling date, April 8. By June, the numbers still present in the mainstem upriver areas and the tributaries were greatly reduced. In 1977, the University of Washington Cooperative Fishery Research Unit collected fish samples in the salt marsh at the mouth of the Skagit River. Juvenile chinook salmon were collected as early as March 23, 1977 (J. L. Congleton, Assist. Professor, U.W., Cooperative Fisheries Research Unit, personal communication). Preliminary results from our 1978 marking study indicated that fry marked upstream of Marblemount before March 18, 1978, were found downstream of Rockport by April and May.

In 1976, chinook fry catches began to diminish in June and July at the river stations and in Bacon Creek. Chinook fry were unavailable by August 1 at all study sites (Table 8.1). In 1977, despite the earlier emergence, there were still chinook fry present at most sampling sites as late as or later than in 1976 (Table 8.2). This extra rearing time helped send them to sea at a larger size than in 1976 (Sec. 8.4.1.2) which may favorably influence their return as adults. As in 1976, chinook fry catches at the Skagit sites began declining around early July. The Rockport Station, the farthest downstream of the Skagit River sites, had low catches first. Goodell and Bacon creeks stopped yielding chinook fry somewhat earlier than the upper three Skagit sites, while Diobsud yielded its last chinook fry in the second week of July. The Sauk had a late second peak of large fish that were possibly spring chinook from the Suiattle River.

8.4.1.2 Chinook Salmon Fry Size and Condition after Emergence. The changes in length, weight, and condition factor over time are not necessarily the result of growth alone because the extent and timing of fry mixing and migration is largely unknown. Confounding factors could include protracted emergence of small fry from the gravel, emigration of larger fry to deeper, faster flowing rearing areas or downstream, and immigration of larger fry from upstream. To some extent in 1976 and 1977, deeper, faster areas were sampled both with the backpack shocker and with the boat shocker without finding larger chinook fry. Results from incubation studies suggested that earlier-emerging fish were smaller than later-emerging fish (Sec. 7.5.3).

The mean lengths, weights, and condition factors of the 1973 brood of chinook fry captured by electroshocking in 1974 are presented in Tables 8.3 through 8.10. Sampling was conducted over only part of the period that chinook fry are now known to be present in the area. The trends in the length, weight, and condition factor changes were similar to those seen in 1974 through 1976 broods. There was an initial period when the mean size and condition parameters increased only slightly. Then they increased aburptly, in this case in May, a little later than in 1975, 1976, or 1977, probably because the temperatures over the incubation and rearing periods were cooler than usual in the 1973-1974 incubation and rearing season, according to SCL records. The range of lengths increased through the rearing period. Small fish were present through May and June, indicating a prolonged emergence of small fish from the gravel.

Tables 8.11, 8.12, and 8.13 show the mean lengths, mean dry and wet weights, and mean condition factors (wet and dry) from chinook fry of the 1974 brood from the upper three Skagit sites, and the Sauk and Cascade rivers. Dry weights were taken of 1,663 fish--910 from the Skagit, 501 from the Sauk, and 252 from the Cascade. Dry weights were thought to be more accurate because of results in laboratory experiments which reportedly indicated that starving fish would absorb water to maintain body shape. Apparently, chinook fry in our sample area were not often under that degree of stress because wet weights were found to be about six times the dry weights with little variation. Over the sampling period, January through July 1, the average lengths, dry weights, and condition factors for Skagit fry sampled for dry weights were 41.6 mm, 0.1169 g and 0.153, respectively (Table 8.14). Averages were unweighted means for all samples from which dry weights were made. This compares to 43.8 mm, 0.1565 g and 0.165 for the Sauk; and 43.2 mm, 0.1396 g, and 0.161 for the Cascade. Skagit fry averaged shorter than the fry from the other two rivers, and their average condition factor was the lowest of the fry from the three rivers. Over the estimated period in which the majority of emergence occurred (January to April 15) (Table 8.14), Skagit fry had an intermediate condition factor, were slightly smaller in average length, and had a slightly lower average dry weight.

However, through part of the emergence period (February and March) Skagit fry averaged slightly higher or very close in condition to fry from the other two systems (Fig. 8.4). After mid-April, Cascade and particularly Sauk fry showed a trend toward better condition. The fact that the condition of Skagit fry was eventually surpassed by the condition of fry from the Sauk, and Cascade, may be due to racial differences in the stocks, to environmental differences in the rivers affecting the fish

Table 8.3 Mean lengths, weights, and condition factors of Skagit River chinook fry captured by electroshocking at sites near County Line, 1973 brood.

Date	Number of fish	Length (mm)		Mean weight (g)	Mean condition factors
		Range	Mean		
1974					
Feb 14	22	38-44	41.2	0.55	0.79
25	18	37-43	40.3	0.59	0.91
Mar 11	60	37-45	40.8	0.57	0.84
25	43	39-46	42.5	0.62	0.81
Apr 8	35	38-44	40.9	0.64	0.94
10	1	41	41	0.7	1.0
17	3	40-41	40.3	0.50	0.77
24	9	41-43	42.1	0.59	0.79
May 6	33	36-46	41.5	0.58	0.80
8	28	38-45	41.4	0.62	0.87
21	26	38-45	40.9	0.72	1.04
21	23	37-47	40.7	0.58	0.84
Jun 13	25	36-43	39.9	0.72	1.13
Jul 3	24	38-58	44.3	1.08	1.15
3	18	39-50	43.2	1.01	1.24
Aug 15	1	50	50	1.6	1.3

Table 8.4 Mean lengths, weights, and condition factors of Skagit River chinook fry captured by electroshocking at sites near Talc Mine, 1973 brood.

Date	Number of fish	Length (mm) Range	Length (mm) Mean	Mean weight (g)	Mean condition factor
1974					
Feb 15	15	39-43	40.9	0.51	0.75
26	76	39-48	41.7	0.56	0.77
Mar 12	71	37-44	41.4	0.54	0.75
26	20	37-45	41.2	0.64	0.91
Apr 9	24	38-47	40.9	0.56	0.82
17	23	33-43	40.2	0.59	0.89
23	10	40-45	42.4	0.62	0.81
May 7	43	38-47	41.2	0.64	0.91
20	22	38-48	42.8	0.71	0.91
Jul 5	1	45	45	0.90	0.99

Table 8.5 Mean lengths, weights, and condition factors of Skagit River chinook fry captured by electroshocking at sites near Marblemount, 1973 brood.

Date	Number of fish	Length (mm)		Mean weight (g)	Mean condition factor
		Range	Mean		
1974					
Feb 15	46	37-45	41.3	0.54	0.77
22	78	37-45	40.3	0.57	0.88
26	62	33-45	40.7	0.55	0.80
Mar 12	68	33-45	41.5	0.57	0.80
26	45	39-44	41.1	0.61	0.87
Apr 9	44	38-46	41.4	0.70	0.97
17	34	37-46	41.8	0.69	0.94
23	34	38-48	40.6	0.54	0.81
May 7	36	37-46	41.3	0.63	0.88
20	30	41-53	44.1	0.79	0.91
Jun 12	13	37-47	43.5	0.83	1.00
Jul 2	2	46-47	46.5	1.10	1.09

Table 8.6 Mean lengths, weights, and condition factors of Cascade River chinook fry captured by electroshocking, 1973 brood.

Date	Number of fish	Length (mm) Range	Length (mm) Mean	Mean weight (g)	Mean condition factor
1974					
Feb 22	110	34-46	40.4	0.55	0.82
27	63	34-46	39.3	0.48	0.79
Mar 3	33	37-45	40.8	0.54	0.78
26	51	36-45	40.4	0.56	0.84
Apr 9	37	36-42	38.7	0.51	0.87
17	26	37-42	40.0	0.53	0.82
23	49	38-45	39.9	0.59	0.92
May 7	34	36-45	40.6	0.61	0.90
21	12	38-45	40.9	0.59	0.85
Jun 12	19	38-51	44.5	1.07	1.17
Jul 2	7	41-54	47.6	1.46	1.35

Table 8.7 Mean lengths, weights, and condition factors of Sauk River chinook fry captured by electroshocking, 1973 brood.

Date	Number of fish	Length (mm) Range	Mean	Mean weight (g)	Mean condition factor
1974					
Feb 21	30	30-43	34.9	0.53	1.25
27	50	33-43	39.9	0.50	0.79
Mar 13	58	37-44	40.0	0.50	0.77
26	70	33-46	41.2	0.62	0.88
Apr 9	32	37-45	41.0	0.65	0.92
23	36	39-50	43.0	0.81	1.01
May 7	18	38-45	41.0	0.68	0.98
21	13	39-59	47.2	1.16	1.03
Jun 13	4	46-53	49.8	1.88	1.50
Jul 3	5	40-54	49.0	1.82	1.58

Table 8.8 Mean lengths, weights, and condition factors of Goodell Creek chinook fry captured by either electroshocking or fyke netting, 1973 brood.

Date	Number of fish	Length (mm) Range	Mean	Mean weight (g)	Mean condition factor
1974					
Mar 13	27	38-44	40.7	0.55	0.82
25	21	39-45	42.1	0.64	0.86
Apr 8	8	38-43	40.1	0.61	0.94
10*	2	39-41	40.0	0.60	0.94
10	2	41	41.0	0.70	1.02
17	9	41-44	42.2	0.63	0.84
24	6	39-45	41.4	0.77	1.09
May 6	2	43-47	45.0	1.0	1.1
20	8	38-48	45.4	0.86	0.88

*fyke net sampling

Table 8.9 Mean lengths, weights, and condition factors of Bacon Creek chinook fry captured by either electroshocking or fyke netting, 1973 brood.

Date	Number of fish	Length (mm) Range	Mean	Mean weight (g)	Mean condition factor
1974					
Apr 9*	42	37-43	40.9	0.58	0.82
10*	30	36-44	41.1	0.60	0.86
10	20	37-44	40.0	0.63	0.97
17	27	37-45	40.3	0.61	0.92
23	26	38-49	41.4	0.62	0.86
May 8	21	38-45	40.7	0.58	0.85
20	13	38-42	40.3	0.58	0.90
21*	2	40-42	41.0	0.45	0.65
Jun 13	10	39-47	42.7	-	-
Jul 3	4	41-49	44.0	1.25	1.44

*fyke net samples

Table 8.10 Mean lengths, weights, and condition factors of Diobsud Creek chinook fry captured by either electroshocking or fyke netting, 1973 brood.

Date	Number of fish	Length (mm) Range	Length (mm) Mean	Mean weight (g)	Mean condition factor
1974					
Mar 12	45	39-45	41.1	0.56	0.80
25	38	39-46	42.0	0.60	0.81
Apr 10	30	34-43	37.3	0.52	1.00
17	32	33-45	38.7	0.48	0.83
23	37	38-49	42.0	0.61	0.83
May 7*	8	39-44	41.3	0.61	0.87
8	29	38-47	41.7	0.63	0.86
20	21	39-54	42.9	0.75	0.92
21*	5	39-42	40.2	0.46	0.72
Jun 13	14	36-45	39.0	0.61	1.03
Jul 2	12	37-49	41.5	0.73	0.97
18*	1	46	46	2.0	2.0

*fyke net samples

Table 8.11 Mean lengths, weights, and condition factors of chinook fry from the upper three Skagit sites captured by electroshocking, 1974 brood.

Date	Number fish	Length (mm) Range	Length (mm) Mean	Average dry weight (g)	Average wet weight (g)	Condition factors dry weight	Condition factors wet weight
1975							
Jan 7	3	38-40	38.7	--	0.45	--	0.78
8	7	36-42	39.6	0.0781	0.49	0.121	0.76
14	17	36-42	39.1	0.0820	0.52	0.137	0.84
18	37	36-42	38.8	--	0.55	--	1.01
21	34	34-41	38.6	0.0864	0.50	0.145	0.86
Feb 1	29	36-42	39.4	0.0876	0.57	0.144	0.95
4	47	36-43	39.9	0.0891	0.58	0.141	0.82
11	30	36-44	40.0	0.0894	0.54	0.140	0.84
18	30	37-43	40.4	0.0876	0.53	0.132	0.79
25	15	38-42	40.9	--	0.53	--	0.74
Mar 4	30	38-43	40.9	0.0947	0.57	0.138	0.83
11	30	38-44	41.5	0.0967	0.58	0.138	0.80
25	26	38-46	40.6	0.0987	0.64	0.147	0.95
Apr 1	42	38-45	40.1	0.1048	0.63	0.148	0.89
8	56	39-47	42.6	0.1126	0.69	0.152	0.93
15	63	39-47	42.0	0.1180	0.70	0.158	0.94
22	66	37-49	41.6	0.1130	0.70	0.154	0.95
May 2	119	36-51	42.3	0.1276	0.79	0.159	0.99
13	93	38-49	42.1	0.1152	0.75	0.152	0.99
29	83	38-54	44.9	0.1644	0.99	0.182	1.09
Jun 16	49	37-51	43.5	0.1426	0.86	0.163	1.03
25	19	39-54	44.9	0.2134	1.12	0.198	1.19
Jul 1	41	40-57	47.9	0.2371	1.41	0.208	1.26
14	13	42-56	49.9	--	1.55	--	1.22
Aug 1	68	45-64	55.4	--	2.11	--	1.23
22	3	56-72	66.0	--	3.80	--	1.26

Table 8.12 Mean lengths, weights, and condition factors of Sauk chinook fry captured by electroshocking, 1974 brood.

Date	Number fish	Length (mm) Range	Mean	Average dry weight (g)	Average wet weight (g)	Condition factors dry weight	Condition factors wet weight
1975							
Jan 7							
8	8	37-42	39.6	0.0728	0.48	0.117	0.78
14	5	37-41	38.4	0.0866	0.44	0.153	0.77
18							
21							
Feb 1							
4	14	39-41	40.3	0.0868	0.50	0.132	0.76
11	12	38-42	40.1	0.0853	0.50	0.132	0.78
18							
25							
Mar 4	10	37-43	39.6	0.0811	0.50	0.131	0.80
11	15	37-45	40.9	0.0967	0.57	0.141	0.84
25	22	38-45	41.5	0.1034	0.65	0.144	0.90
Apr 1	38	37-49	41.4	0.1187	0.72	0.165	1.00
8	35	39-54	44.6	0.1517	0.96	0.167	1.08
15	55	39-50	43.4	0.1392	0.86	0.167	1.05
22	41	39-57	46.0	0.1699	1.06	0.168	1.05
May 2	67	39-60	44.8	0.1571	0.98	0.168	1.05
13	54	36-53	43.1	0.1510	0.84	0.170	1.02
29	55	37-65	50.1	0.2558	1.52	0.195	1.14
Jun 16	25	40-57	50.3	0.2873	1.60	0.223	1.21
25	24	39-62	50.8	0.3335	1.69	0.213	1.22
Jul 1	21	41-57	50.0	0.2841	1.70	0.219	1.33
14	7	55-63	58.7	--	3.00	--	1.49
Aug 4	43	58-83	71.1	--	4.40	--	1.19
22	8	70-77	72.5	--	5.38	--	1.41

Table 8.13 Mean lengths, weights, and condition factors of Cascade chinook fry captured by electroshocking, 1974 brood.

Date	Number fish	Length (mm) Range	Length (mm) Mean	Average dry weight (g)	Average wet weight (g)	Condition factors dry weight	Condition factors wet weight
1975							
Jan 7							
8							
14							
18							
21							
Feb 1							
4							
11							
18	10	41-43	41.9	0.1050	0.61	0.143	0.83
25	5	38-42	40.6	--	0.52	--	0.77
Mar 4	12	37-43	40.6	0.0879	0.53	0.131	0.79
11	10	37-46	40.3	0.0835	0.51	0.129	0.76
25	10	37-45	40.7	0.1010	0.61	0.146	0.89
Apr 1	13	39-45	41.5	0.1039	0.63	0.144	0.88
8	24	39-42	40.4	0.0890	0.57	0.135	0.86
15	23	37-45	41.3	0.1044	0.66	0.146	0.92
22	20	38-46	41.7	0.1125	0.71	0.154	0.97
May 2	41	39-51	42.6	0.1386	0.86	0.182	1.09
13	21	39-48	43.6	0.1555	0.90	0.184	1.07
29	23	39-57	47.6	0.2022	1.23	0.180	1.10
Jun 16	17	39-60	46.6	0.2019	1.23	0.185	1.16
25	20	37-63	48.3	0.2282	1.33	0.189	1.12
Jul 1	8	39-59	47.8	0.2409	1.45	0.208	1.28
14	11	46-66	54.7	--	2.14	--	1.25
Aug 4	3	56-66	61.0	--	2.73	--	1.20
22	11	56-78	66.6	--	3.80	--	1.25

Table 8.14 Mean lengths, dry weights, and condition factors of chinook fry captured by electroshocking, 1974 brood.

River	Time period	Number fish	Average length (mm)	Average dry weight (g)	Condition factor dry weight
	1975				
Skagit	January-April 15	378	40.2	0.0923	0.140
	April 15-July 1	533	43.7	0.1539	0.172
	January-July 1	911	41.6	0.1169	0.153
Sauk	January-April 15	159	40.7	0.0981	0.142
	April 15-July 1	342	47.3	0.2222	0.190
	January-July 1	501	43.8	0.1565	0.165
Cascade	January-April 15	79	40.9	0.0951	0.138
	April 15-July 1	173	44.9	0.1730	0.179
	January-July 1	252	43.2	0.1396	0.161

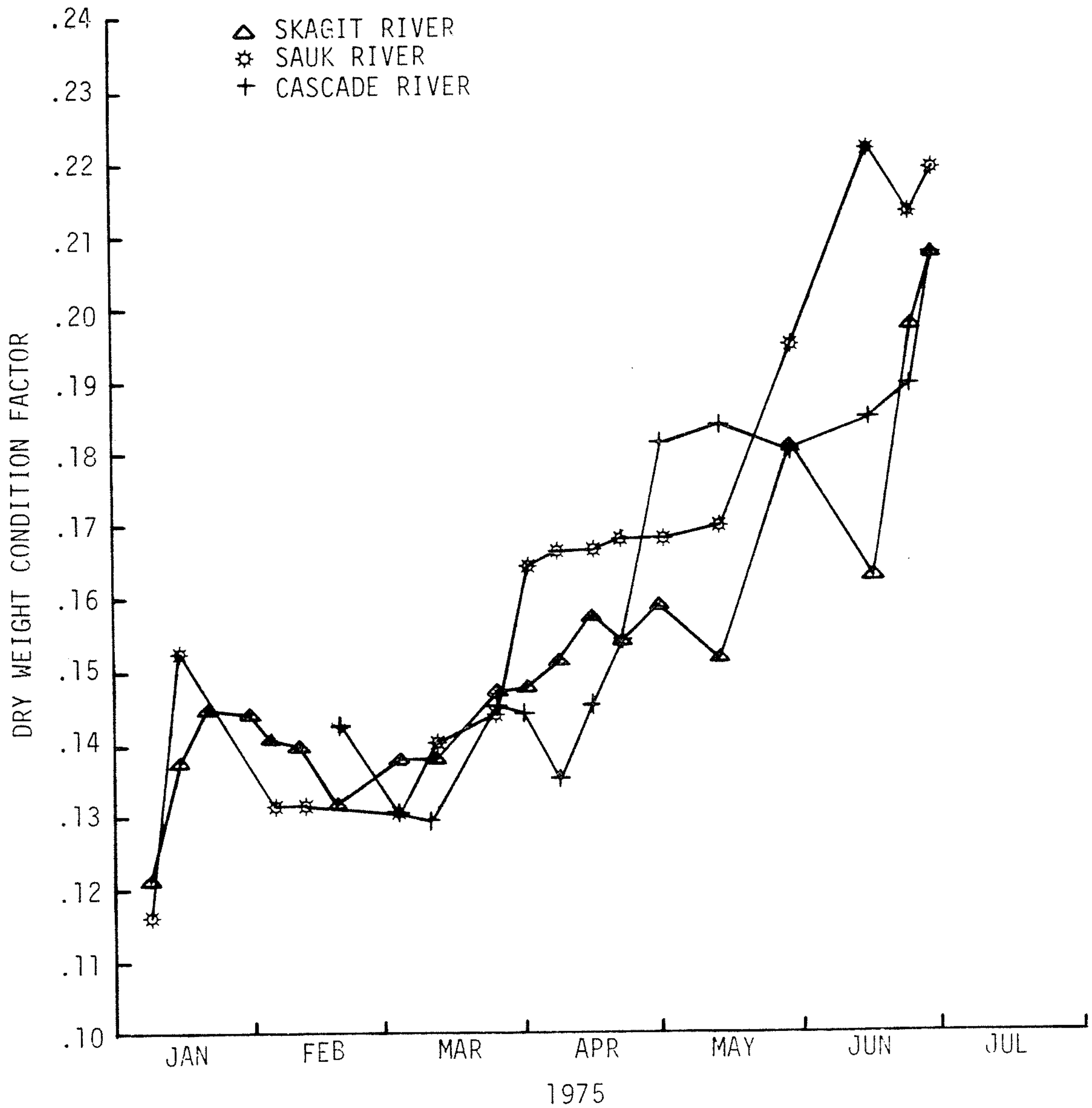

Fig. 8.4 Mean dry weight condition factors of Skagit, Sauk, and Cascade chinook fry taken by electrofishing, 1974 brood.

after emergence, or to differences in the timing of fry emergence or migration in the Skagit, Sauk, and Cascade.

Mean length, weight, and condition factors from samples of more than one fish are presented for the 1975 and 1976 broods in Figs. 8.5 through 8.37. The sizes of samples for this analysis are shown in Figs. 8.38 to 8.43.

For each brood, the Skagit River sites were similar in timing of initial emergence, apparent growth, and time of disappearance (Figs. 8.5, 8.6, 8.16, and 8.17). Regionally distinct groups of chinook fry were thus indiscernible. Fry from the Skagit creeks each year showed growth similar to fry from the Skagit, but emerged later and disappeared sooner (Figs. 8.8, 8.9, 8.19, and 8.20).

Temperature during the incubation period appears to affect timing of first emergence. In both the 1975-1976 and 1976-1977 fry rearing seasons, the Cascade River and the minor Skagit tributaries yielded their first samples of chinook fry about a month later than the Skagit and Sauk rivers, probably because of the cooler temperatures in the smaller streams (Figs. 8.10, 8.11, 8.14, and 8.15). The 1976 brood of chinook fry started emerging a month or more earlier at all sites in the winter of 1976-1977 than the 1975 brood appeared in the winter of 1975-1976. (Figs. 8.7, 8.10, 8.11, 8.12, and 8.13). The Sauk River was most strongly affected (Fig. 8.13). This earlier emergence can be explained by accelerated egg development due to milder temperatures in the winter of 1976-1977 (Figs. 2.29 and 2.30).

Both brood years show an initial period of low apparent growth and close similarity between all river sites, then an accelerated size increase in April (Figs. 8.14, 8.15, 8.25, and 8.26).

Exceptions to this initial level period are the first fry from the Sauk and the Skagit rivers for the 1976 brood which not only emerged several weeks earlier in the year than the 1975 brood, but also averaged smaller in length and weight (Figs. 8.7, 8.13, 8.18, and 8.24). Sampling with the electrofisher began in both seasons prior to the appearance of emergent fry. Average lengths and weights of the 1976 brood from the Skagit and Sauk rivers became comparable to initial levels of the 1975 brood by January 1977.

The initial level period is partly due to continuing emergence of small fish through this period. Due to decreasing temperatures over the spawning period, emergence is protracted into April (Fig. 7.9). Chinook fry with unabsorbed yolk have been collected as late as May (Sec. 8.4.1.3).

The end of this initial level period may indicate the point in time when the number of smaller fry emerging from the gravel began to decrease and older fry that had been growing for some time were more numerous than newly emerged fry. Preliminary length frequency analysis suports this contention. This point should be somewhat after peak emergence. The end

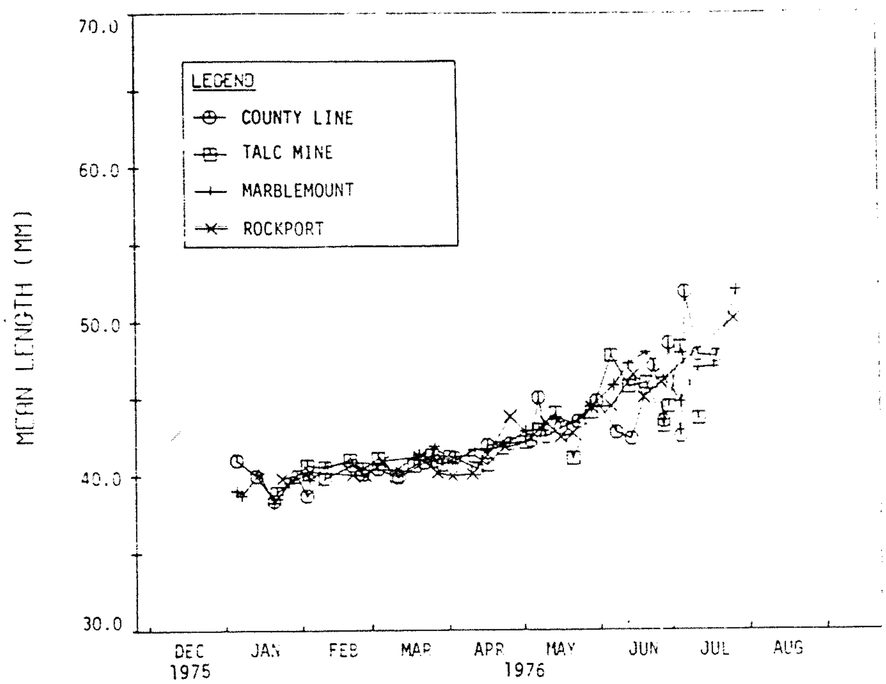

Fig. 8.5 Mean lengths of chinook fry from the four Skagit sites, 1975 brood.

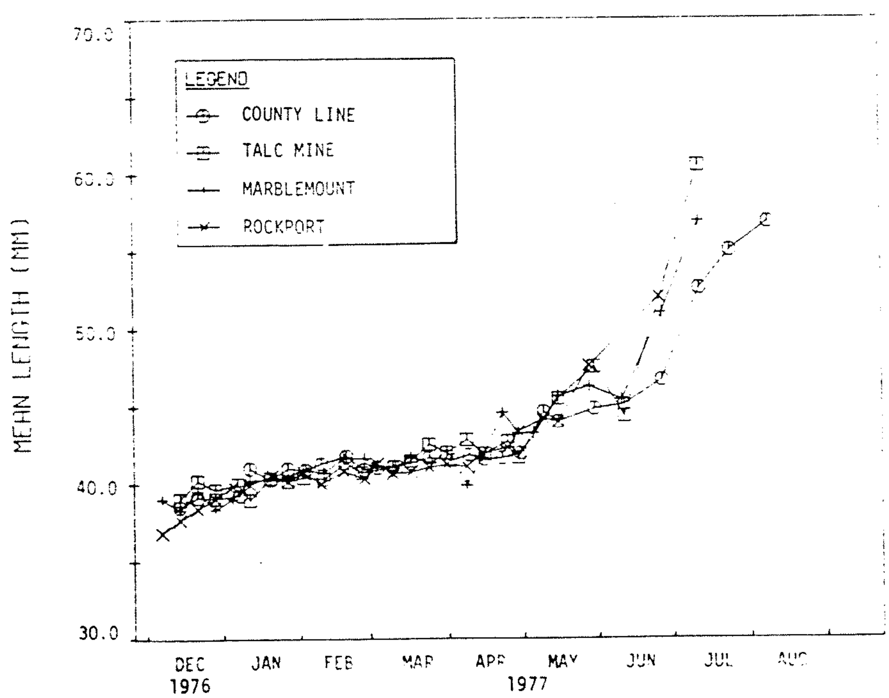

Fig. 8.6 Mean lengths of chinook fry from the four Skagit sites, 1976 brood.

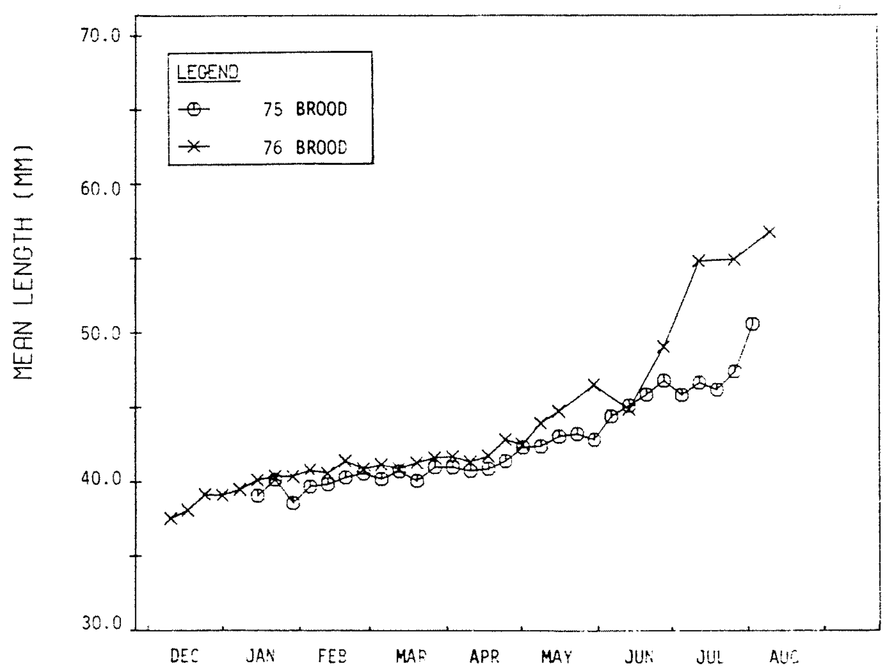

Fig. 8.7 Mean lengths of chinook fry for Skagit sites, combined, 1975 brood compared with 1976 brood.

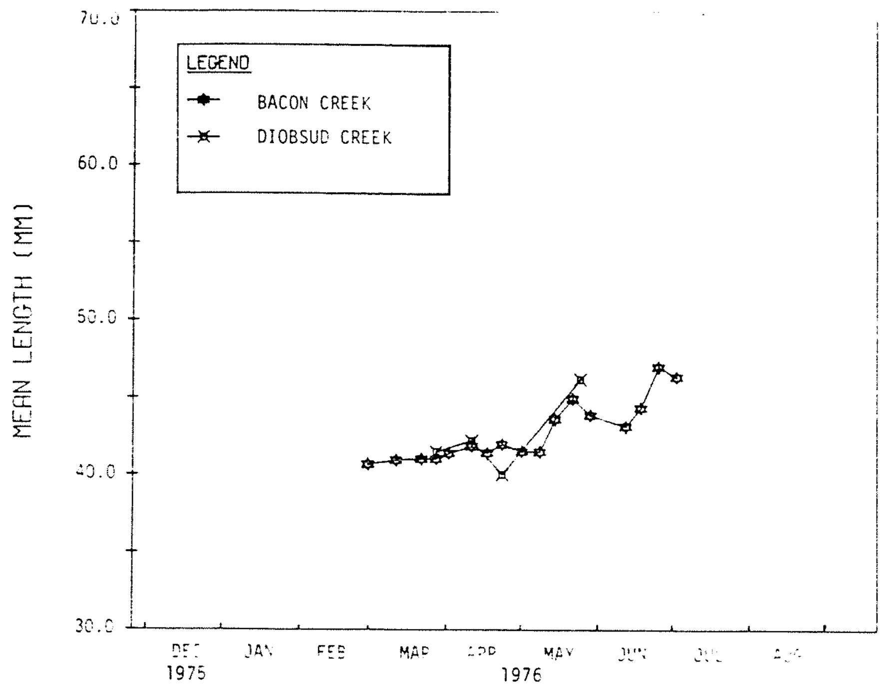

Fig. 8.8 Mean lengths of chinook fry from Skagit creeks, 1975 brood.

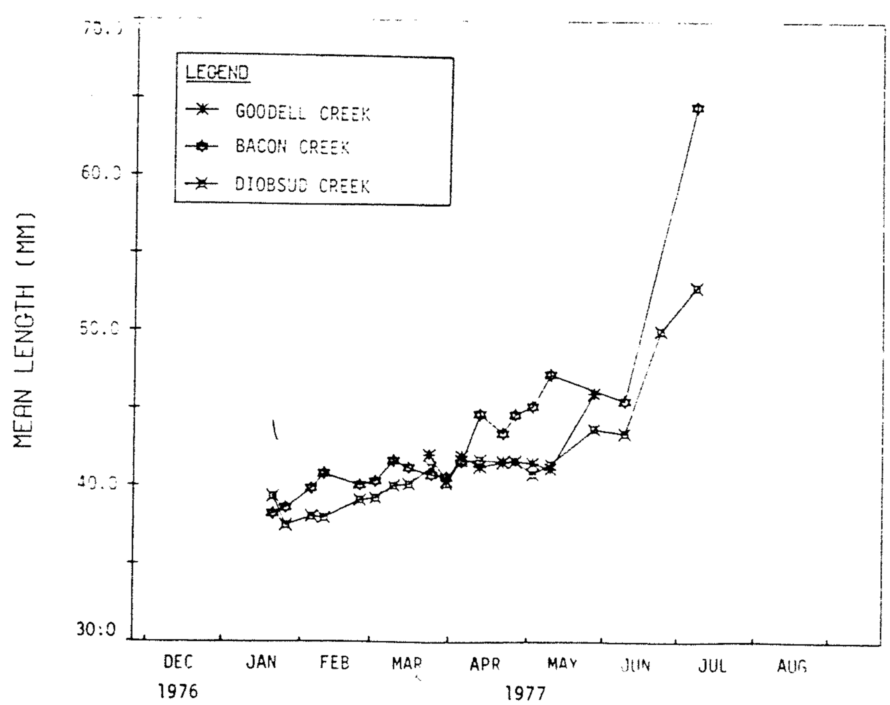

Fig. 8.9 Mean lengths of chinook fry from Skagit creeks, 1976 brood.

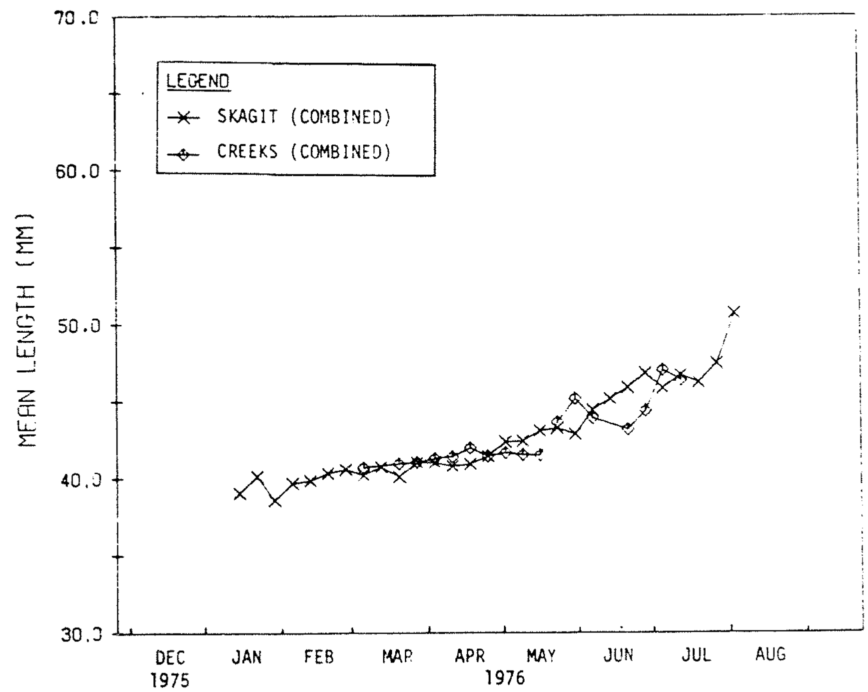

Fig. 8.10 Mean lengths of chinook fry, Skagit sites, combined, and Skagit creeks, combined, 1975 brood.

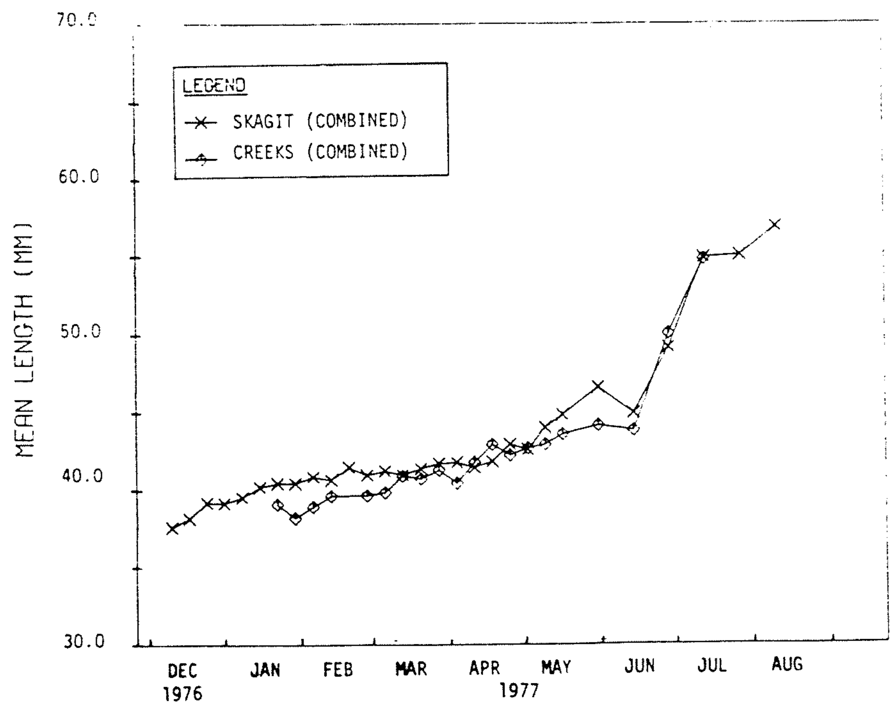

Fig. 8.11. Mean lengths of chinook fry, Skagit sites, combined, and Skagit creeks, combined, 1976 brood.

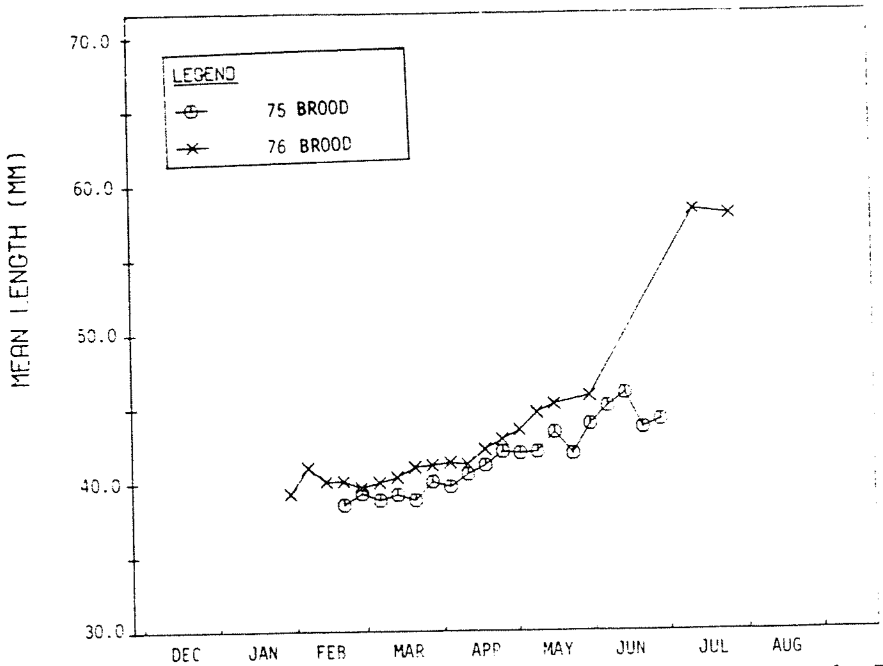

Fig. 8.12 Mean lengths of chinook fry from the Cascade River, 1975 and 1976 broods.

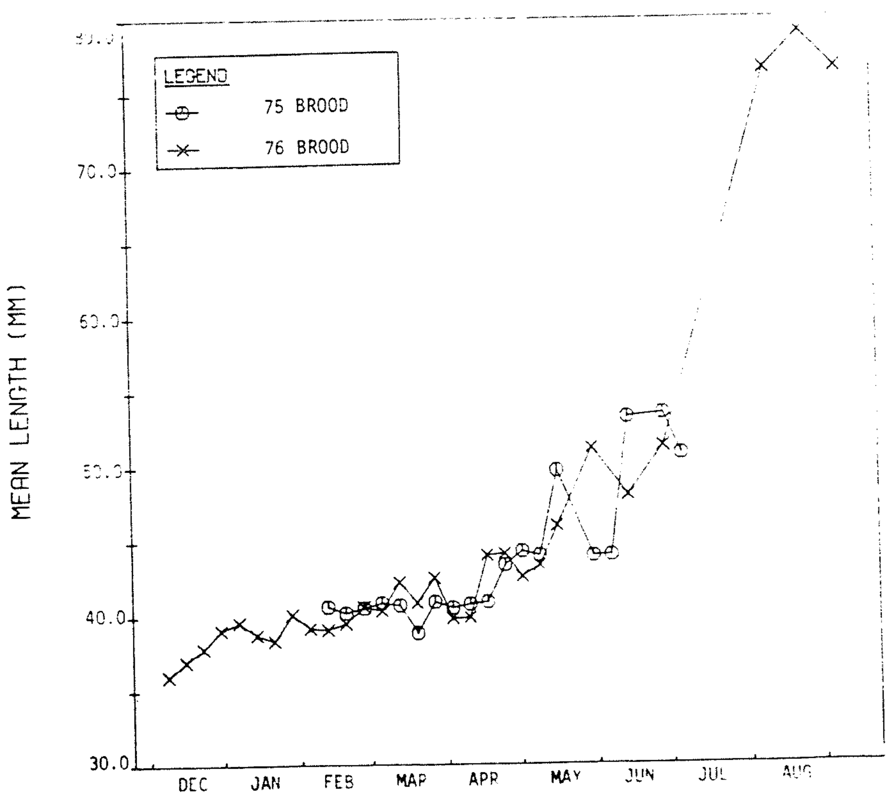

Fig. 8.13 Mean lengths of chinook fry from the Sauk River, 1975 and 1976 broods.

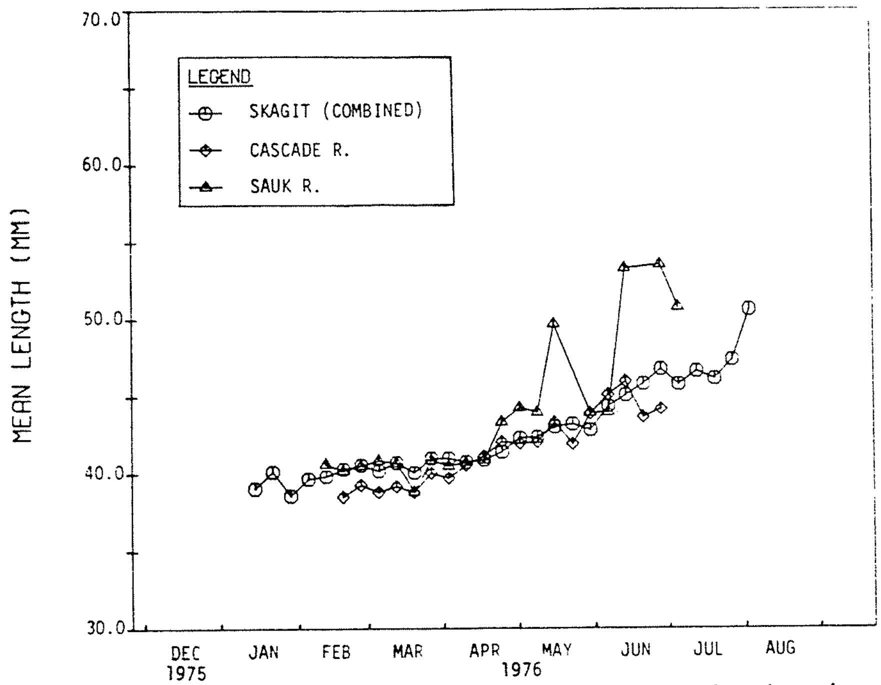

Fig. 8.14 Mean lengths of chinook fry from the Skagit sites, combined, and from the Cascade and Sauk rivers, 1975 brood.

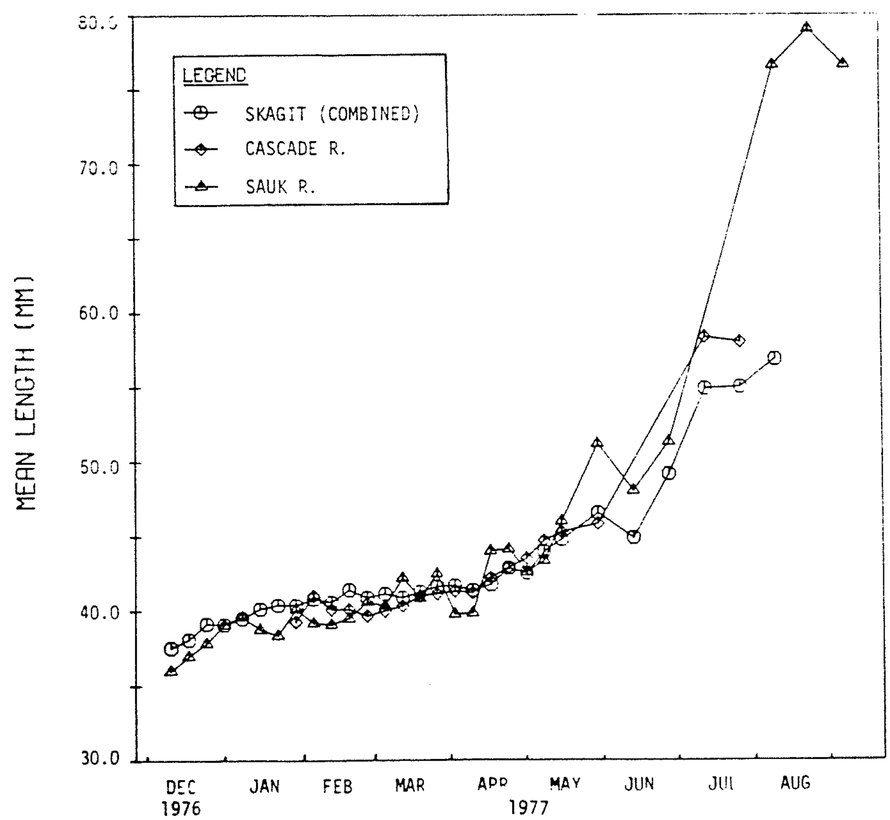

Fig. 8.15 Mean lengths of chinook fry from the Skagit sites, combined, and from the Cascade and Sauk rivers, 1976 brood.

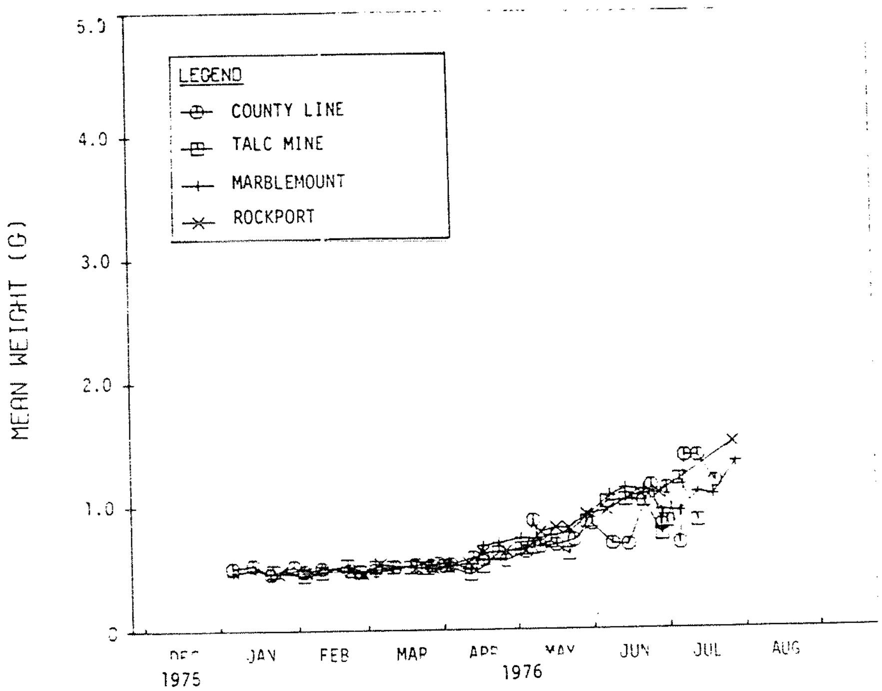

Fig. 8.16 Mean weights of chinook fry from the four Skagit sites, 1975 brood.

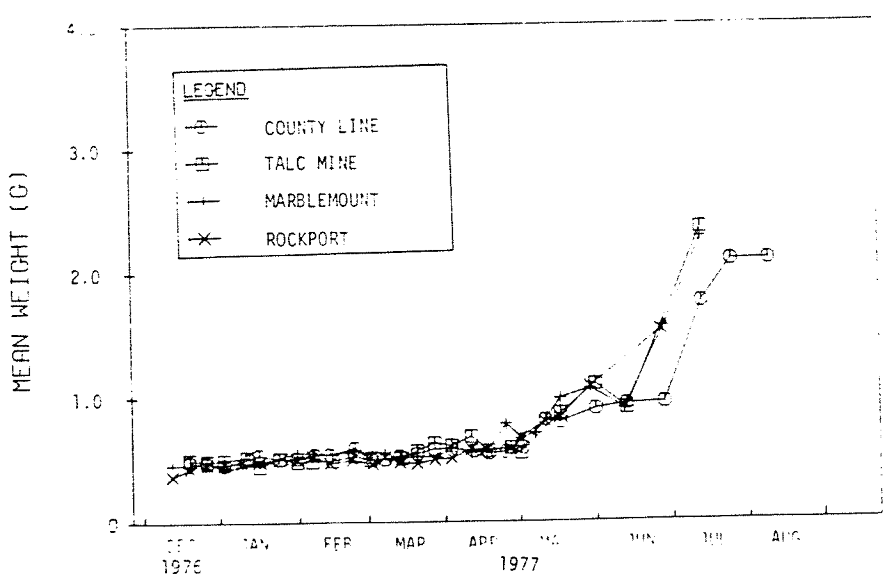

Fig. 8.17 Mean weights of chinook fry from the four Skagit sites, 1976 brood.

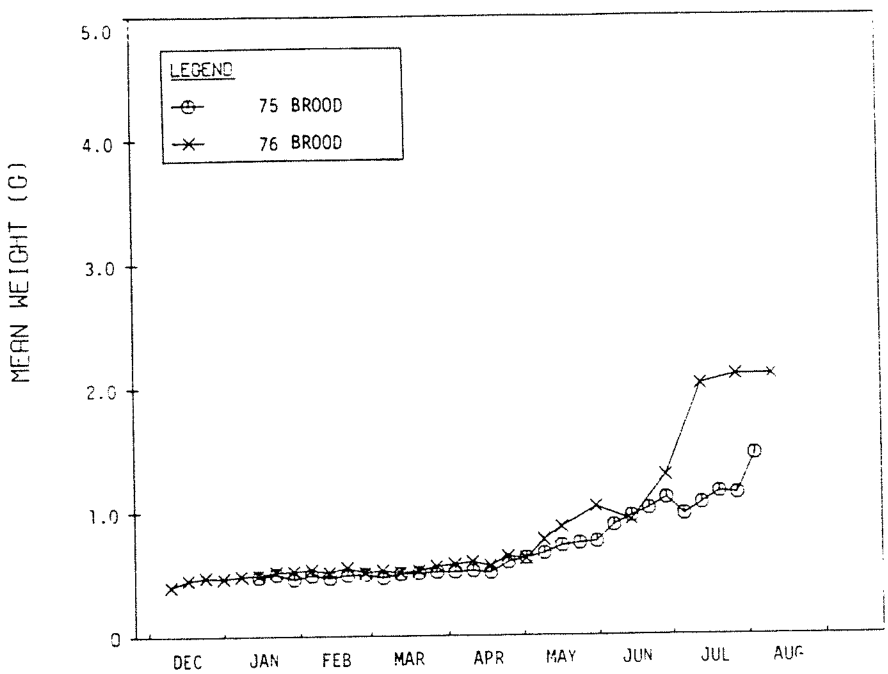

Fig. 8.18 Mean weights of chinook fry for Skagit sites, combined, 1975 brood compared with 1976 brood.

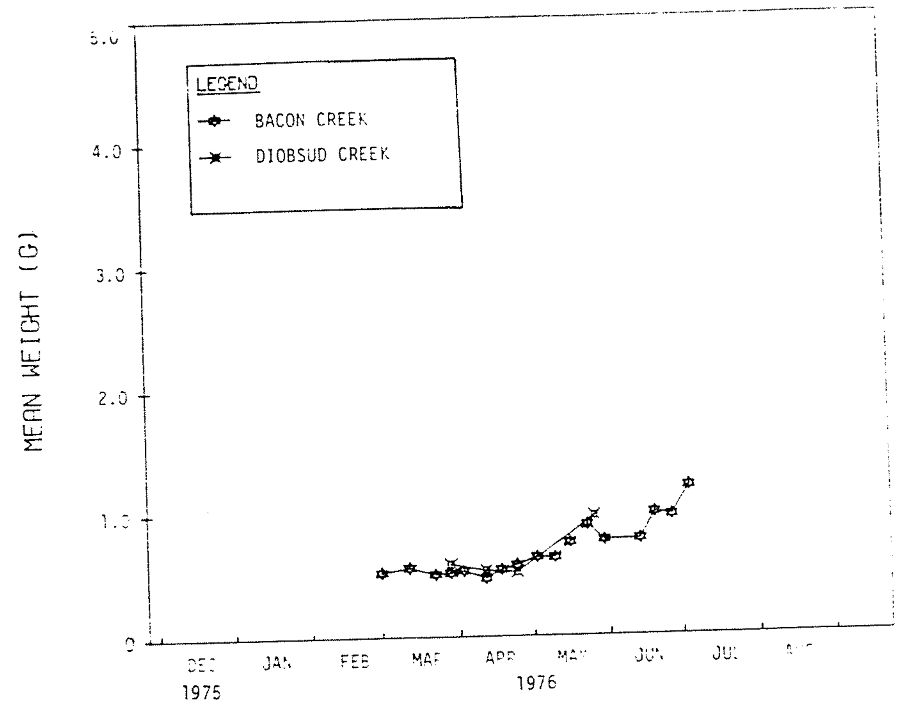

Fig. 8.19 Mean weights of chinook fry from Skagit creeks, 1975 brood.

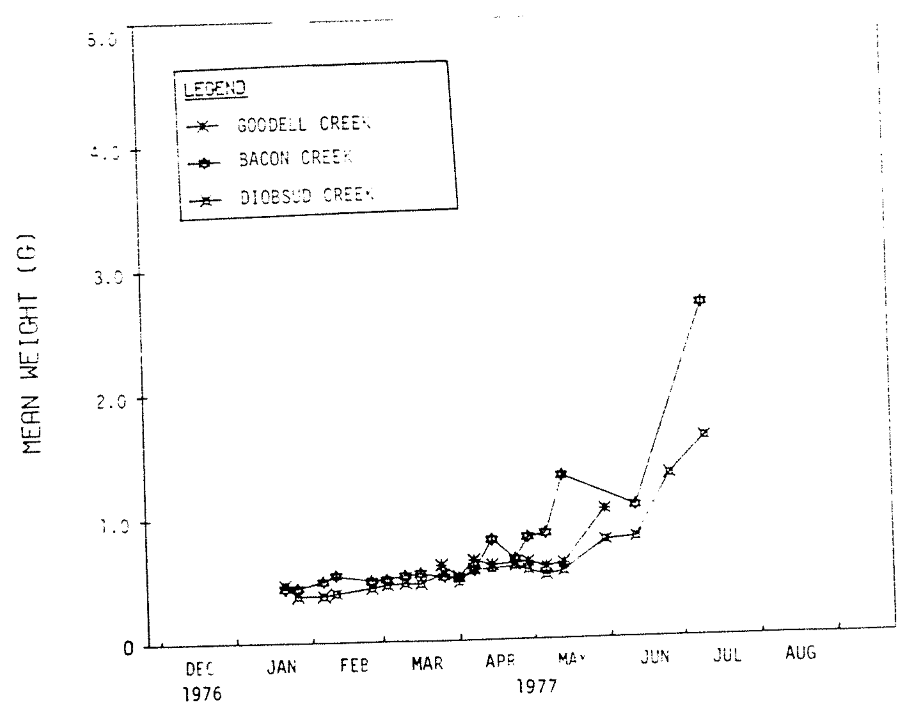

Fig. 8.20 Mean weights of chinook fry from Skagit creeks, 1976 brood.

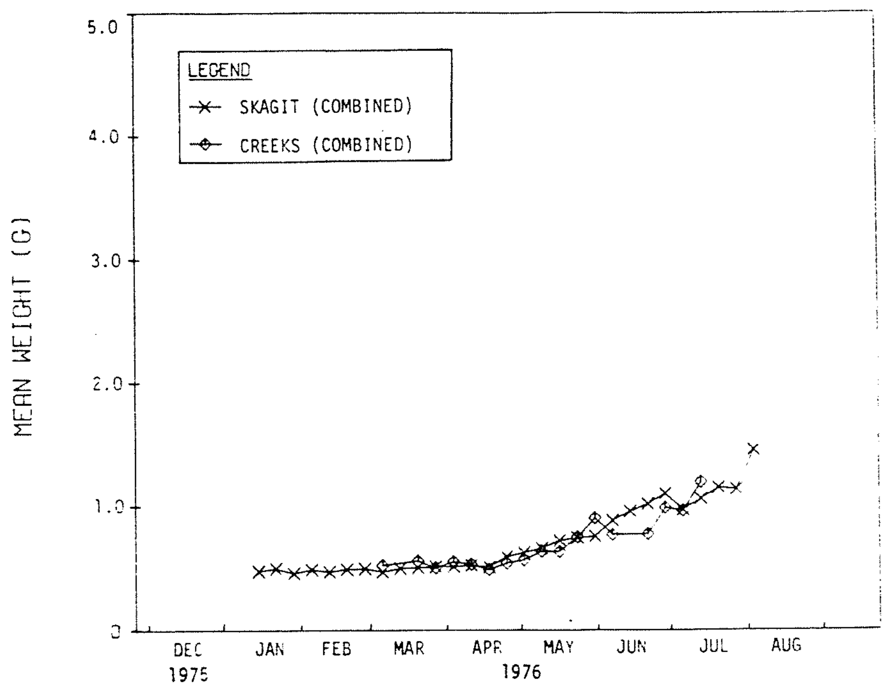

Fig. 8.21 Mean weights of chinook fry, Skagit sites, combined, and Skagit creeks, combined, 1975 brood.

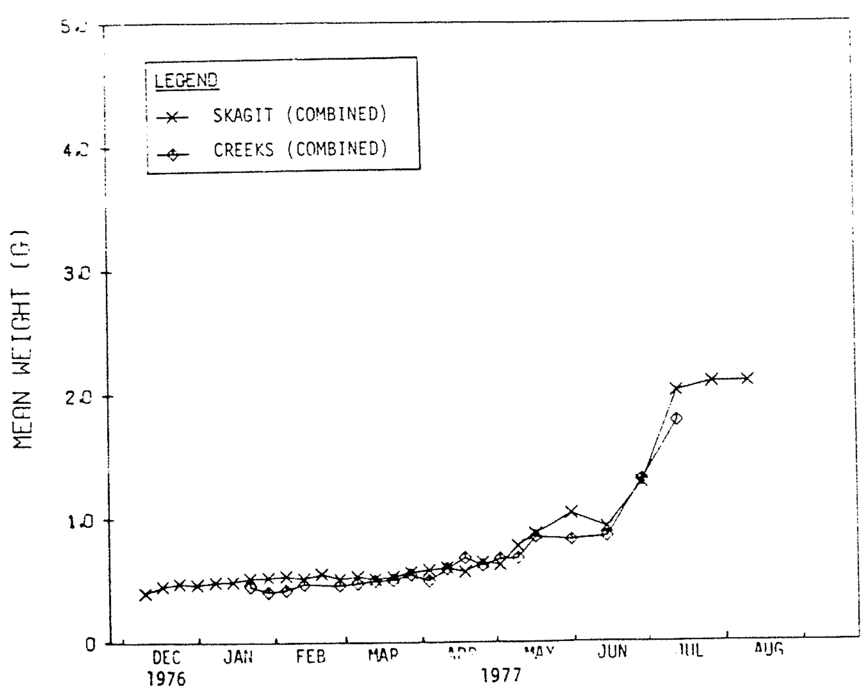

Fig. 8.22 Mean weights of chinook fry, Skagit sites, combined, and Skagit creeks, combined, 1976 brood.

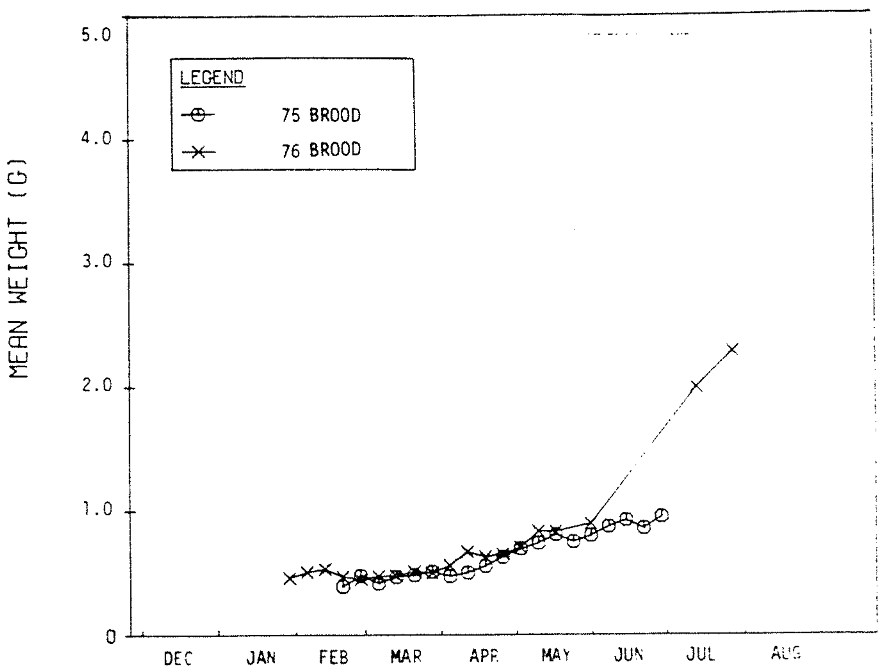

Fig. 8.23 Mean weights of chinook fry from the Cascade River, 1975 and 1976 broods.

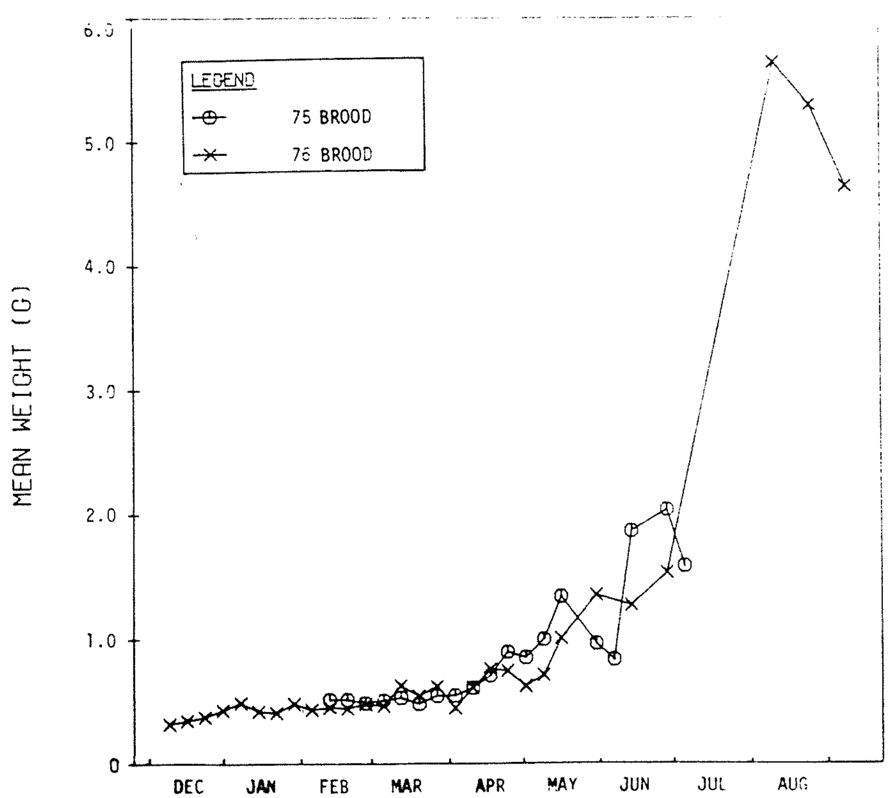

Fig. 8.24 Mean weights of chinook fry from the Sauk River, 1975 and 1976 broods.

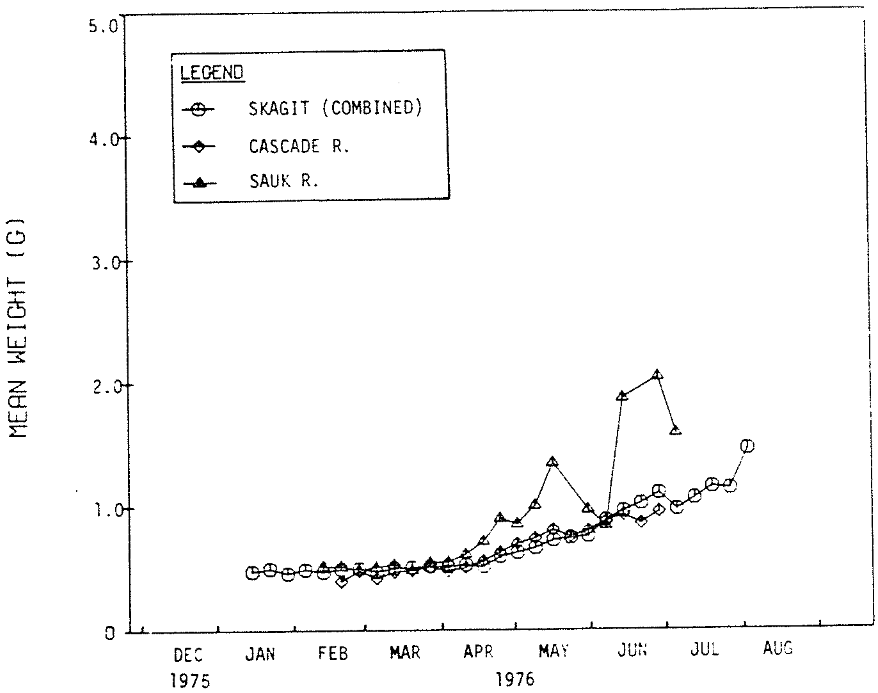

Fig. 8.25 Mean weights of chinook fry from the Skagit sites, combined, and from the Cascade and Sauk rivers, 1975 brood.

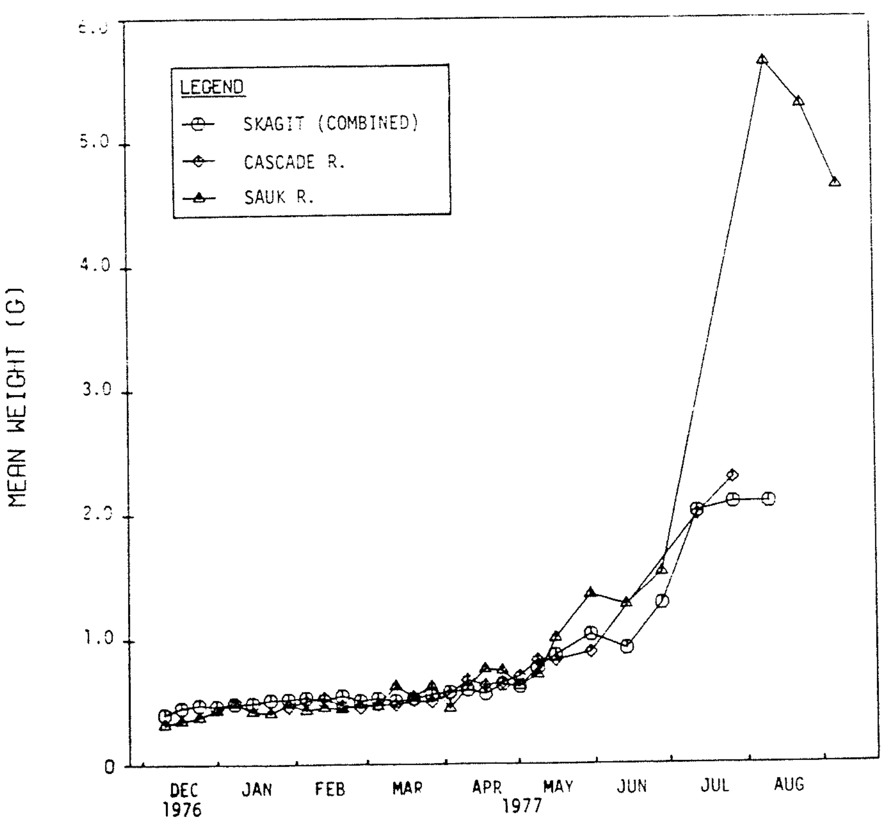

Fig. 8.26 Mean weights of chinook fry from the Skagit sites, combined, and from the Cascade and Sauk rivers, 1976 brood.

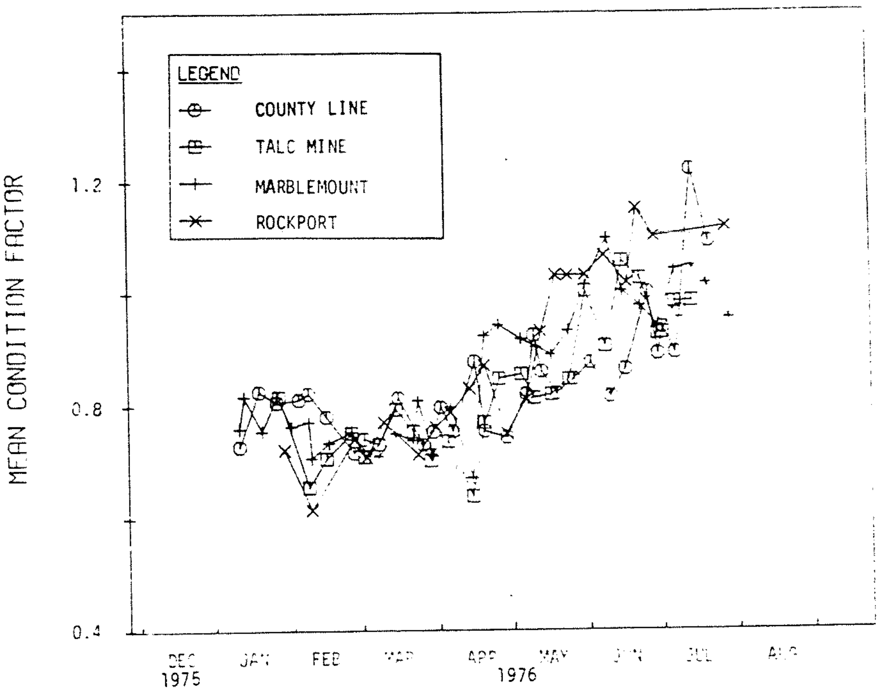

Fig. 8.27 Mean condition factors from the four Skagit sites, 1975 brood.

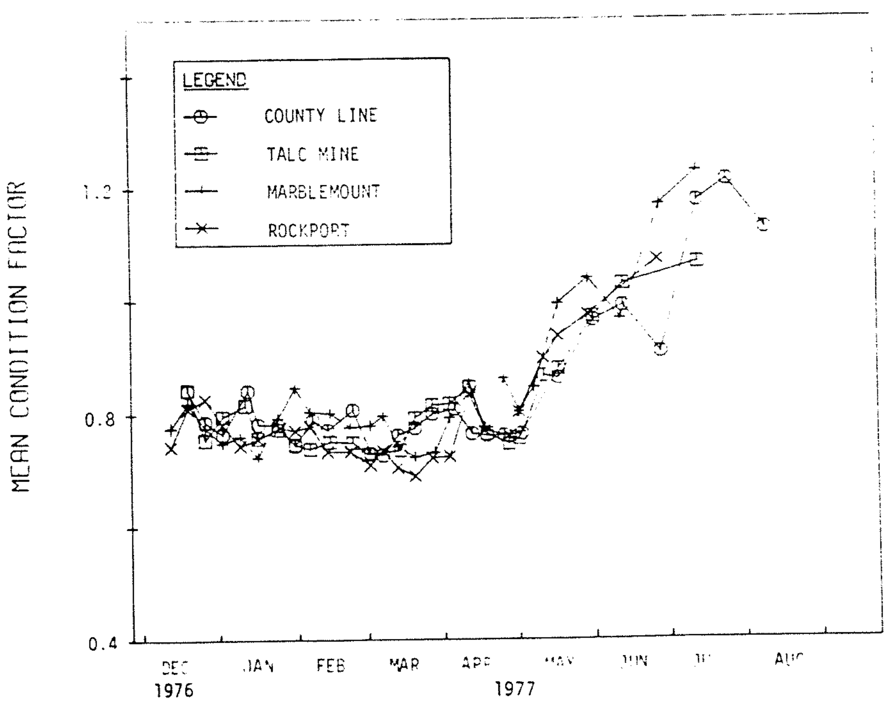

Fig. 8.28 Mean condition factors from the four Skagit sites, 1976 brood.

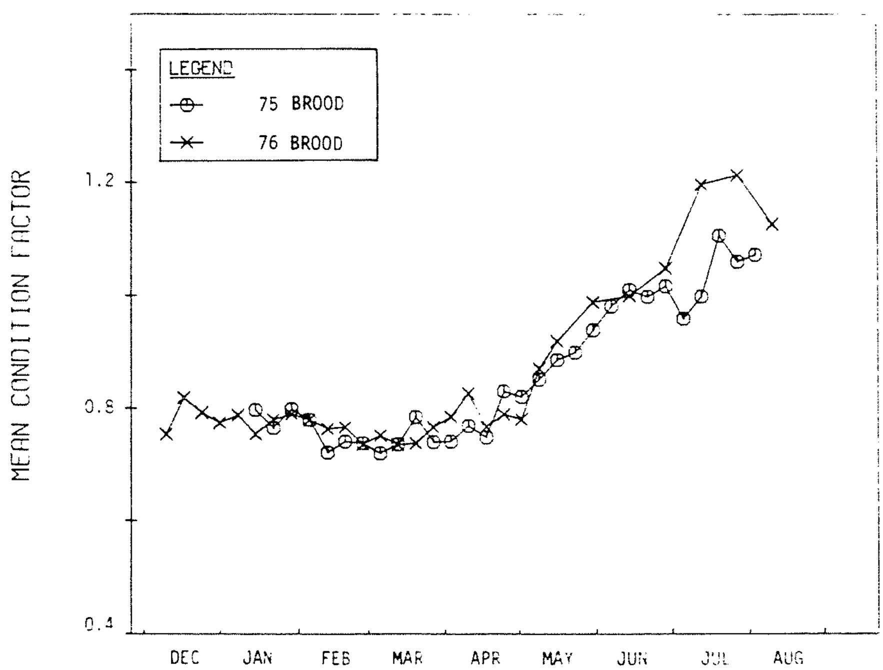

Fig. 8.29 Mean condition factors of chinook fry for the Skagit sites, combined, 1975 brood compared with 1976 brood.

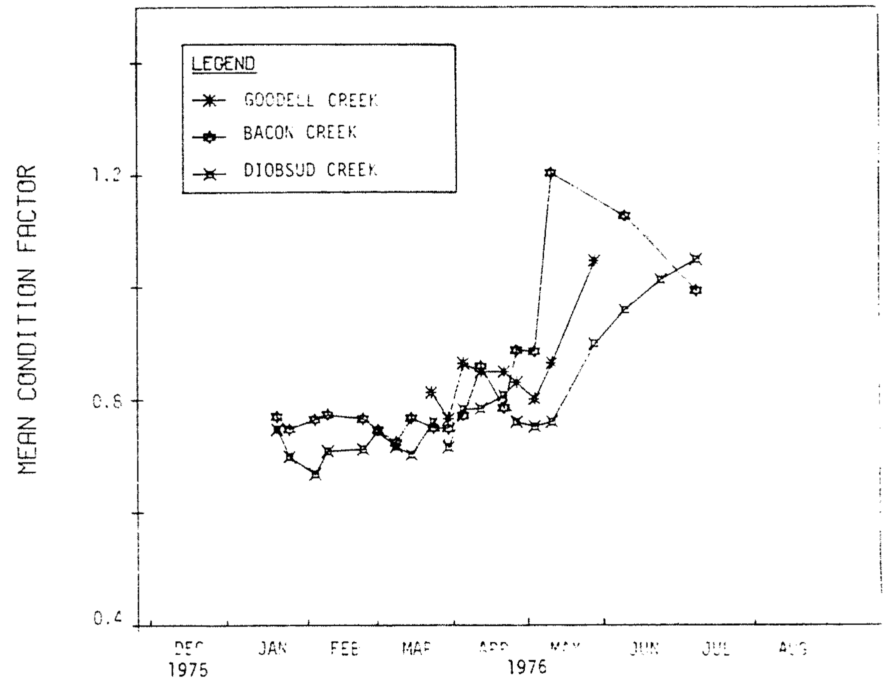

Fig. 8.30 Mean condition factors of chinook fry from Skagit creeks, 1975 brood.

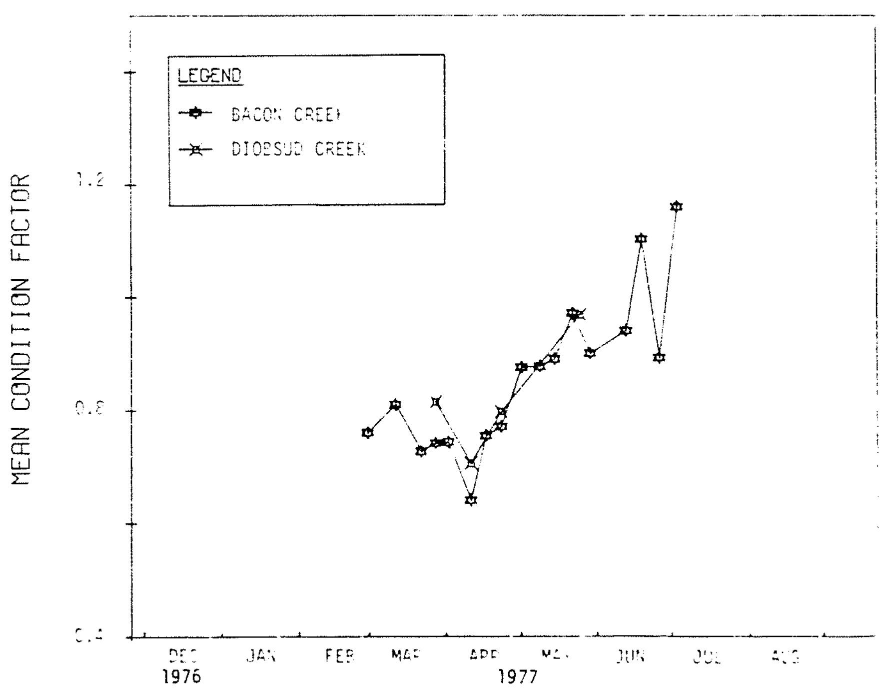

Fig. 8.31 Mean condition factors of chinook fry from Skagit creeks, 1976 brood.

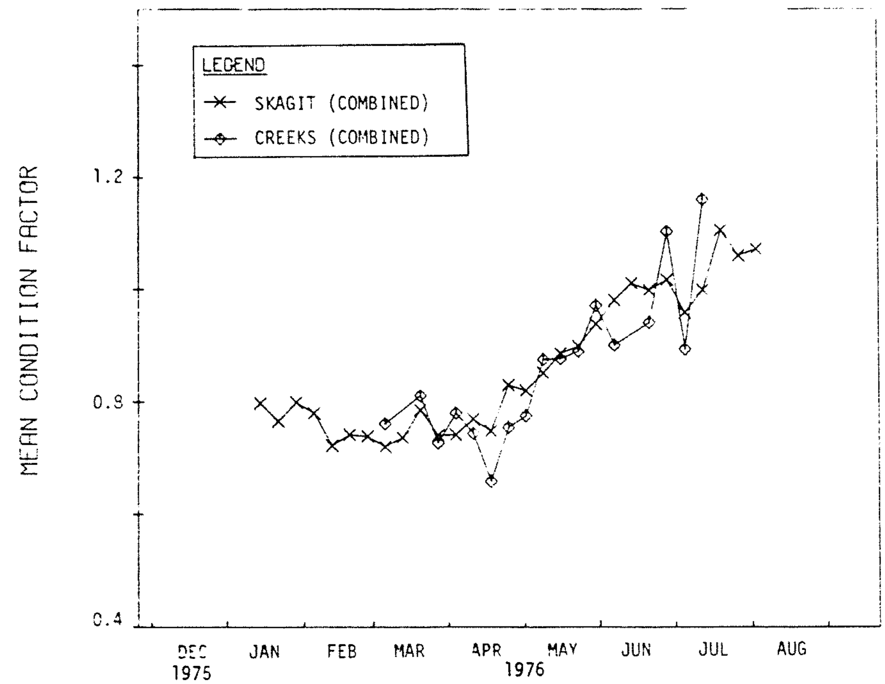

Fig. 8.32 Mean condition factors of chinook fry, Skagit sites, combined, and Skagit creeks, combined, 1975 brood.

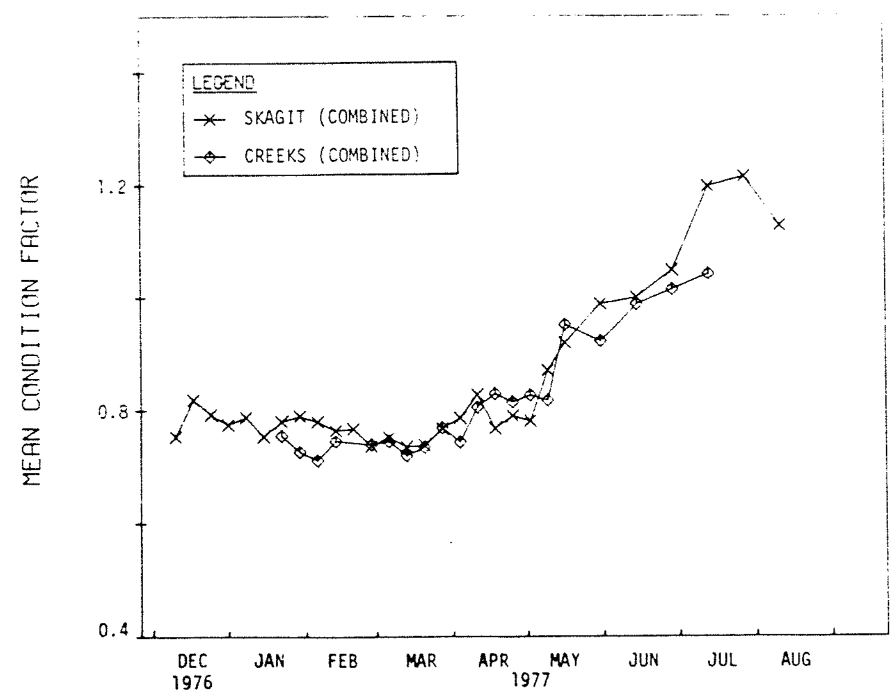

Fig. 8.33 Mean condition factors of chinook fry, Skagit sites, combined, and Skagit creeks, combined, 1976 brood.

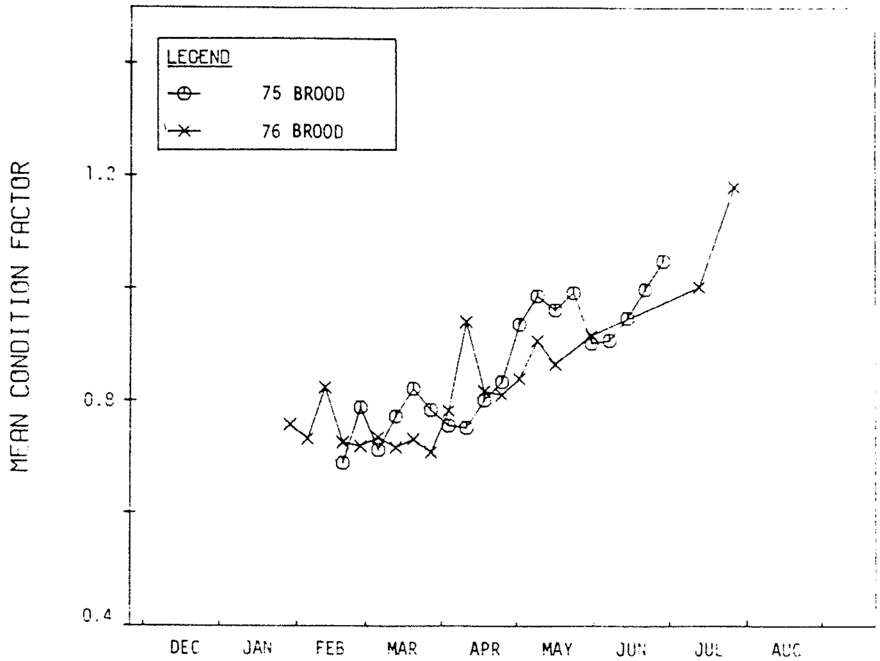

Fig. 8.34 Mean condition factors of chinook fry from the Cascade River, 1975 and 1976 broods.

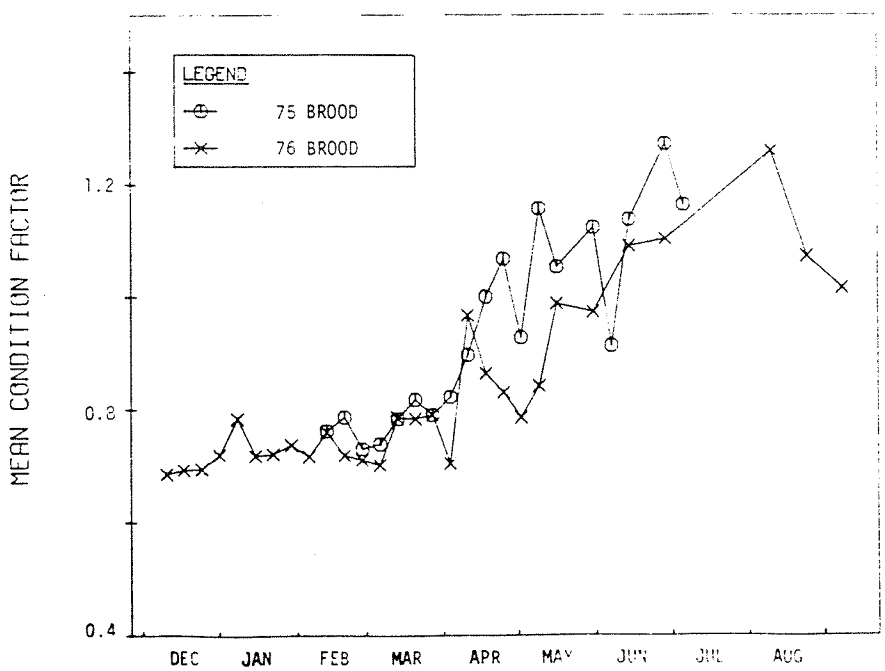

Fig. 8.35 Mean condition factors of chinook fry from the Sauk River, 1975 and 1976 broods.

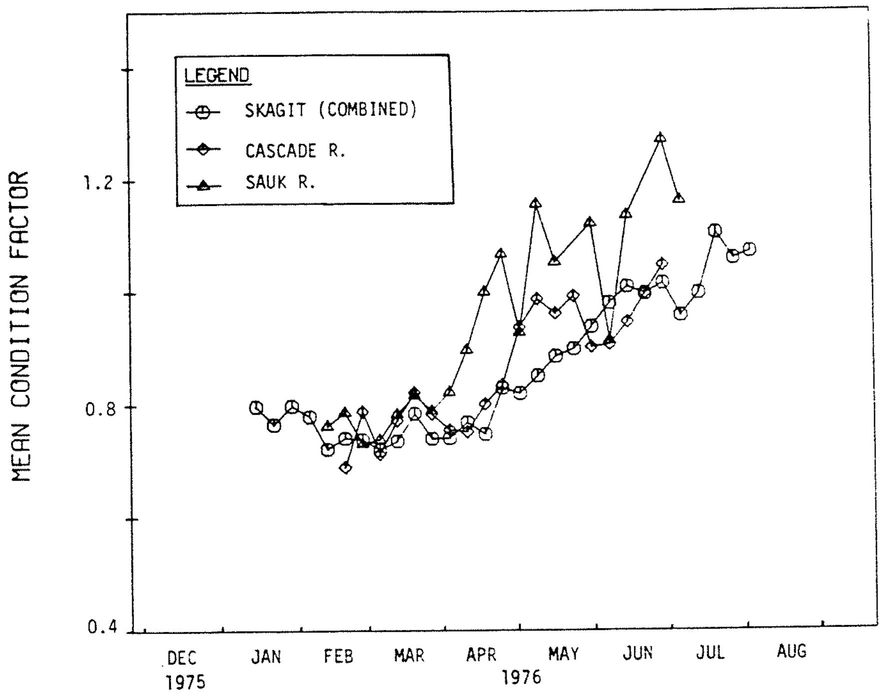

Fig. 8.36 Mean condition factors of chinook fry from the Skagit sites, combined, and from the Cascade and Sauk rivers, 1975 brood.

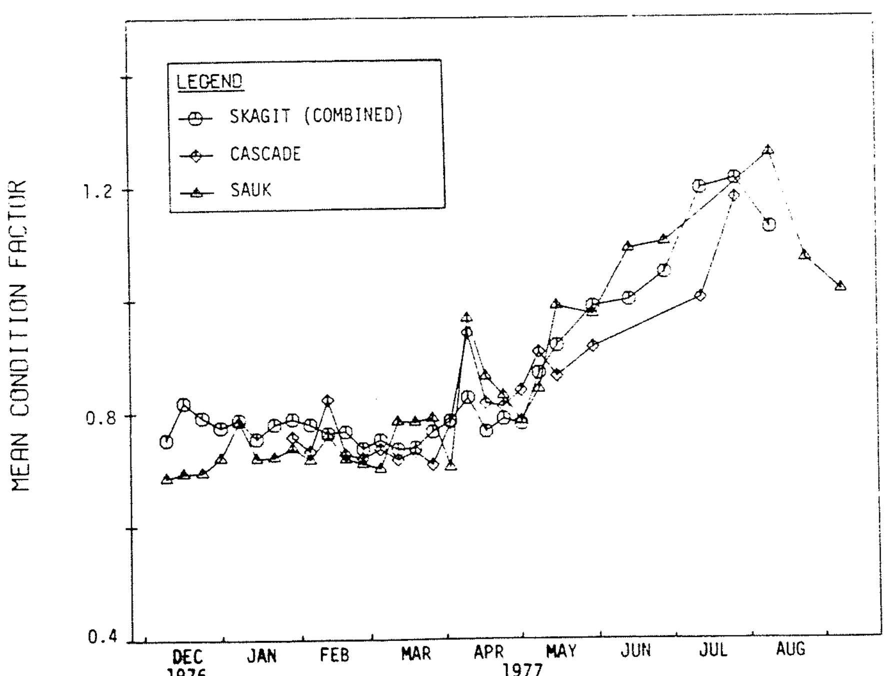

Fig. 8.37 Mean condition factors of chinook fry from the Skagit sites, combined, and from the Cascade and Sauk rivers, 1976 brood.

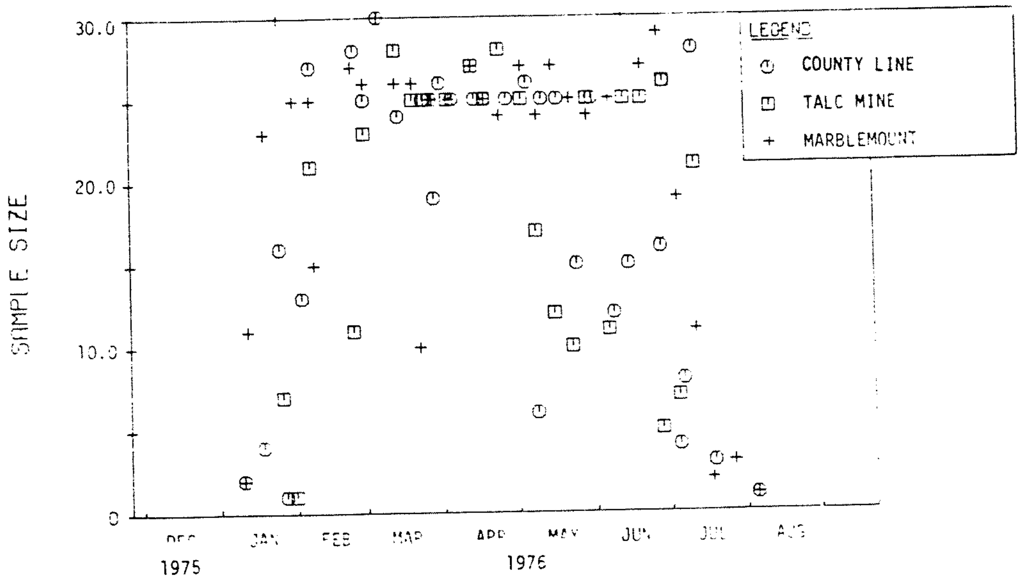

Fig. 8.38 Sizes of length, weight, and condition factor samples of chinook fry from the 1975 brood from the upper three Skagit River stations.

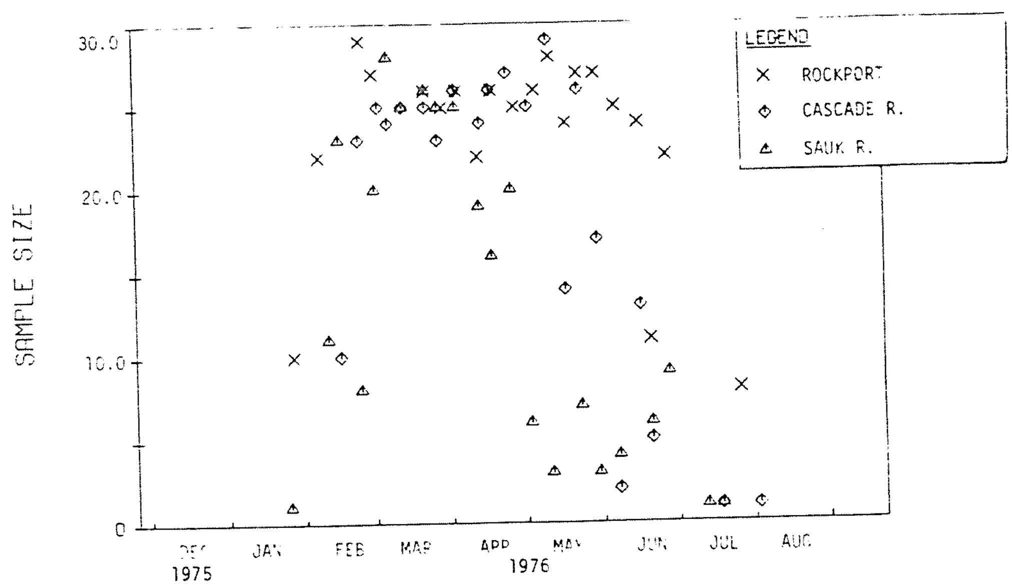

Fig. 8.39 Sizes of length, weight, and condition factor samples of chinook fry from the 1975 brood from the Rockport station on the Skagit River, the Cascade River, and the Sauk River.

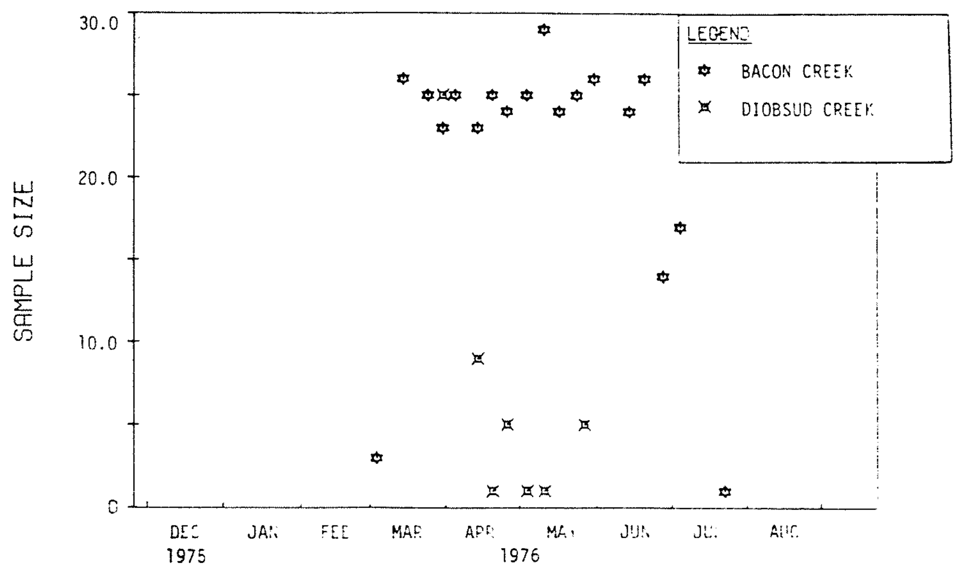

Fig. 8.40 Sizes of length, weight, and condition factor samples of chinook fry from the 1975 brood from two Skagit creeks.

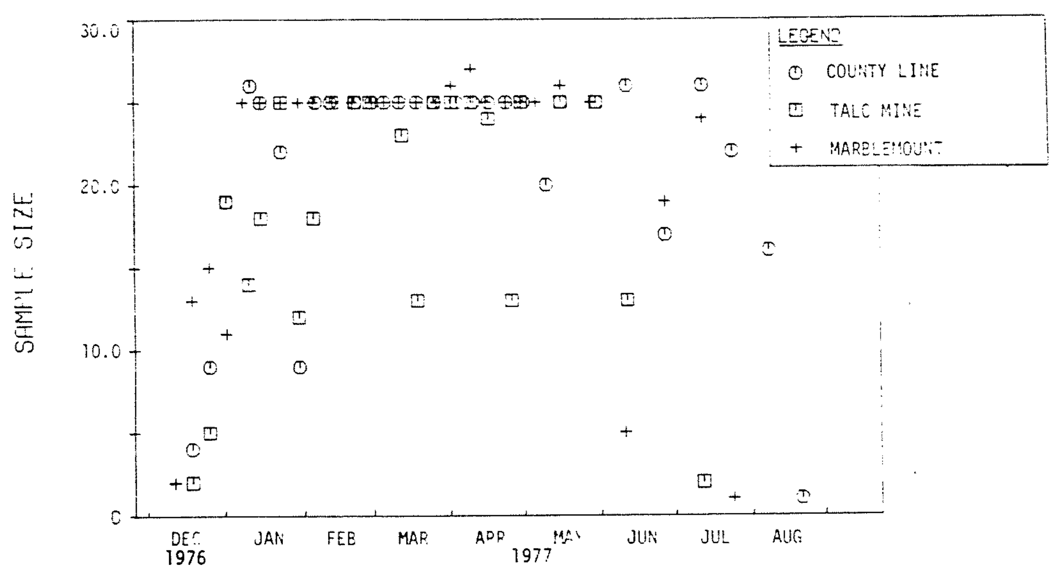

Fig. 8.41 Sizes of length, weight, and condition factor samples of chinook fry from the 1976 brood from the upper three Skagit River stations.

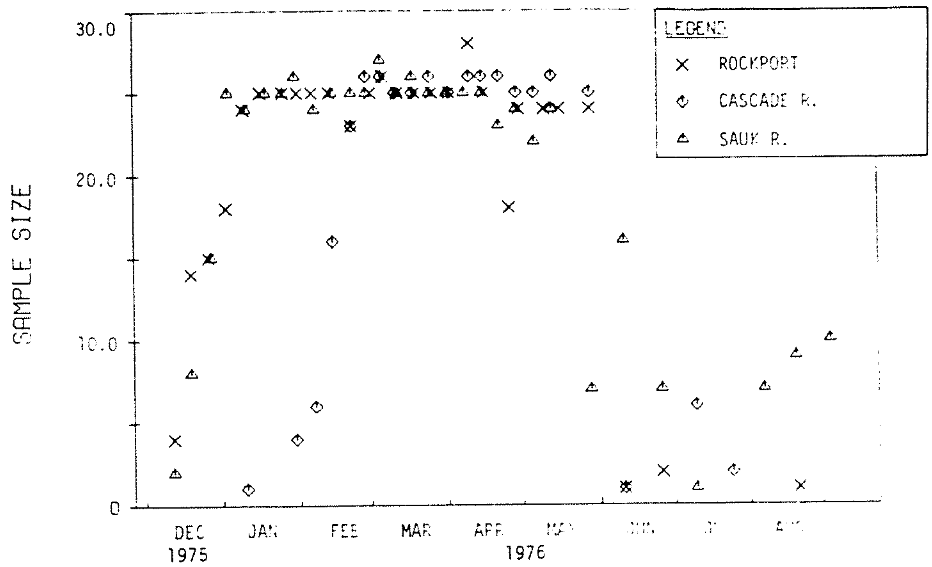

Fig. 8.42 Sizes of length, weight, and condition factor samples of chinook fry from the 1976 brood from the Rockport station on the Skagit River, the Cascade River, and the Sauk River.

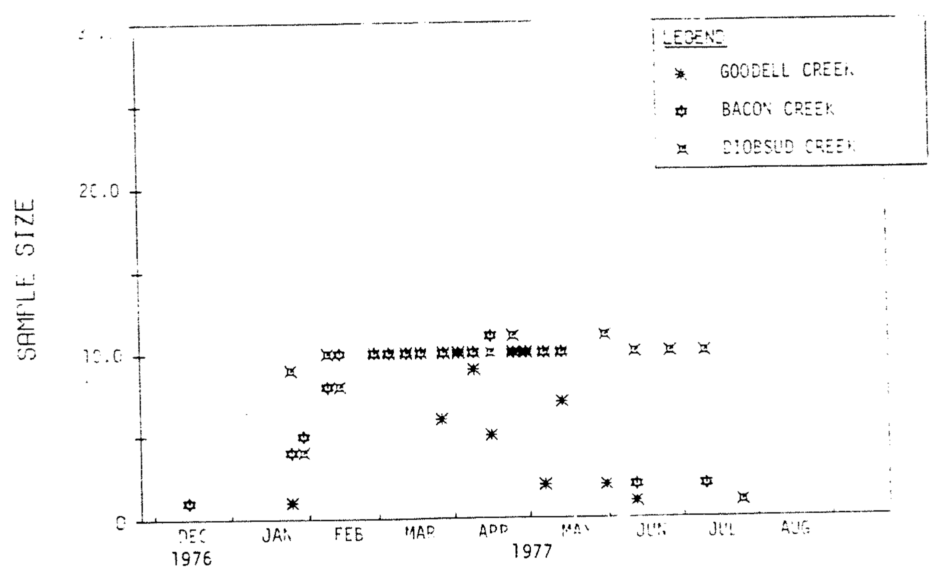

Fig. 8.43 Sizes of length, weight, and condition factor samples of chinook fry from the 1976 brood from three Skagit creeks.

of this initial level period was near March 20 in 1976 and near March 1 in 1977. Estimates derived from observations of peak spawning and temperature unit accumulation placed peak emergence for summer-fall chinook in the Skagit River at February 18 in 1976 and January 18 in 1977 (Table 7.10), five to six weeks before the end of the initial level period. Peak chinook fry abundance at the County Line Station in 1976 occurred in mid-April, several weeks after the end of the initial level period. In 1977, peak abundance at the County Line Station occurred about two weeks after the end of the initial level period, while at the Marblemount Station, it occurred two weeks before this point (Fig. 8.3).

There were several important differences between 1975-1976 and 1976-1977 in the rearing environment of the chinook fry. The 1976 brood of chinook fry experienced warmer temperatures during incubation and rearing, lower precipitation, lower water levels, increased turbidity, and higher solar radiation at all the sites, and less flow fluctutions in the Skagit. Adult returns in 1976 were higher and, for much of the rearing period, fry densities were higher in 1977 than in 1976 (Fig. 8.3).

The clearest differences in length and weight between the 1975 and the 1976 broods were seen in the Skagit and Cascade rivers (Figs. 8.7, 8.12, 8.18, and 8.23). Other sites showed increased size of chinook fry in the latter part of the rearing period only. Examination of similarities in environmental contrasts between 1975-1976 and 1976-1977 in the Cascade River and the Skagit River may help to delineate the factors most important to chinook fry rearing.

Warmer temperatures in the winter of 1976-1977 apparently advanced the timing of first emergence of the 1976 brood at all stations (Tables 8.1 and 8.2). This early start and continued warmer temperatures may have, in part, produced fry larger than the 1975 brood in the Cascade and Skagit rivers. The Sauk River exhibited the largest advance in first emergence timing, yet the 1976 brood from the Sauk River did not show the distinct increase in fry size throughout the year as seen in the 1976 brood from the Skagit and Cascade rivers. The Sauk produced some larger fry toward the end of the rearing period each year, but it is not known how much this was due to spring run chinook fry from the Suiattle River migrating through our study area.

Lower precipitation resulted in lower water levels in 1977 at all sites which reduced the size of the fry-rearing environment. The unregulated Cascade was perhaps more affected than the regulated, larger, Skagit yet chinook fry from the Cascade and Sauk rivers showed similar between-the-year differences in chinook fry length and weight. Thus flow apparently did not account for growth differences.

Solar radiation can probably safely be assumed to be similar between the major river sites each year.

The Cascade and the Skagit experienced about the same increase in turbidity in 1977. This increase was much lower than the increase in turbidity in the Sauk (Tables 3.8 and 3.9). Increased turbidity was strongly indicated as a causative factor in decreased primary and secondary production at the lower Sauk site in 1977 (Sec. 3.4.3.2). Noggle (1978) found in artificial stream experiments that feeding efficiency of salmonid fry was reduced in turbid water.

In 1977, the Skagit River experienced decreased flow fluctuations (Tables 3.2 and 3.3). The Cascade River did not. However, the reduction in flow fluctuations in the Skagit were in effect primarily after May 1977, about 5 months after the 1976 brood of chinook fry began to emerge. Later emerging species should reveal more about the effect on fry size and condition of reduced fluctuation.

In summary, the environmental factor that apparently held chinook fry size and condition in the Sauk at the same level in 1977 as in 1976, but not in the Cascade and Skagit rivers, was the higher turbidity in the Sauk, which counteracted the effects of generally warmer temperatures and increased solar radiation in the 1977 fry growing season.

The mean condition factor (Figs. 8.27 to 8.37) shows much more variability than do the length and weight data. This is to be expected since it is the ratio of two variable quantities, one of which is cubed. The condition factor data show less difference between brood years than do the length and weight data. Again, the Sauk River samples have very high points late in the rearing period that appear to be older fish, perhaps spring chinook from the Suiattle. After initial emergence, there is generally a slight decrease in condition factors for the first few months.

8.4.1.3 Chinook Salmon Fry Diet. The results of stomach content analysis of 412 chinook fry collected in 1975 are shown in Tables 8.15, 8.16, and 8.17. Two-hundred and fifty Skagit River fry stomachs, 113 Sauk River fry stomachs, and 49 Cascade River fry stomachs were examined.

In the 1975 study, aquatic insects accounted for the largest number of food items found in stomachs of chinook fry except in the Skagit where, in some April samples, zooplankton (copepods and cladocerans) originating from the upstream reservoirs were in greater number. A few annelids, terrestrial insects, sand, vegetation, and unknown insect matter were also found in stomachs.

The 1975 stomach samples indicated that in the Skagit and Sauk, Diptera were eaten by chinook fry more frequently than any other order. Of the Diptera, chironomid larvae were most abundant with chironomid adults next in numbers. In the Skagit samples the second most abundant component was copepods, mostly *Diaptomus*; third was Ephemeroptera nymphs; fourth was cladocerans (*Bosmina*); and fifth was Plecoptera nymphs. Unlike the Skagit samples, Sauk River fry in 1975 samples had more Plecoptera nymphs than Ephemeroptera nymphs in their stomachs. The primary food found in the 1975 Cascade River samples was Ephemeroptera nymphs, with chironomid larvae and Plecoptera nymphs second and third, respectively.

The results of chinook fry stomach sample analysis from the 1975 and 1976 broods are presented in Tables 8.18 to 8.23. The column "freq.

Table 8.15 Chinook fry stomach contents, Skagit River, 1974 brood.

Food Items	Date 1975	1/18		2/1		2/11		2/25		3/11		3/25		4/1		4/8	
	Sample size	38		27		30		15		15		10		15		15	
		Total no.	% occur.	Total no.	% occur.	Total no.	% occur.	Total	% occur.	Total no	% occur.	Total	% occur.	Total no.	% occur.	Total no.	% occur.
Collembola		1	0.14	1	2.44					1	1.04	1	0.47	3	0.41	2	0.52
Ephemeroptera	nymphs	148	20.73	19	46.63	11	5.26	50	46.30	31	32.29	31	14.42	78	10.64	17	4.45
	adults																
Plecoptera	nymphs	7	0.98	3	7.32	19	9.09	11	10.19	1	1.04	8	3.74	4	0.55	12	3.14
	adults			2	4.98												
Trichoptera	larvae	1	0.14			1	0.48	1	0.93								
	adults																
Diptera																	
Chironomidae	pupae	2	0.28			8	3.83	2	1.85			2	0.93			4	1.05
	larvae	548	76.75	12	29.27	120	57.42	32	29.63	26	27.08	13	6.05	19	2.59	22	5.76
	adults	2	0.28													2	0.52
Simuliidae	larvae	3	0.42	1	2.44	12	5.74	2	1.85							1	0.26
	adults																
Misc. Diptera				1	2.44	1	0.48									2.	0.52
Cladocera						1	0.48	2	1.85			71	33.18	191	26.06	48	12.57
Diaptomus				2	4.88	28	13.40	5	4.63	37	38.54	88	40.93	437	59.62	260	68.06
Misc. aquatic						8	3.83	2	1.85			1	0.47	1	0.14	2	0.52
Misc. terrestrials																1	0.26
Fish eggs																	
Unidentified and Inanimate material								1	0.93							9	2.36

Table 8.15 Chinook fry stomach contents, Skagit River, 1974 brood--Continued.

Food Items		4/15 Total no.	4/15 % occur.	4/22 Total no.	4/22 % occur.	5/2 Total no.	5/2 % occur.	5/13 Total no.	5/13 % occur.	5/28 Total no.	5/28 % occur.	6/16 Total no.	6/16 % occur.	Skagit '75 comb. Total no.	Skagit '75 comb. % occur.
Date 1975		4/15		4/22		5/2		5/13		5/28		6/16		Skagit '75 comb.	
Sample size		15		15		18		17		17		3		250	
Collembola								1	1.20	23	11.68			33	0.71
Ephemeroptera	nymphs	12	6.19	96	39.34	31	12.45	9	10.98	50	25.38	1	9.09	584	16.82
	adults					1	0.40	12	14.63					13	0.28
Plecoptera	nymphs	4	2.06	4	1.64	42	16.87	3	3.66	8	4.06			127	3.66
	adults					3	1.20	3	3.66	3	1.52	1	9.09	12	0.35
Trichoptera	larvae							1	1.20					3	0.09
	adults														
Diptera															
Chironomidae	pupae			4	1.64	9	3.61	4	4.88	31	15.74			66	1.90
	larvae	7	3.61	21	8.61	29	11.65	6	7.23	10	5.08	1	9.09	866	24.94
	adults			1	0.41	99	39.76	23	28.05	33	16.75	7	63.64	167	4.81
Simuliidae	larvae	1	0.52	2	0.82			1	1.22					23	0.66
	adults									4	2.03			4	0.09
Misc. Diptera		2	1.03			4	1.61			15	7.61	1	9.09	24	0.69
Cladocera		94	48.45	31	12.70	14	5.62	9	10.84					461	13.27
Diaptomus		72	37.11	84	34.43	15	6.02	2	2.44					1030	29.66
Misc. aquatic		1	0.52			2	0.08	1	1.22	2	1.02			21	0.61
Misc. terrestrials		1	0.52	1	0.41			5	6.01	2	1.02			10	0.29
Fish eggs															
Unidentified and inanimate material								3	3.66	16	8.12			29	0.84

Table 8.16 Chinook fry stomach contents, Cascade River, 1974 brood.

Food items		Date 1975	3/11		3/25		4/1		4/8		4/15		4/22	
		Sample size	5		5		5		4		5		5	
			Total no.	% occur.	Total no.	% occur.	Total no.	% occur.	Total no.	% occur.	Total no.	% occur.	Total no.	% occur
Collembola											1	4.00	1	3.33
Ephemeroptera	nymphs		2	28.57	3	27.27	4	23.53	5	26.32	3	12.00	14	46.67
	adults													
Plecoptera	nymphs		3	42.86	2	18.19			2		1	4.00	1	3.33
	adults										1	4.00		
Trichoptera	larvae													
	pupae				1	9.09								
Diptera														
Chironomidae	pupae						5	29.41			3	12.00	5	16.67
	larvae		1	14.29			6	35.29	9	47.37	9	36.00	7	23.33
	adults													
Simuliidae	larvae				1	9.09			1	5.26	1	4.00		
	adults													
Misc. Diptera									1	5.26				
Cladocera														
Diaptomus														
Misc. aquatics									1	5.26				
Misc. terrestrials														
Fish eggs														
Unidentified and inanimate material			1	14.29	4	36.36	2	11.76			6	24.00	2	6.67

Table 8.16 Chinook fry stomach contents, Cascade River, 1974 brood--Continued.

Food Items	Date 1975 / Sample size	5/2 6 Total no.	% occur.	5/13 5 Total no.	% occur.	5/28 6 Total no.	% occur.	6/16 3 Total no.	% occur.	Cascade R.'75 comb. 49 Total no.	% occur.
Collembola				1	0.74					3	0.80
Ephemeroptera	nymphs	30	50.85	45	33.33	5	29.41	37	67.27	148	39.47
	adults					3	17.65			3.	0.80
Plecoptera	nymphs	6	10.17	7	5.19	1	5.88	5	9.09	28	7.47
	adults					1	5.88			2	0.27
Trichoptera	larvae			2	1.48	1	5.88			3	1.34
	pupae					1	5.88			2	.53
Diptera											
Chironomidae	pupae	8	13.56	2	1.48			2	3.64	25	6.67
	larvae	12	20.34	62	45.93	3	17.65	4	7.27	113	30.13
	adults	2	3.39	6	4.44	1	5.88	2	3.64	11	2.93
Simuliidae	larvae			2	1.48					5	1.33
	adults			1	0.74					1	0.27
Misc. Diptera				6	4.44			3	5.45	10	2.67
Cladocera											
Diaptomus											
Misc. aquatics				1	0.74	1	5.88	2	3.64	5	1.33
Misc. terrestrials											
Fish eggs											
Unidentified and inanimate material		1	1.69							16	4.27

Table 8.17 Chinook fry stomach contents, Sauk River, 1974 brood.

Food items	Date / Sample size	2/11 (12) Total no.	2/11 (12) % occur	3/11 (5) Total no.	3/11 (5) % occur	3/25 (10) Total no.	3/25 (10) % occur	4/1 (10) Total no.	4/1 (10) % occur	4/8 (10) Total no.	4/8 (10) % occur	4/15 (10) Total no.	4/15 (10) % occur
Collembola		3	10.71										
Ephemeroptera	nymphs	6	21.43			9	2.44	8	15.69	5	7.81	2	2.86
	adults											2	2.86
Plecoptera	nymphs	3	10.71	3	20.00	125	33.88			9	14.06		
	adults												
Trichoptera	larvae			3	20.00	2	.54					2	2.86
	adults												
Diptera													
Chironomidae	pupae					3	.81	1	1.96	8	12.50	44	62.86
	larvae	16	57.14	4	26.67	70	18.97	17	33.33	16	25.00	3	4.29
	adults					2	.54					2	2.86
Simuliidae	larvae					156	42.28			1	1.56	14	20.00
	adults												
Misc. Diptera						1	.27			1	1.56		
Cladocera													
Diaptomus													
Misc. aquatics				5	33.33	1	.27			1	1.56		
Misc. terrestrials										2	3.13	1	1.43
Fish eggs													
Unidentified and inanimate material								25	49.02	21	32.81		

Table 8.17 Chinook fry stomach contents, Sauk River, 1974 brood--Continued.

Food Items	Date 1975 / Sample size	4/22 (10) Total no.	4/22 (10) % occur.	5/2 (10) Total no.	5/2 (10) % occur.	5/13 (13) Total no.	5/13 (13) % occur.	5/28 (14) Total no.	5/28 (14) % occur.	6/16 (8) Total no.	6/16 (8) % occur.	Sauk R. '75 comb. (113) Total no.	Sauk R. '75 comb. (113) % occur.
Collembola						1	.21					4	.29
Ephemeroptera	nymphs	7	9.72	21	61.76	49	10.38	19	18.10	59	55.14	185	13.34
	adults											2	.14
Plecoptera	nymphs	3	4.17	7	20.59	19	4.03	14	13.33	13	12.15	196	14.13
	adults			1	2.94			17	16.19	1	0.93	19	1.37
Trichoptera	larvae					4	.85					11	.79
	adults												
Diptera													
Chironomidae	pupae	50	69.44	2	5.88	9	1.91	16	15.24	0	0	133	9.59
	larvae	5	6.94	1	2.94	367	77.75	24	22.86	25	23.36	548	39.51
	adults	2	2.78	2	5.88	2	.42	6	5.71	2	1.87	18	1.30
Simuliidae	larvae					9	1.91	1	0.95	1	0.93	182	13.12
	adults					5	1.06	1	0.95			6	.43
Misc. Diptera						5	1.06	5	4.76	6	5.61	18	1.30
Cladocera													
Diaptomus													
Misc. aquatics		2	2.78			1	.21	1	0.95			11	.79
Misc. terrestrials		1	1.39			1	.21	1	0.95			6	.43
Fish eggs													
Unidentified and inanimate material		2	2.78									48	3.46

Table 8.18 Chinook fry stomach contents, Skagit River, 1975 brood.

Date		Feb '76			March '76			April '76			May '76			June '76			July '76		
Location and sample size		County Line 9 Talc Mine 12 Marblemount 10			County Line 10 Talc Mine 5			County Line 5 Talc Mine 5 Marblemount 5			County Line 6 Talc Mine 5 Marblemount 5			County Line 5 Talc Mine 5 Marblemount 5			County Line 5 Talc Mine 3		
% Empty		48			26			6			1			0			0		
		Freq. occur.	Total no.	% occur	Freq. occur.	Total no.	% occur.	Freq. occur.	Total no.	% occur.	Freq. occur.	Total no.	% occur.	Freq. occur.	Total no.	% occur.	Freq. occur.	Total no.	% occur.
Collembola																			
Ephemeroptera	nymphs	25.0	5	7.14	36.4	12	7.64	57.1	18	8.41	60.0	30	11.63	53.3	36	24.00	62.5	16	11.68
	adults																		
Plecoptera	nymphs				9.1	1	.64	21.4	4	1.87	46.7	18	6.98	33.3	7	4.67	50.0	5	3.65
	adults							7.1	1	.47				6.7	1	.67			
Trichoptera	larvae	12.5	2	2.86	9.1	1	.64	14.3	3	1.40	33.3	7	2.71	20.0	3	2.00	25.0	2	1.46
	adults										6.7	1	.39	6.7	1	.67			
Diptera																			
Chironomidae	pupae							14.3	6	2.80	13.3	2	.78						
	larvae	12.5	2	2.86	54.5	38	24.20	92.9	81	37.85	66.7	48	18.60	26.7	59	39.33	62.5	85	62.04
	adults				9.1	1	.64	35.7	9	4.21	66.7	133	51.55	33.3	18	12.00	50.0	11	8.03
Simuliidae	larvae																		
misc. Diptera		25.0	8	11.43				14.3	2	.93	26.7	7	2.71	26.7	4	2.67	12.5	1	.73
Daphnia		12.5	10	14.29	45.5	82	52.23	35.7	71	33.18	13.3	3	1.16	6.7	6	4.00	25.0	3	2.19
Bosmina		12.5	17	24.29															
Diaptomus	adults	25.0	21	30.00	45.5	22	14.01	28.6	18	8.41	6.7	1	.39						
	nauplii																		
Misc. Aquatics								7.1	1	.47				20.0	11	7.33	12.5	3	2.19
Misc. terrestrials		18.7	3	4.29							40.0	8	3.10	26.7	4	2.67	50.0	10	7.30
Fish eggs																			
Unidentified and inanimate material		12.5	2	2.86													12.5	1	.73

Table 8.19 Chinook fry stomach contents, Cascade River, 1975 brood.

Date		Feb '76			March '76			April '76			May '76			June '76			Dec '76		
Location and sample size		Cascade 1			Cascade 5			Cascade 5			Cascade 5			Cascade 8			Cascade 1		
% Empty		0			0			0			0			0			0		
		Freq. occur.	Total no.	% occur	Freq. occur.	Total no.	% occur.	Freq. occur.	Total no.	% occur.	Freq. occur.	Total no.	% occur.	Freq. occur.	Total no.	% occur.	Freq. occur.	Total no.	% occur.
Collembola								20.0	1	2.56	20.0	1	2.17						
Ephemeroptera	nymphs				80.0	7	29.17	40.0	5	12.82	80.0	20	43.48	62.5	9	15.25			
	adults																		
Plecoptera	nymphs	100	1	100	60.0	9	37.5	40.0	3	7.69	20.0	1	2.17	25.0	5	8.47	100	6	100
	adults				20.0	2	8.33	40.0	3	7.69									
Trichoptera	larvae				20.0	1	4.17				20.0	3	6.52						
	adults																		
Diptera																			
Chironomidae	pupae							20.0	1	2.56									
	larvae				20.0	2	8.33	40.0	4	10.26	60.0	6	13.04	50.0	7	11.86			
	adults				40.0	3	12.50	60.0	15	38.46	80.0	8	17.39	50.0	35	59.32			
Simuliidae	larvae							20.0	1	2.56	20.0	1	2.17						
misc. Diptera								40.0	5	12.82	60.0	5	10.87	12.5	1	1.69			
Daphnia																			
Bosmina																			
Diaptomus	adults																		
	nauplii																		
Misc. Aquatics											20.0	1	2.17						
Misc. terrestrials								20.0	1	2.56				12.5	1	1.69			
Fish eggs														12.5	1	1.69			
Unidentified and inanimate material																			

Table 8.29 Chinook fry stomach contents, Sauk River, 1975 brood.

Date / Location and sample size		March '76 Sauk 1			June '76 Sauk 5		
% Empty		0			0		
		Freq. occur.	Total no.	% occur	Freq. occur.	Total no.	% occur.
Collembola							
Ephemeroptera	nymphs	100.0	2	3.70	80.0	25	75.76
	adults						
Plecoptera	nymphs	100.0	1	1.85	40.0	3	9.09
	adults						
Trichoptera	larvae				20.0	1	3.03
	adults						
Diptera							
Chironomidae	pupae						
	larvae	100.0	50	92.59			
	adults				20.0	3	9.09
Simuliidae	larvae						
misc. Diptera							
Daphnia							
Bosmina							
Diaptomus	adults						
	nauplii						
Misc. Aquatics							
Misc. terrestrials					20.0	1	3.03
Fish eggs							
Unidentified and inanimate material		100.0	1	1.85			

Table 8.21 Chinook fry stomach contents, Skagit River, 1976 brood.

Date		Jan 1977			Feb 1977			Mar 1977			Apr 1977			May(1st wk)1977			May(4th wk)1977			Jun 1977		
Location and sample size		County Line 5 Talc Mine 5 Marblemount 3			County Line 5 Talc Mine 5 Marblemount 5			County Line 5 Talc Mine 5 Marblemount 5			County Line 5 Talc Mine 4 Marblemount 5			County Line 4 Marblemount 5			County Line 12 Talc Mine 11 Marblemount 11			County Line 10 Talc Mine 7 Marblemount 10		
% Empty		0			0			20			0			0			0			0		
		Freq. occur.	Total no.	% occur	Freq. occur.	Total no.	% occur.	Freq. occur.	Total no.	% occur.	Freq. occur.	Total no.	% occur.	Freq. occur.	Total no.	% occur.	Freq. occur.	Total no.	% occur.	Freq. occur.	Total no.	% occur.
Collembola		23.1	9	1.38	13.3	4	.44				28.6	12	6.25				17.6	8	2.01	3.7	1	.40
Ephemeroptera	nymphs	84.6	243	37.38	86.7	567	62.38	75.0	18	54.55	71.4	51	26.56	66.7	6	9.38	55.9	30	7.52	63.0	36	14.46
	adults																23.5	59	14.79	3.7	2	.8
Plecoptera	nymphs	76.9	48	7.38	60.0	17	1.87	8.3	1	3.03	28.6	9	4.69	44.4	12	18.75	41.2	30	7.52	22.2	7	2.81
	adults							8.3	1	3.03				22.2	2	3.13	8.8	3	.75			
Trichoptera	larvae	15.4	2	.31	6.7	1	.11													11.1	5	2.01
	adults																5.9	2	.50	7.4	4	1.61
Diptera																						
Chironomidae	pupae																					
	larvae	92.3	236	36.31	86.7	206	22.66	33.3	4	12.12	35.7	5	2.60				29.4	14	3.51	22.2	11	4.42
	adults	7.7	1	.15	6.7	12	1.32				35.7	54	28.13	44.4	32	50.0	55.9	73	18.3	59.3	90	36.14
Simuliidae	larvae	69.2	58	8.92	53.3	90	9.90	8.3	5	15.15	7.1	3	1.56				8.8	3	.75	7.4	2	.80
misc. Diptera								8.3	1	3.03	50.0	18	9.38	22.2	4	6.26	50.0	51	12.78	59.3	34	13.65
Daphnia		7.7	1	.15	13.3	7	.77				14.3	2	1.04				2.9	13	3.26			
Bosmina																	17.6	40	10.03			
Diaptomus	adults	7.7	37	5.69	6.7	1	.11	8.3	1	3.03	28.6	5	2.60									
	nauplii	7.7	1	.15	6.7	1	.11															
Misc. Aquatics		23.1	6	.92	6.7	1	.11				21.4	5	2.60	22.2	3	4.69	17.6	11	2.76	22.2	7	2.81
Misc. terrestrials		30.8	8	1.23	6.7	1	.11	16.7	2	6.06	71.4	24	12.50	22.2	5	7.81	50.0	39	9.77	48.1	41	16.47
Fish eggs																						
Unidentified and inanimate material					6.7	1	.11				14.3	4	2.08				32.4	23	5.76	22.2	9	3.61

Table 8.22 Chinook fry stomach contents, Cascade River, 1976 brood.

Date Location and sample size		Feb '77 Cascade 6			March '77 Cascade 5			April '77 Cascade 5			May '77 Cascade 8			June '77 Cascade 3		
% Empty		16			20			20			0			0		
		Freq. occur.	Total no.	% occur	Freq. occur.	Total no.	% occur.	Freq. occur.	Total no.	% occur.	Freq. occur.	Total no.	% occur.	Freq. occur.	Total no.	% occur.
Collembola								50.0	3	2.75	25.0	13	8.18			
Ephemeroptera	nymphs	40.0	7	24.14	50	2	40.0	25.0	3	2.75	87.5	73	45.91	33.3	1	7.69
	adults															
Plecoptera	nymphs	60.0	6	20.69	50	2	40.0	75.0	8	7.34	62.5	7	4.40	33.3	1	7.69
	adults										12.5	1	.63			
Trichoptera	larvae	20.0	1	3.45	25	1	20.0	25.0	2	1.83	37.5	4	2.52			
	adults															
Diptera																
Chironomidae	pupae							25.0	3	2.75	12.5	1	.63			
	larvae	40.0	8	27.59				50.0	59	54.13	87.5	20	12.58	33.3	4	30.77
	adults							75.0	6	5.50	37.5	16	10.06	100	4	30.77
Simuliidae	larvae															
misc. Diptera		20.0	6	20.69				100.0	18	16.51	37.5	19	6.30			
Daphnia																
Bosmina																
Diaptomus	adults															
	nauplii															
Misc. Aquatics								50.0	2	1.83	25.0	8	5.03			
Misc. terrestrials		20.0	1	3.45				75.0	5	4.59	12.5	1	.63	33.3	3	23.08
Fish eggs																
Unidentified and inanimate material											37.5	5	3.14			

Table 8.23 Chinook fry stomach contents, Sauk River, 1976 brood.

Date		Dec. '76			Jan '77			Feb '77			March '77			April '77			May (1st wk.)'77			May (4th wk.)'77			June '77		
Location and sample size		Sauk 5			Sauk 6			Sauk 5			Sauk 5			Sauk 5			Sauk 5			Sauk 4			Sauk 5		
% Empty		20			0			60			0			0			0			0			0		
		Freq. occur.	Total no.	% occur.	Freq. occur.	Total no.	% occur	Freq. occur.	Total no.	% occur.	Freq. occur.	Total no.	% occur.	Freq. occur.	Total no.	% occur.	Freq. occur.	Total no.	% occur.	Freq. occur.	Total no.	% occur.	Freq. occur.	Total no.	% occur.
Collembola														20.0	1	5.56	40.0	4	8.00	25.0	12	29.27	20.0	1	.83
Ephemeroptera	nymphs	75.0	6	15.00	100	317	44.9	20	1	.03	80.0	8	7.02	40.0	4	22.22	20.0	2	4.00	50.0	3	7.32	80.0	17	14.17
	adults																20.0	2	4.00						
Plecoptera	nymphs	25.0	1	2.50	100	142	20.11				60	4	3.51				20.0	1	2.00	25.0	1	2.44	60.0	5	4.17
	adults																								
Trichoptera	larvae																			25.0	1	2.44	40.0	2	1.67
	adults																								
Diptera																									
Chironomidae	pupae																			25.0	1	2.44			
	larvae	75.0	10	25.00	100	245	34.7				60	100	87.72	60.0	3	16.67	60.0	19	38.00	75.0	12	29.27	100.0	46	38.33
	adults	25.0	22	55.00										60.0	3	16.67	60.0	7	14.0				60.0	22	18.33
Simuliidae	larvae				20.0	2	.28													25.0	2	4.88			
misc. Diptera														80.0	7	38.89	40.0	6	12.00	25.0	1	2.44	60.0	20	16.67
Daphnia																									
Bosmina																									
Diaptomus	adults																								
	nauplii																								
Misc. Aquatics																									
Misc. terrestrials		25.0	1	2.50				20	10	83.33	40.0	2	1.75				60.0	9	18.00	75.0	6	14.63	40.0	6	5.0
Fish eggs																									
Unidentified and inanimate material								20	1	.03										25.0	2	4.88	20.0	1	.83

occur." represents the percentage of non-empty stomachs in a sample group that contained a certain prey organism. The next column, "total no.", gives the total number of individuals of the prey counted in the sample group. The next column "% occur.", is the percentage by number of the prey organism among all prey types encountered in the sample group.

Comparisons of chinook diet in 1976 to chinook diet in 1977 (Table 8.24) is especially interesting because of the environmental contrasts between these years. There was increased solar radiation and warmer temperatures, decreased water fluctuations, and increased benthic production in the Skagit in 1977. Zooplankton utilization by the chinook fry in Skagit samples was light in 1977. Increases in percent occurrence were seen in Ephemeroptera, Plecoptera, and Simuliidae. Utilization of chironomids showed a decrease in 1977. In general, the changes in diet paralleled the changes in benthic insect standing crop (Sec. 3.0), and the Skagit chinook fry diet in 1977 became more similar to the chinook fry diet reflected in Cascade and Sauk river samples. The most important contrast, perhaps, was the decrease in empty stomachs in the 1977 Skagit River samples which may indicate better rearing conditions and may help to explain the increased size of chinook fry in 1977 (Sec. 8.4.1.2).

The seasonal pattern of zooplankton utilization by chinook fry has little similarity between years. In contrast, the seasonal fluctuation in abundance in Ross Lake, the probable source of much of the zooplankton in the river, was similar over several years--1971,1972,and 1973 (SCL 1974).

In 1975, zooplankton percent occurrence in stomachs of Skagit chinook fry started low, increased to late April, and then decreased (Table 8.15). In 1976, utilization of zooplankton started high and declined through the year (Table 8.18). It appeared that chinook fry as they grew might be shifting to larger prey items. In 1977, the highest percent occurrence by numbers of zooplankton in the Skagit chinook fry stomach samples was in late May, although the stomach samples from the Skagit River before and after the late May sampling period contained no zooplankton (Table 8.21). In the plankton drift sampling, which started in April 1977, the highest crustacean zooplankton densities in the Skagit River were found in late May, concurrent with the highest occurrence of zooplankton in chinook fry stomach samples in 1977. But moderate plankton densities were found in the plankton samples taken in April and June.

Tables 8.25 through 8.30 present the occurrence of incompletely absorbed yolk in chinook fry captured for stomach analysis. In 1976 and 1977, yolk absorption did not necessarily precede emergence from the gravel in the Skagit and Sauk (Tables 8.25, 8.27, 8.28, 8.30). Many fry with incompletely absorbed yolk were found with food items in their guts. Although fry hiding in the surface gravel could be pulled out with the electrofisher, it seems unlikely that incubating alevins could be drawn from deep within redds or that incubating alevins would have been feeding. This precocious emergence and feeding was not found in the smaller sample of 31 fry from the Cascade (Tables 8.26 and 8.29). This could imply that warmer temperatures in the Sauk and the Skagit resulted in precocious emergence.

Table 8.24 Chinook fry stomach contents, summary of 1975 and 1976 broods.

Date & location		Skagit 1976			Skagit 1977			Cascade 1976			Cascade 1977			Sauk 1976			Sauk 1977		
Sample size		100			127			25			27			8			33		
% Empty		21			2			0			11			0			10		
Organism		Freq. occur.	Total no.	% occur.	Freq. occur.	Total no.	% occur.	Freq. occur.	Total no.	% occur.	Freq. occur.	Total no.	% occur.	Freq. occur.	Total no.	% occur.	Freq. occur.	Total no.	% occur.
Collembola					12.9	34	1.36	8.0	2	1.16	16.7	16	5.08				14.3	18	1.63
Ephemeroptera	nymphs	48.1	117	11.87	68.5	951	38.1	60.0	41	23.7	54.2	86	27.3	87.5	44	34.65	62.9	358	32.52
	adults				7.3	61	2.44										2.9	2	.18
Plecoptera	nymphs	25.3	35	3.55	38.7	124	4.97	40.0	23	13.29	58.3	24	7.62	62.5	22	17.32	37.1	153	13.90
	adults	2.5	2	.20	4.8	6	0.24	12.0	5	2.89	4.2	1	0.32				2.9	1	.09
Trichoptera	larvae	19.0	18	1.83	4.8	8	0.32	8.0	4	2.31	25.0	8	2.54	12.5	1	.79	8.6	3	.27
	adults	2.5	2	.20	3.2	6	0.24												
Diptera																			
Chironomidae	pupae	5.1	8	.81				4.0	1	0.58	8.3	4	1.27						
	larvae	50.6	313	31.74	40.3	476	19.07	40.0	19	10.98	50.0	91	28.89	25.0	52	40.94	2.9	1	.09
	adults	31.6	172	17.44	37.1	262	10.5	52.0	61	35.26	37.5	26	8.25	25.0	4	3.15	71.4	435	39.51
Simuliidae	larvae				19.4	161	6.45	8.0	2	1.16				12.5	1	.79	5.7	4	.36
misc. Diptera		19.0	22	2.23	34.7	108	4.33	24.0	11	6.36	33.3	34	10.79				28.6	34	3.09
Daphnia		21.5	175	17.75	5.6	23	0.92												
Bosmina		2.5	17	1.72	4.8	40	1.60												
Diaptomus	adults	19.0	63	6.39	5.6	44	1.76												
	nauplii				1.6	2	0.08												
Misc. aquatics		6.3	15	1.52	16.9	33	1.32	4.0	1	0.58	16.7	10	3.17						
Misc. terrestrials		21.5	25	2.54	39.5	120	4.81	8.0	2	1.16	25.0	10	3.17	25.0	2	1.57	34.3	34	3.09
Fish eggs								4.0	1	0.58									
Unidentified and inanimate material		3.8	3	.30	16.1	37	1.48				12.5	5	1.59	8.3	1	0.6	8.6	4	.36

Table 8.25 Yolk in emerged chinook fry, upper three Skagit sites, 1975 brood.

	Feb 76		Mar 76		Apr 76		May 76	
Number of stomachs examined	31		15		15		16	
Fry with empty gut and yolk	15	48%	1	7%	0	0%	1	6%
Fry with non-empty gut and yolk	9	29%	1	7%	0	0%	0%	0%
Fry with empty gut and no yolk	0	0%	3	20%	1	7%	0%	0%
Fry with non-empty gut and no yolk	7	23%	10	67%	14	93%	15	94%

Table 8.26 Yolk in emerged chinook fry, Cascade River, 1975 brood.

	Feb 76		Mar 76		Apr 76		May 76	
Number of stomachs examined	0		5		5		5	
Fry with empty gut and yolk			0	0%	0	0%	0	0%
Fry with non-empty gut and yolk			0	0%	0	0%	0	0%
Fry with empty gut and no yolk			0	0%	0	0%	0	0%
Fry with non-empty gut and no yolk			5	100%	5	100%	5	100%

Table 8.27 Yolk in emerged chinook fry, Sauk River, 1975 brood.

	Feb 76		Mar 76		Apr 76		May 76	
Number of stomachs examined	0		5		5		5	
Fry with empty gut and yolk			0	0%	0	0%	0	0%
Fry with non-empty gut and yolk			2	40%	0	0%	0	0%
Fry with empty gut and no yolk			0	0%	0	0%	0	0%
Fry with non-empty gut and no yolk			3	60%	5	100%	5	100%

Table 8.28 Yolk in emerged chinook fry, upper three Skagit sites, 1976 brood.

	Jan 77		Feb 77		Mar 77		Apr 77	
Number of stomachs examined	13		15		15		14	
Fry with empty gut and yolk	0	0%	0	0%	0	0%	0	0%
Fry with non-empty gut and yolk	5	38%	2	13%	0	0%	0	0%
Fry with empty gut and no yolk	0	0%	0	0%	3	20%	0	0%
Fry with non-empty gut and no yolk	8	62%	13	87%	12	80%	14	100%

Table 8.29 Yolk in emerged chinook fry, Cascade River, 1976 brood.

	Jan 77	Feb 77		Mar 77		Apr 77	
Number of stomachs examined	0	6		5		5	
Fry with empty gut and yolk	0	0	0%	0	0%	0	0%
Fry with non-empty gut and yolk	0	0	0%	0	0%	0	0%
Fry with empty gut and no yolk	0	1	17%	1	20%	1	20%
Fry with non-empty gut and no yolk	0	5	83%	4	80%	4	80%

Table 8.30 Yolk in emerged chinook fry, Sauk River, 1976 brood.

	Dec 76		Jan 77		Feb 77		Mar 77		Apr 77	
Number of stomachs examined	5		5		5		5		5	
Fry with empty gut and yolk	1	20%	0	0%	0	0%	0	0%	0	0%
Fry with non-empty gut and yolk	2	40%	0	0%	2	40%	0	0%	0	0%
Fry with empty gut and no yolk	0	0%	0	0%	1	20%	0	0%	0	0%
Fry with non-empty gut and no yolk	2	40%	5	100%	2	40%	5	100%	5	100%

8.4.2 Pink Salmon Fry

8.4.2.1 Pink Salmon Fry Availability. Pink salmon fry were available for sampling only in even years. They followed chinook fry in emergence timing in the Skagit Basin. In the 1974 sampling by WDF, pink fry of the 1973 brood first appeared in electrofishing samples on March 4 and were last captured on April 26. Only 22 were captured, while over 1,800 chinook fry were captured (Orrell 1976). Some sampling of pink fry was also done by FRI in 1974 between February 21 and May 21 (Tables 8.31 and 8.32). In the 1976 sampling by FRI, two fry of the 1975 brood were captured in the mainstem Skagit in the first half of January, and scattered numbers were taken into early May (Table 8.33). Highest numbers were taken in April. Pink fry were captured in the Sauk only in April and in Bacon and Diobsud creeks only in March (one fry each creek). No pink fry were taken in the Cascade River or Goodell Creek during the weekly sampling in 1976. Numbers captured overall were low, in part, because of the tendency of the fry to migrate at once following emergence and not to seek the shoreline waters. Incubation survival was probably reduced by floods in January 1974, and December 1975, especially in unregulated waters.

8.4.2.2 Pink Salmon Fry Size and Condition after Emergence. Size and condition data for Skagit Basin pink fry captured during 1974 are presented in Tables 8.31 and 8.32. In general, pink fry are smaller than chinook fry. Most sites showed little change in mean length, mean weight, or mean condition factor with time. Downstream migration was probably continual. Too few fry were captured in the Cascade and Sauk rivers in 1974 to make meaningful comparisons with the Skagit.

Size and condition data for Skagit and Sauk river pink fry captured during 1976 are presented in Table 8.34. The length and weight data showed a general increase from January through May, while the condition factors decreased slightly. Fry captured from both systems during the peak month, April, were similar in size and condition factor.

8.4.3 Chum Salmon Fry

8.4.3.1 Chum Salmon Fry Availability. Because chum salmon spawning is late in the fall, emergence is later in timing than for summer-fall chinook and pink fry in spite of fewer temperature units required by chum salmon for embryonic development. Chum fry spend little time in freshwater and migrate downstream soon after emerging from the gravel, mainly at night. They feed a little if the migration is long (McPhail and Lindsey 1970). These habits made few fry available to our electroshocking effort.

In 1973, WDF sampling first encountered chum fry of the 1972 brood in the Marblemount-Rockport area of the Skagit on March 22. Peak numbers were captured in April, but fish were still present on May 21, the last sampling date (Phinney 1974a). In 1974, WDF sampling encountered chum fry of the 1973 brood only in April and May (Orrell 1976). FRI sampling in 1974 found chum fry from April 9 to May 20 in the Skagit, from February 2

Table 8.31 Mean lengths, weights, and condition factors of pink salmon fry captured by electroshocking in the Skagit River, 1973 brood.

Location	Date	Number of fish	Length (mm) Range	Length (mm) Mean	Mean weight (g)	Mean condition factor
	1974					
Skagit River near Newhalem	Feb 21	1	27	27	-	-
	Mar 11	4	33-36	34.5	0.25	0.61
	Apr 8	4	34-38	36.0	0.46	1.00
	10	1	35	35	0.35	0.82
	17	2	34-37	35.5	0.30	0.68
	24	4	35-38	36.7	0.30	0.61
	May 6	1	34	34	0.3	0.8
Skagit River near Talc Mine	Feb 26	3	34-35	34.3	0.20	0.50
	Mar 12	6	31-35	33.2	0.25	0.69
	26	21	33-36	34.4	0.28	0.69
	Apr 9	20	32-37	34.5	0.27	0.65
	17	4	33-36	34.8	0.23	0.53
	23	13	33-39	36.5	0.26	0.54
	May 7	3	34-36	35.3	0.30	0.68
Skagit River near Marblemount	Feb 22	1	33	33	0.25	0.70
	25	1	31	31	-	-
	Mar 12	1	35	35	0.25	0.58

Table 8.32 Mean lengths, weights, and condition factors of pink salmon fry captured by either electroshocking or fyke netting in Skagit tributaries, 1973 brood.

Location	Date	Number of fish	Length (mm) Range	Length (mm) Mean	Mean weight (g)	Mean condition factor
	1974					
Cascade River	Feb 27	2	31	31.0	0.15	0.50
Sauk River	Mar 26	1	37	37	0.4	0.8
Bacon Creek	Apr 9*	45	33-39	35.9	0.29	0.64
	10*	34	32-37	35.5	0.31	0.69
	10	1	35	35	0.3	0.7
	24*	6	33-38	35.9	0.29	0.63
Diobsud Creek	Apr 9*	14	30-37	34.4	0.30	0.73
	10*	9	31-37	34.7	0.31	0.74
	24*	19	31-37	34.1	0.24	0.60
	May 7*	21	34-39	36.2	0.29	0.60
	8	2	34-35	34.5	0.20	0.49
	21*	6	33-38	34.2	0.23	0.58

*fyke net sample

Table 8.33 Pink fry catches at Skagit Basin sampling sites using electrofisher, 1975 brood.

Date	Skagit River at				Cascade River	Sauk River	Goodell Creek	Bacon Creek	Diobsud Creek
	County Line	Talc Mine	Marble-mount	Rock-port					
1975									
12/19-1/3	-		-		-	-			
1976									
1/4 -1/10	-	-	1		-	-			
1/11 -1/17	1	-	-		-	-			
1/18 -1/24	-	-	-	-	-	-			
1/25 -1/31	5	-	-		-	-		-	
2/1 -2/7	-	-	1	2	-	-			
2/8 -2/14	2	-	-		-	-			
2/15 -2/21	-	-	-	2	-	-			
2/22 -2/28	-	-	-	-	-	-	-	-	-
2/29 -3/6	-	-	1	-	-	-			1
3/7 -3/13	2	3	-		-	-	-	-	
3/14 -3/20	-	1	2	-	-	-	-	-	-
3/21 -3/27	-	-	1	3	-	-	-	1	-
3/28 -4/3	-	-	-	-	-	-	-	-	-
4/4 -4/10	-	-	-	-	-	2	-	-	-
4/11 -4/17	16	1	-	7	-	-	-	-	-
4/18 -4/24	3	-	-	8	-	6	-	-	-
4/25 -5/1	6	2	-	2	-	1	-	-	-
5/2 -5/8	1	-	-	2	-	-	-	-	-
5/9 -5/15	-	-	-	-	-	-		-	-
5/16 -5/22	-	-	-	-	-	-	-	-	-

Note: dash (-) signifies catch was zero.
blank signifies sampling not conducted.

Table 8.34 Mean lengths, weights, and condition factors of Skagit and Sauk rivers pink salmon fry captured by electroshocking, 1975 brood.

Month	Number of fish	Mean length (mm)	Mean weight (g)	Mean condition factor
SKAGIT RIVER				
1976				
January	7	30.3	0.24	0.86
February	7	31.4	0.22	0.71
March	12	33.6	0.24	0.63
April	45	36.5	0.27	0.56
May	3	35.7	0.30	0.66
SAUK RIVER				
1976				
April	9	36.3	0.26	0.54

to February 27 in the Cascade, from April 23 to May 21 in the Sauk, and on April 17 in Diobsud Creek (Table 8.35). In the 1976 sampling by FRI, chum fry of the 1975 brood were taken from early March to early June in the Skagit and late March to early June in the Sauk (Table 8.36). One chum fry was caught in the Cascade River in early April 1976. The flood of December 1975 probably caused the abundance of the 1975 brood to be low. Chum fry were more available to electrofishing in the upper Skagit River in 1977 (Table 8.37), and were taken from early March until mid-June, with peak abundance in April-May (Fig. 8.44). Chum fry were captured in the Sauk River in small numbers from late March until early June. Only three chum fry were captured in the Cascade River in 1973. No chum fry were taken in the weekly sampling in Goodell, Bacon, and Diobsud creeks.

8.4.3.2 Chum Salmon Fry Size and Condition after Emergence. Table 8.35 presents the mean length, weight, and condition factor data for chum fry of the 1973 brood caught in 1974. The samples were too small to detect time and area differences. Mean lengths, weights, and condition factors of the 1976 samples (Table 8.38) showed a tendency to increase over the months of March through May. Fry from the Sauk River samples averaged slightly longer and heavier than those from Skagit River samples from March through May.

8.4.3.3 Chum Salmon Fry Diet. Few fish from the 1975 brood were available for stomach analysis and these were all caught from April through June 1976 (Table 8.39). Eight of the Skagit River chum fry for stomach sample analysis were captured downstream at the Concrete Station. Four captured at Marblemount on May 4 had empty guts and fully absorbed yolk. Chironomids were the most important element in the freshwater diet. A few Ephemeroptera nymphs, Plecoptera nymphs, and Trichoptera larvae were also found. No zooplankton were found in these stomachs.

8.4.4 Coho Salmon Fry

8.4.4.1 Coho Salmon Fry Availability. Because coho are late season spawners and spawn primarily in the tributaries, fry tend not to be encountered in the upper Skagit River until April. Fry first appear in the tributaries and the later buildup in the mainstem river is apparently a result of redistribution from the tributaries. In 1973, Skagit River sampling by WDF of coho fry of the 1972-1973 brood were first encountered on April 13. Coho fry broods encompass two years since the spawning starts in December of one year and carries over into the next year. In sampling in 1974 by FRI, coho fry of the 1973-1974 brood were first encountered in the mainstem Skagit near County Line and in Goodell Creek on March 25; they first appeared in catches in Diobsud and Bacon creeks by early April, and by late April at the rest of the sites (Tables 8.40 through 8.47). Early samples tend to be small partly because of initial low effort on coho fry collection. Although coho fry were still present, the sampling was not continued into the fall of 1974.

In the 1975-1976 brood the coho fry in the creeks other than Diobsud Creek and in the Cascade River preceded appearance of coho fry in the mainstem Skagit and Sauk (Table 8.48). In the 1976-1977 brood, this

Table 8.35 Mean lengths, weights, and condition factors of chum salmon fry captured by electroshocking, 1973 brood.

Location	Date	Number of fry	Length (mm) Range	Length (mm) Mean	Mean weight (g)	Mean condition factor
	1974					
Skagit River near Talc Mine	Apr 9	2	40-41	40.5	0.48	0.72
	Apr 17	3	37-38	37.3	0.40	0.77
Skagit River near Marblemount	Apr 23	1	40	40	0.5	0.8
	May 7	4	37-41	39.0	0.40	0.68
	May 20	3	44-45	44.3	0.62	0.71
Cascade River	Feb 2	2	37	37.0	0.40	0.79
	Feb 27	1	34	34	0.2	0.5
Sauk River	Apr 23	2	36-37	36.5	0.40	0.82
	May 7	20	37-40	38.9	0.46	0.78
	May 21	6	37-40	38.2	0.38	0.68
Diobsud Creek	Apr 17	1	40	40	0.45	0.70

Table 8.36 Chum fry catches at Skagit Basin sampling sites using electrofisher, 1975 brood.

Date	Skagit River at County Line	Skagit River at Talc Mine	Skagit River at Marble-mount	Skagit River at Rock-port	Cascade River	Sauk River	Goodell Creek	Bacon Creek	Diobsud Creek
1976									
2/22 -2/28	-	-	-	-	-	-	-	-	-
2/29 -3/6	-	-	-	-	-	-			-
3/7 -3/13	1	-	-		-	-	-	-	
3/14 -3/20	2	-	5	-	-	-	-	-	-
3/21 -3/27	3	-	-	-	-	-	-	-	-
3/28 -4/3	4	-	2	28	-	1	-	-	-
4/4 -4/10	-	-	-	1	1	5	-	-	-
4/11 -4/17	-	-	23	3	-	7	-	-	-
4/18 -4/24	-	-	34	6	-	9	-	-	-
4/25 -5/1	-	-	-	4	-	9	-	-	-
5/2 -5/8	-	-	3	-	-	2	-	-	-
5/9 -5/15	-	1	-	-	-	1		-	-
5/16 -5/22	-	2	1	1	-	5	-	-	-
5/23 -5/29	-	-	-	1	-	1	-	-	-
5/30 -6/5	-	-	-	2	-	1			
6/6 -6/12	-	-	-	-	-	-	-	-	-
6/13 -6/19	-	-	-	-	-	-	-	-	

Note: dash (-) signifies catch was zero.
blank signifies sampling not conducted.

Table 8.37 Chum fry catches at Skagit Basin sampling sites using electrofisher, 1976 brood.

Date	Skagit River at County Line	Skagit River at Talc Mine	Skagit River at Marble-mount	Skagit River at Rock-port	Cascade River	Sauk River	Goodell Creek	Bacon Creek	Diobsud Creek
1977									
2/20 -2/26	-	-	-	-	-	-	-	-	-
2/27 -3/5	-		-	2	-	-	-	-	-
3/6 -3/12	-	-	-	-	-	-	-	-	-
3/13 -3/19	1	1	1	3	-	-	-	-	-
3/20 -3/26	3	-	-	13	-	1	-	-	-
3/27 -4/2	14	-	9	54	-	3	-	-	-
4/3 -4/9	61	14	32	191	-	-	-	-	-
4/10 -4/16	17	4	19	94	-	1	-	-	-
4/17 -4/23	6	65	6	219	2	6	-	-	-
4/24 -4/30	20	19	6	16	-	1	-	-	-
5/1 -5/7	40		12	40	1	1	-	-	-
5/8 -5/21	10	36	51	88	-	8	-	-	-
5/22 -6/4	1	3	1	21	-	1	-	-	-
6/5 -6/18	-	2	3	16	-	1	-	-	-
6/19 -7/2	-	-	-	-	-	-	-	-	-

Note: dash (-) signifies catch was zero.
blank signifies sampling not conducted.

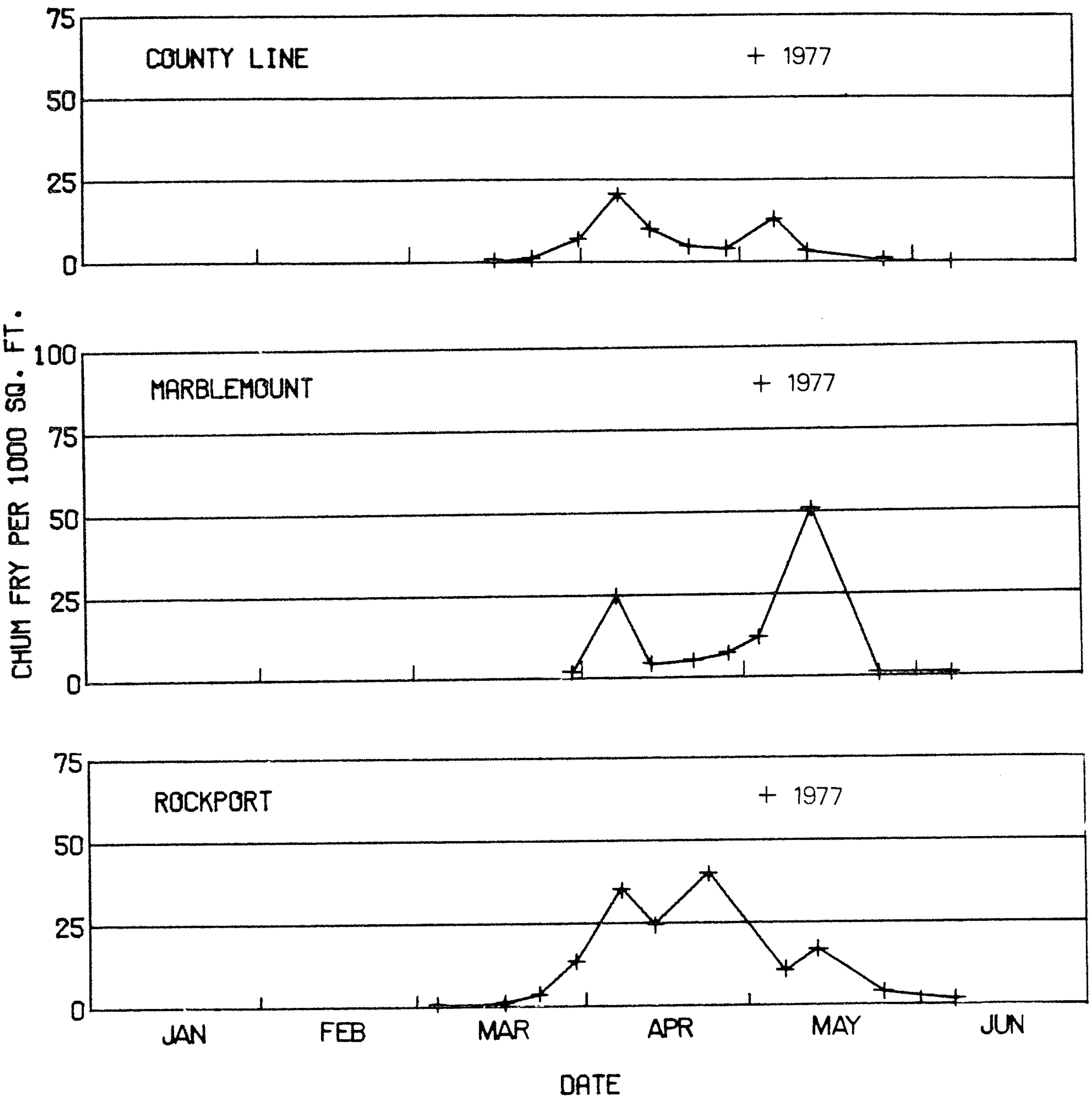

Fig. 8.44 Chum salmon availability at Skagit River sampling sites from standardized electrofishing effort, 1977.

Table 8.38 Mean lengths, weights, and condition factors of Skagit and Sauk rivers chum salmon fry captured by electroshocking, 1975 brood.

Month	Number of fish	Mean length (mm)	Mean weight (g)	Condition factor
SKAGIT RIVER				
1976				
March	45	35.1	0.25	0.58
April	62	38.5	0.38	0.67
May	6	39.7	0.46	0.74
June	2	38.5	0.36	0.63
SAUK RIVER				
1976				
March	1	38	0.28	0.51
April	30	39.3	0.41	0.68
May	9	42.4	0.56	0.73

Table 8.39 Chum fry stomach contents, 1975 brood, April through June, 1976.

River:	Cascade	Sauk		Skagit(combined)	
Number of stomachs examined	0	1		12	
Fry with empty gut and yolk		0		0	
Fry with non-empty gut and yolk		0		3	
Fry with empty gut and no yolk		0		4	
Fry with non-empty gut and no yolk		1		5	
Organism		Total no.	% occur	Total no.	% occur
Diptera					
Chironomid larvae		9	31	196	84
Chironomid pupae				3	1
Chironomid adults		16	55	22	9
Other aquatic Diptera				1	< 1
Ephemeroptera nymphs		4	14	3	1
Plecoptera nymphs				2	< 1
Trichoptera larvae				3	1
Miscellaneous and unknown				4	2

Table 8.40 Mean lengths, weights, and condition factors of Skagit River coho fry captured by electroshocking at sites near County Line, 1973-74 brood.

Date	Number of fry	Length (mm) Range	Length (mm) Mean	Mean weight (g)	Mean condition factor
1974					
Mar 25	1	35	35	0.3	0.7
Apr 8	8	35-39	36.7	0.46	0.93
10	2	35	35.0	0.40	0.93
17	1	35	35	0.35	0.82
24	3	34-39	37.1	0.43	0.86
May 6	5	35-37	35.8	0.38	0.84
8	1	37	37	0.3	0.6
21	1	38	38	0.3	0.5
21	3	35-38	36.7	0.43	0.88
Jun 13	3	33-36	35.0	0.57	1.30
Jul 3	7	34-41	37.3	0.73	1.36
3	1	34	34	0.8	2.0
Aug 15	22	34-58	43.3	1.16	1.31

Table 8.41 Mean lengths, weights, and condition factors of Skagit River coho fry captured by electroshocking near Talc Mine, 1973-74 brood.

Date	Number of fry	Length (mm) Range	Length (mm) Mean	Mean weight (g)	Mean condition factor
1974					
Apr 17	2	34	34.0	0.35	0.89
23	1	39	39	0.4	0.7
May 7	2	35-36	35.5	0.40	0.90
20	1	35	35	0.3	0.7
Jun 13	1	35	35	0.5	1.2
Jul 5	22	31-50	36.9	0.54	0.98
Aug 15	11	35-51	46.8	-	-
Sep 4	9	40-63	47.9	1.31	1.07

Table 8.42 Mean lengths, weights, and condition factors of Skagit River coho fry captured by electroshocking near Marblemount, 1973-74 brood.

Date	Number of fish	Length (mm) Range	Length (mm) Mean	Mean weight (g)	Mean condition factor
1974					
Apr 17	1	33	33	0.3	0.8
May 5	1	37	37	0.4	0.8
Jun 12	12	33-38	35.7	0.40	0.88
Jul 2	18	31-42	36.5	0.52	0.99
Aug 15	10	34-53	39.5	-	-

Table 8.43 Mean lengths, weights, and condition factors of Cascade River coho fry captured by electroshocking, 1973-74 brood.

Date	Number of fish	Length (mm)		Mean weight (g)	Mean condition factor
		Range	Mean		
1974					
Apr 23	3	34-35	34.7	0.35	0.84
May 7	5	32-36	34.2	0.37	0.92
21	21	31-40	34.7	0.32	0.77
Jun 12	9	32-34	33.5	0.41	1.09
Jul 2	16	32-43	37.8	0.62	1.10
Aug 9	15	35-62	45.7	1.21	1.21

Table 8.44 Mean lengths, weights, and condition factors of Sauk River coho fry captured by electroshocking, 1973-74 brood.

Date	Number of fish	Length (mm) Range	Length (mm) Mean	Mean weight (g)	Mean condition factor
1974					
Apr 23	6	33-39	36.2	0.48	1.02
May 21	3	35-36	35.7	0.40	0.88
Jun 13	2	32-33	32.5	0.50	1.46
Jul 3	2	41-42	41.5	1.10	1.54
Aug 9	7	47-60	54.0	2.06	1.28

Table 8.45 Mean lengths, weights, and condition factors of Goodell Creek coho fry captured by either electroshocking or fyke netting, 1973-74 brood.

Date	Number of fish	Length (mm) Range	Length (mm) Mean	Mean weight (g)	Mean condition factor
1974					
Mar 25	26	33-39	36.5	0.39	0.79
Apr 8	28	33-39	35.8	0.38	0.86
10*	57	30-38	34.6	0.37	0.89
10	19	33-39	35.9	0.47	1.00
17	28	34-39	36.2	0.41	0.86
24	30	34-40	36.9	0.43	0.87
May 6	38	32-42	35.3	0.38	0.83
20	29	33-41	37.5	0.49	0.92
21*	34	31-38	34.9	0.36	0.84
Jul 2	32	31-52	36.4	0.53	0.98
Aug 9	3	31-40	34.7	0.57	1.33
15	21	36-44	39.4	0.80	1.27

*fyke net samples

Table 8.46 Mean lengths, weights, and condition factors of Bacon Creek coho fry captured by either electroshocking or fyke netting, 1973-74 brood.

Date	Number of fish	Length (mm) Range	Length (mm) Mean	Mean weight (g)	Mean condition factor
1974					
Apr 9*	59	32-39	35.7	0.32	0.70
10*	33	33-38	35.1	0.31	0.71
10	10	31-35	33.1	0.36	0.99
17	16	32-37	34.7	0.39	0.94
23	14	33-40	35.7	0.36	0.79
May 8	12	33-38	36.0	0.40	0.84
20	21	32-37	34.9	0.35	0.83
21*	43	34-40	36.4	0.38	0.78
Jun 13	9	31-41	35.3	-	-
Jul 3	48	31-50	35.4	0.45	0.98
18	11	33-51	37.6	0.60	1.01
25*	7	32-36	34.3	0.44	1.09
Aug 1	3	32-35	34.0	0.37	0.94
9	3	35-36	35.3	0.53	1.20
15	10	37-47	39.8	-	-

*fyke net samples

Table 8.47 Mean lengths, weights, and condition factors of Diobsud Creek coho fry captured by either electroshocking or fyke netting, 1973-74 brood.

Date	Number of fish	Length (mm) Range	Length (mm) Mean	Mean weight (g)	Mean condition factor
1974					
Apr 10*	2	32-34	33.0	0.40	1.12
10	1	37	37	0.5	1.0
17	4	34-39	36.7	0.39	0.79
23	1	36	36	0.3	0.6
May 8	3	37-39	38.0	0.43	0.78
20	11	33-37	35.8	0.39	0.86
Jun 13	12	33-37	34.2	0.41	1.03
Jul 2	12	33-38	35.0	0.38	0.90
18*	3	34-37	36.0	0.47	1.00
25	11	32-36	34.0	0.38	0.97
Aug 9	17	31-38	34.0	0.37	0.92

*fyke net samples

Table 8.48 Coho fry catches at Skagit Basin sampling sites using electrofisher, 1975-76 brood.

Date	Skagit River at County Line	Skagit River at Talc Mine	Skagit River at Marble-mount	Skagit River at Rock-port	Cascade River	Sauk River	Goodell Creek	Bacon Creek	Diobsud Creek
1976									
2/22 -2/28	-	-	-	-	-	-	-	-	-
2/29 -3/6	-	-	-	-	2	-			-
3/7 -3/13	-	-	-		11	-	3	25	
3/14 -3/20	-	-	-	-	27	-	4	25	-
3/21 -3/27	-	-	-	-	25	-	8	31	-
3/28 -4/3	-	-	-	-	24	-	19	26	-
4/4 -4/10	-	-	-	-	31	1	29	28	-
4/11 -4/17	-	-	-	1	24	1	40	28	18
4/18 -4/24	2	2	22	1	35	3	22	25	-
4/25 -5/1	2	-	4	-	48	1	31	26	-
5/2 -5/8	2	-	-	2	50	10	26	38	-
5/9 -5/15	2	-	-	4	29	9		33	-
5/16 -5/22	16	-	-	-	27	3	25	24	1
5/23 -5/29	-	-	2	7	24	4	25	25	-
5/30 -6/5	40	-	14	6	67	36			
6/6 -6/12	16	3	26	4	29	3	38	25	4
6/13 -6/19	34	5	26	7	33	10	24	26	
6/20 -6/26	45	8	23	10	50	41	25	28	-
6/27 -7/3	45	3	10	-	42	31	28	27	3
7/4 -7/10	32	17	8		51	3	25	32	
7/11 -7/17	23	1	18		32	7	27	28	27
7/18 -7/24	1		22	25	26	-	39	29	24
7/25 -7/31	14		34	25	35	7	26	29	29
8/1 -8/7	33		38	37	36	11	26	28	32
8/8 -8/14	29	4	25	25	25	4	26	29	
8/15 -8/28	24	14	25	25	25	9	29	34	30
8/29 -9/11	16	31	28	33	23	7	-	27	36
9/12 -9/25	25	28	32		26	2	26	12	26
9/26 -10/9		5	5	4	5	-			
10/10-10/23	10	10	24	9	5	-	3	27	34
10/24-11/6	26	1	30	30	14	-	5	34	33
11/7 -11/20	13	17	27	9	12	2	-	11	11
11/21-12/4	15	14	21	11	17	23	-	14	15
12/5 -12/11	14	6	10	9	11	8	-	10	12
12/12-12/18	19	5	7	15	9	-	-	11	15
12/19-12/25	14	7	2	12	10	-	1	12	-
12/26-1/1	10	3	4	7	2	-	-	15	2
1977									
1/2 -1/8	1	10	6	-	11	-	-	13	-
1/9 -1/15	-	-	-	-	1	-	-	5	5
1/16 -1/22	7	-	-	2	7	-	1	-	4
1/23 -1/29	-	-	-	-	-	1	1	-	4
1/30 -2/5	-	-	-	-	-	-	8	6	2

Table 8.48 Coho fry catches at Skagit Basin sampling sites using electrofisher, 1975-76 brood - continued.

Date	Skagit River at County Line	Skagit River at Talc Mine	Skagit River at Marble-mount	Skagit River at Rock-port	Cascade River	Sauk River	Goodell Creek	Bacon Creek	Diobsud Creek
1977									
2/6 -2/12	-	-	-	-	-	-	-	-	-
2/13 -2/19	2	-	-	-	-	-			
2/20 -2/26	-	-	-	-	-	-	1	3	1
2/27 -3/5	-		-	-	-	-	-	-	2
3/6 -3/12	-	-	-	-	2	-	-	1	1
3/13 -3/19	-	-	-	-	1	1	-	-	-
3/20 -3/26	-	-	-	-	-	-	1	-	-
3/27 -4/2	-	3	-	-	-	-	-	-	1
4/3 -4/9	-	-	-	-	-	1	-	-	-
4/10 -4/16	-	1	-	-	-	-	-	-	-
4/17 -4/23	-	-	-	-	-	1	-	-	-
4/24 -4/30	-	1	-	-	1	-	-	-	-
5/1 -5/7	-		-	-	-	-	-	1	-
5/8 -5/21	-	-	-	-	-	-	-	1	-
5/22 -6/4	-	-	-	-	-	-	-	-	-

Note: dash (-) signifies catch was zero.
blank signifies sampling not conducted.

pattern suggesting first emergence in the smaller tributaries and redistribution into the Skagit and Sauk rivers was generally repeated although sporatic early catches in the Skagit and Sauk made this trend less distinct (Table 8.49).

Tables 8.48 and 8.49 show the extended freshwater rearing stage inherent to the species. Coho fry from broods which emerged in February through March of one year were still present at the sampling sites more than a year later. Catches of these older fry with the electrofisher are disproportionately lower than their abundance because the older coho tend to take up feeding stations somewhat beyond the range of the backpack electrofisher. Large fry were observed in January and February 1977, around the Newhalem incubation boxes in 4 to 6 ft of water in the backwater of a submerged log. The timing of downstream migration is difficult to pinpoint because of this decreasing effectiveness of the gear to older fry, but catch data (Tables 8.48 and 8.49) indicated that fry disappeared from the sampling sites during the spring of their second year.

8.4.4.2 Coho Salmon Fry Size and Condition after Emergence. Mean lengths, weights, and condition factors of coho fry from the 1973-1974 brood are presented in Tables 8.40 through 8.47. Fry from most sites showed some increase in size and condition with time.

Length and weight data for coho fry of the 1975-1976 brood (Figs. 8.45 and 8.46) showed patterns similar to chinook data. From first appearance through June for Cascade and Sauk fry and through July for Skagit (Marblemount) fry, length and weight were fairly constant or increased slightly. After those respective dates, the two parameters increased at all three sites, with the values for the Sauk samples increasing most rapidly, for the Skagit (Marblemount) least rapidly, and at an intermediate rate for the Cascade. The sharp dip in both length and weight for fry from the Cascade and Sauk rivers during late November (November 24) corresponds with a day when natural flows were increasing rapidly because of rain (Fig. 2.5) and resulted in either reduced sampling efficiency or reduced availability of the larger fry, or both.

Condition factors (Fig. 8.47) showed more variability than length or weight. For the period from March through September, mean condition factor at Cascade and Sauk sites increased and thereafter appeared to level off or decrease slightly to about 1.2. Skagit (Marblemount) coho condition factor was fairly constant from April through July, increased from August to October, and then leveled off at values similar to those for Cascade and Sauk coho fry. Even though condition factors were comparable for this latter period, Cascade and Sauk river fry were longer and heavier. The reduced size and availability of Sauk River coho fry during late November and December indicated that larger fry may have been able to avoid capture or may have moved to faster flowing and deeper rearing habitats outside the range of the backpack electroshocker.

The differences in growth patterns of coho fry between the three rivers appear to reflect benthic insect density (Figs. 3.15 and 3.16) in

Table 8.49 Coho fry catches at Skagit Basin sampling sites using electrofisher, 1976-77 brood.

Date	Skagit River at County Line	Skagit River at Talc Mine	Skagit River at Marble-mount	Skagit River at Rock-port	Cascade River	Sauk River	Goodell Creek	Bacon Creek	Diobsud Creek
1977									
1/25 -1/29	-	-	-	-	-	-	-	-	-
1/30 -2/5	-	-	-	-	1	-	-	-	-
2/6 -2/12	1	-	-	-	4	1	-	-	6
2/13 -2/19	-	-	-	-	-	-			
2/20 -2/26	-	-	1	-	-	-	-	-	-
2/27 -3/5	-		-	-	-	-	3	-	-
3/6 -3/12	-	-	-	-	-	-	-	-	-
3/13 -3/19	-	-	-	-	-	-	8	1	-
3/20 -3/26	-	-	-	-	1	-	2	-	-
3/27 -4/2	2	1	-	-	-	-	4	1	-
4/3 -4/9	-	2	2	-	35	1	10	-	-
4/10 -4/16	2	-	1	-	31	-	15	30	1
4/17 -4/23	1	2	-	1	28	-	11	10	-
4/24 -4/30	6	4	5	7	40	1	29	11	1
5/1 -5/7	5		2	3	40	15	22	22	2
5/8 -5/21	1	20	1	15	36	3	22	13	7
5/22 -6/4	62	39	1	57	42	37	16	15	11
6/5 -6/18	143	39	10	26	32	46	16	17	13
6/19 -7/2	75	39	29	15	46	34	16	14	9
7/3 -7/16	67	31	28	31	30	31	12	12	12
7/17 -7/30	117	49	60	27	41	49	12	19	17
7/31 -8/13	90	36	32	25	25	16	12	16	11
8/14 -8/27	68	39	28	18	25	9	12	10	16
8/28 -9/3	79	24	29	25	45	-			
9/20 -9/21	46	37	17	9	38	5			
10/19-10/22	83	5	17	3	37	-			
11/18-11/20	24	36	13	24	20	4			
12/15-12/20	-	8	1	-	21	-			
1978									
1/11	-		-	-					
1/18 -1/22	-	-	-	-	-	-			
2/1	-		-	-					
2/10	-		-	-					
2/17	-		-	-					
2/24 -2/26	-	-	-	-	-	-			
3/3	-		-	-					
3/10	-		-	-					
3/17	-		-	-					
3/24 -3/27	-	-	-	-	5	1			
3/31	-		-	-					
4/7	1		-	-					

Note: Dash (-) signifies catch was zero.
Blank signifies sampling not conducted.

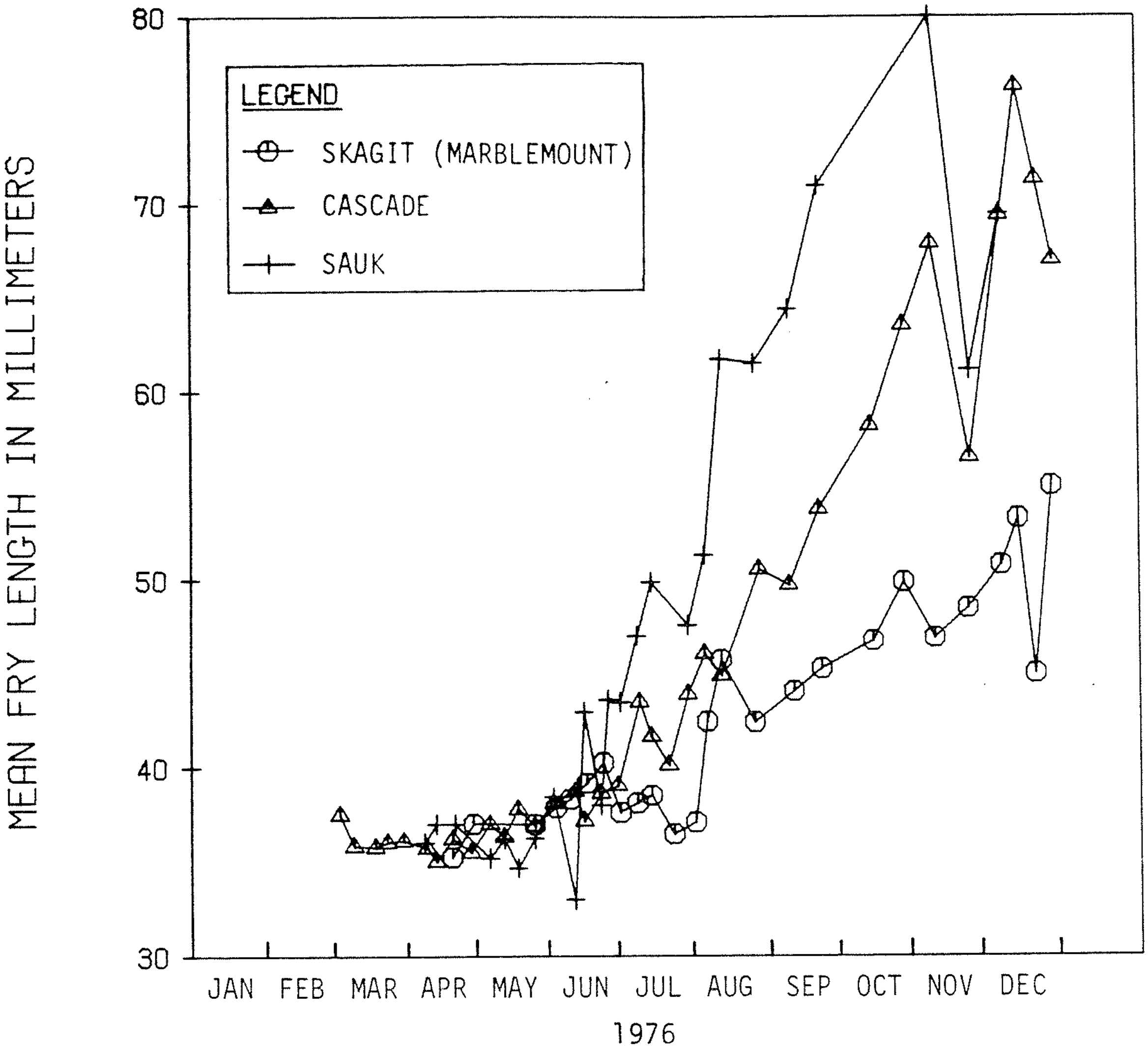

Fig. 8.45 Mean lengths of Skagit, Cascade, and Sauk coho fry taken by electrofishing, 1975-76 brood.

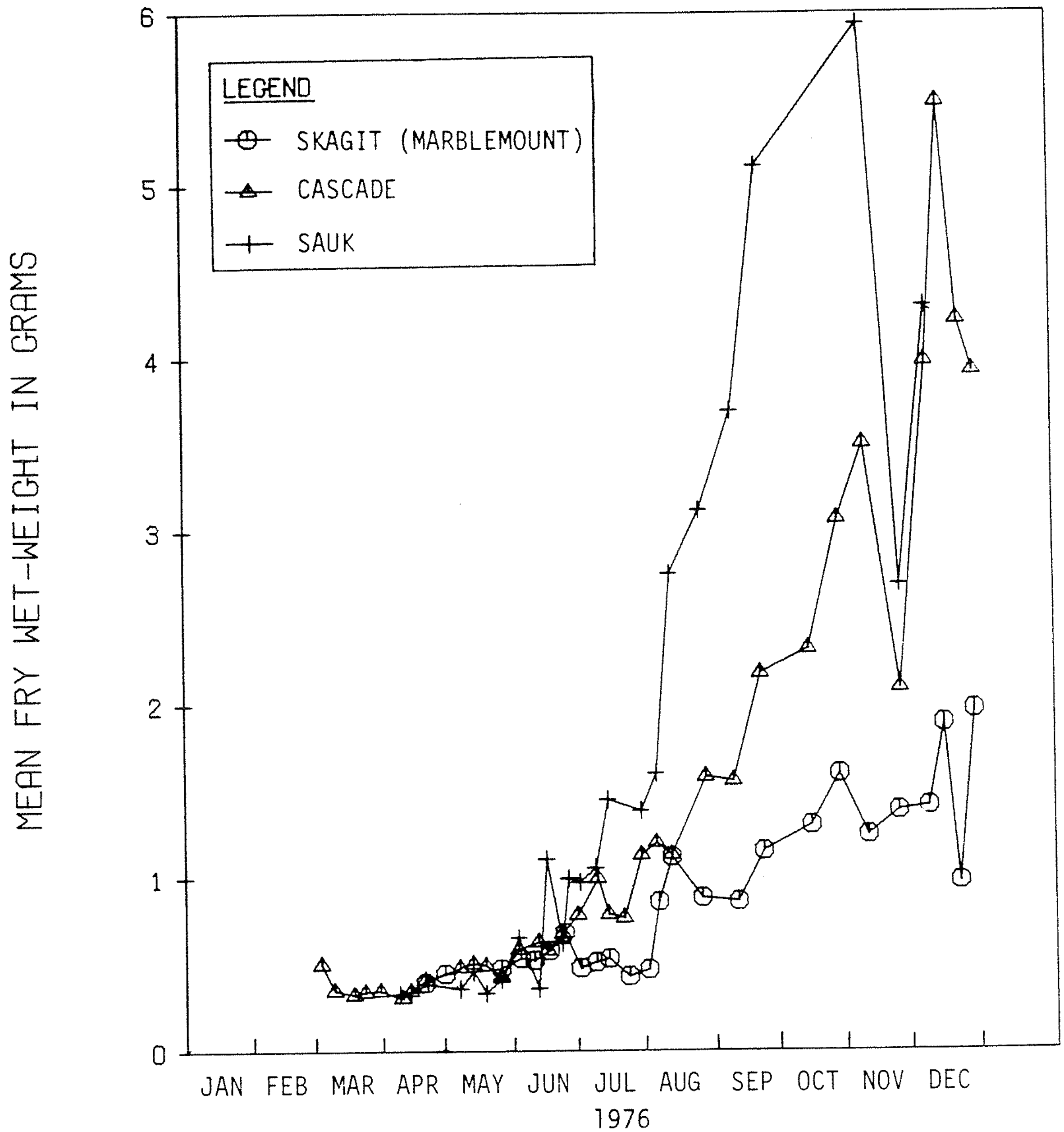

Fig. 8.46 Mean wet weights of Skagit, Cascade, and Sauk coho fry taken by electrofishing, 1975-76 brood.

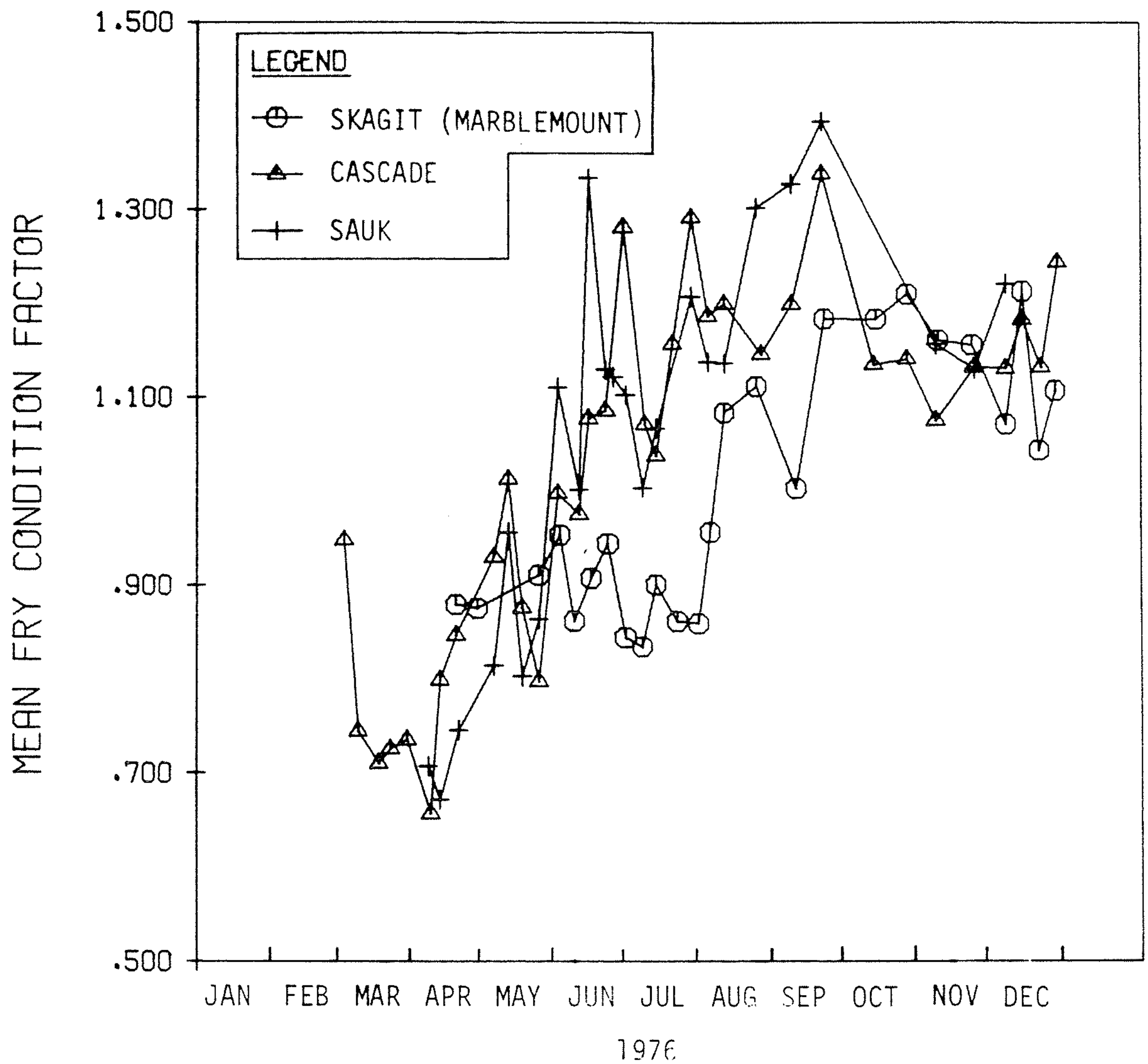

Fig. 8.47 Mean condition factors of Skagit, Cascade, and Sauk coho fry taken by electrofishing, 1975-76 brood.

the three rivers for the periods for which data are available. They do not correlate well with water temperature data for 1976. From May through September, Skagit (at Alma Creek) water temperature was intermediate to Sauk (warmer) and Cascade (cooler) water temperatures, and after mid-October was warmer than both (Fig. 2.26). Comparative water quality in the different rivers may also be a factor.

8.4.4.3 Coho Salmon Fry Diet. The stomach samples that have been analysed from the 1975-1976 brood of coho fry were collected from May or June through August 1976 at the Skagit stations (Tables 8.50-8.53), from March to September 1976 from the Cascade River (Table 8.54), and from June to August 1976 from the Sauk River (Table 8.55). Coho fry stomach samples were unattainable from the Concrete Station on the Skagit River.

As with chinook fry, dipterans were the main diet by numbers in the Skagit, Cascade, and Sauk rivers. Ephemeroptera nymphs were also important in the diet of coho fry (Table 8.56). Coho fry from the Skagit were feeding on zooplankton released from the hydropower reservoirs, and the contribution of zooplankton to their diet is highest at the site closest to Gorge Dam (Tables 8.50-8.53). No zooplankton were found in Sauk or Cascade samples (Tables 8.54 and 8.55). The peak incidence of zooplankton in coho stomachs was in August. However, crustacean zooplankton in the Skagit River below the hydropower reservoirs (Sec. 4.0) showed a peak in density in May and another in October to December 1977.

Only two early coho fry from the Cascade River and one at Rockport had some residual yolk. One from the Cascade River had some unidentifiable matter in the gut. The other two with residual yolk had empty guts. This may indicate that most coho fry remain in the gravel until their yolk is absorbed or that their early post-emergence period is spent in smaller tributaries.

8.4.5 Rainbow-Steelhead Trout Fry

8.4.5.1 Rainbow-Steelhead Trout Fry Availability. Because of the late winter-spring timing of rainbow-steelhead spawning, fry were not abundant until summer (Tables 8.57-8.59). In 1976 (Table 8.58), fry were found as early as mid-June but were not numerous in the mainstem Skagit River stations above the Sauk until August. Fry were abundant in the Sauk River several weeks before other sites. Yearlings from the 1976 brood were still present at all stations except Diobsud Creek at least to July 1977. In the mainstem Skagit, the juveniles of the 1976 brood were less available during much of 1977 than at many of the other stations.

Fry from the 1977 brood emerged much earlier than fry from the 1976 brood (Tables 8.58 and 8.59). This is the largest observed advancement in emergence timing of any of the salmonid species in the study area. There was even a later observed peak of spawning in 1977 in the Skagit River (Sec. 5.4.2.5). Rainbow-steelhead, being spring spawners, may have a different degree or direction of compensation than do the salmon species in temperature units required for emergence under different incubation temperatures. Sampling was continued at three Skagit sites into June 1978

Table 8.50 Coho fry stomach contents, Skagit River at County Line, 1975-76 brood.

Date, 1976:	3 May	3 Jun	1 Jul	4 Aug	31 Aug	Totals #	Totals %
Number of fry:	1	5	5	5	0	16	
Diptera							
Chironomid larvae		9	112	16		137	31%
Chironomid pupae			1			1	< 1
Chironomid adults	3	19		15		37	8
Other aquatic Diptera		2	2			4	< 1
					Subtotal	179	41%
Ephemeroptera							
Baetid nymphs	1	10	7	106		124	28%
Heptagenid nymphs		31	13	12		56	13
					Subtotal	180	41%
Plecoptora							
Nymphs				12		12	3%
Adults		1	1			2	< 1
					Subtotal	14	3%
Trichoptera							
Larvae				2		2	< 1%
Plankton							
Diaptomus			5			5	1%
Daphnia			11			11	2
Bosmina			5	41		46	10
Other			1			1	< 1
					Subtotal	63	14%
Terrestrial invertebrates							
Collembola							
Aphids							
Other							
Misc. and unknown		2				2	< 1%
Total						440	100%

Table 8.51 Coho fry stomach contents, Skagit River at Talc Mine, 1975-76 brood.

Date, 1976:	3 May	1 Jun	2 Jul	--	2 Sept	Totals #	Totals %
Number of fry:	0	0	1		5	6	
Diptera							
Chironomid larvae			3		6	9	20%
Chironomid pupae					1	1	2
Chironomid adults			1		3	4	9
Other aquatic Diptera			1		3	4	9
					Subtotal	18	40%
Ephemeroptera							
Baetid nymphs							
Heptagenid nymphs							
Unidentified nymphs							
Plecoptera							
Nymphs					5	5	11%
Adults					1	1	2
					Subtotal	6	13%
Trichoptera							
Larvae					1	1	2%
Plankton							
Diaptomus							
Daphnia							
Bosmina							
Other							
Terrestrial invertebrates							
Collembola							
Aphids			1		4	5	11%
Other			1		3	4	9
					Subtotal	9	20%
Misc. and unknown			1		10	11	24%
Total						45	100%

Table 8.52 Coho fry stomach contents, Skagit River at Marblemount, 1975-76 brood.

Date, 1976:	4 May	2 Jun	--	4 Aug	2 Sept	Totals #	Totals %
Number of fry:	0	5		5	4	14	
Diptera							
Chironomid larvae		31		2	3	36	31
Chironomid pupae		1		1	1	3	3
Chironomid adults		2		5	12	19	16
Other aquatic Diptera				4		4	3
					Subtotal	62	53
Ephemeroptera							
Baetid nymphs		16				16	14
Heptagenid nymphs		1		5		6	5
Unidentified nymphs							
					Subtotal	22	19
Plecoptera							
Nymphs		9		2	1	12	10
Adults							
Trichoptera							
Larvae				2		2	2
Plankton							
Diaptomus							
Daphnia		1				1	< 1
Bosmina				3		3	3
Other							
					Subtotal	4	3
Terrestrial invertebrates							
Collembola							
Aphids		3				3	3
Other		1		7		8	7
					Subtotal	11	9
Misc. and unknown		2		1		3	3
Total						116	100

Table 8.53 Coho fry stomach contents, Skagit River at Rockport, 1975-76 brood.

Date, 1976:	--	1 Jun	--	5 Aug	Totals	
					#	%
Number of fry:		5		5	10	
Diptera						
Chironomid larvae		2		32	34	29
Chironomid pupae				6	6	5
Chironomid adults		1		39	40	34
Other aquatic Diptera		3		2	5	4
Subtotal					85	72
Ephemeroptera						
Baetid nymphs		1		3	4	3
Heptagenid nymphs						
Unidentified nymphs		1			1	< 1
Subtotal					5	4
Plecoptera						
Nymphs				4	4	3
Adults						
Trichoptera						
Larvae				1	1	< 1
Plankton						
Diaptomus						
Daphnia		2			2	2
Bosmina						
Other						
Terrestrial invertebrates						
Collembola		2		2	4	3
Aphids						
Other		1			1	< 1
Subtotal					5	4
Misc. and unknown		4		12	16	14
Total					118	100

Table 8.54 Coho fry stomach contents, Cascade River, 1975-1976 brood.

Date, 1976:	2 Mar	5 Apr	10 May	1 Jun	30 Jun	--	5 Aug	1 Sep	Totals #	Totals %
Number of fry:	2	5	3	5	3		3	5	26	
Diptera										
Chironomid larvae	26	5	4	12	11		4	7	69	17%
Chironomid pupae		2						22	24	6
Chironomid adult	3	32	19	29	62		28	26	199	50
Other aquatic Diptera	1	6	2	1				13	23	6
							Subtotal		315	79%
Ephemeroptera										
Baetid nymphs	2	2	2	5	3		3		17	4%
Heptagenid nymphs	3		1	1			1		6	2
							Subtotal		23	6%
Plecoptera										
Nymphs	6	1		1	1		1	6	16	4%
Adult		1						1	2	< 1
							Subtotal		18	4%
Tricoptera										
Larvae		2	1	1	1			1	6	2%
Plankton										
Terrestrial invertebrates										
Collembola	2	3							5	1%
Aphids								4	4	1
Other				1	1			17	19	5
							Subtotal		28	7%
Misc. and unknown			7		3				10	2%
Total									400	100%

Table 8.55 Coho fry stomach contents, Sauk River, 1975-76 brood.

Date, 1976:	--	1 Jun	30 Jun	5 Aug	--	Totals #	Totals %
Number of fry:		3	1	5		9	
Diptera							
Chironomid larvae		7	6	19		32	18
Chironomid pupae				3		3	2
Chironomid adult		6	2	66		74	43
Other aquatic Diptera				4		4	2
				Subtotal		113	65
Ephemeroptera							
Baetid nymphs		9		1		10	6
Heptagenid nymphs		11				11	6
				Subtotal		21	12
Plecoptera							
Nymphs		1		1		2	1
Adults							
Trichoptera							
Larvae		1				1	< 1
Plankton							
Terrestrial invertebrates							
Collembola			1	7		8	5
Aphids			11	4		15	9
Other				14		14	8
				Subtotal		37	21
Misc. and unknown							
Total						174	100

Table 8.56 Coho fry stomach contents, 1975-76 brood, summary of sites, February through August 1976.

River:	Cascade		Sauk		Skagit, all sites	
Number of fry:	26		9		46	
	#	%	#	%	#	%
Diptera						
Chironomid larvae	69	18	32	18	216	29
Chironomid pupae	24	6	3	2	6	< 1
Chironomid adults	199	51	74	43	100	13
Other aquatic Diptera	16	4	4	2	17	2
Subtotal	308	78	113	65	339	45
Ephemeroptera						
Baetid nymphs	18	5	10	6	140	19
Heptagenid nymphs	6	2	11	6	62	8
Unidentified nymphs	--		--		4	< 1
Subtotal	24	6	21	12	206	27
Plecoptera						
Nymphs	16	4	2	1	33	4
Adults	2	< 1	--		3	< 1
Subtotals	18	4	2	1	36	5
Trichoptera						
Larvae	6	2	1	< 1	6	< 1
Plankton						
Diaptomus	--		--		5	< 1
Daphnia	--		--		14	2
Bosmina	--		--		49	7
Other	--		--		1	< 1
Subtotal					69	10
Terrestrial invertebrates						
Collembola	5	1	8	5	4	< 1
Aphids	4	1	15	9	9	1
Other	19	5	14	8	13	2
Subtotal	28	7	37	21	26	3
Misc. and unknown	10	2			33	4
Total	394	100	174	100	751	100

Table 8.57 Mean lengths, weights, and condition factors of rainbow-steelhead fry captured by either electroshocking or fyke netting, 1974 brood.

Location	Date	Number of fish	Length (mm) Range	Mean	Mean weight (g)	Mean condition factor
	1974					
Skagit River near Newhalem	Aug 15	5	31-40	34.8	0.40	0.90
	15	6	33-36	34.2	0.32	0.80
Skagit River near Talc Mine	Jul 5	2	31-33	32.0	0.30	0.92
	Aug 15	11	29-39	33.2	-	-
	Sep 4	24	29-44	36.0	0.53	1.06
Skagit River near Marblemount	Jul 2	3	32	32.0	0.33	1.01
	Aug 15	17	29-35	31.9	-	-
Cascade River	Jul 2	7	29-31	30.0	0.26	0.95
	Aug 9	20	31-41	32.9	0.30	0.80
Sauk River	Jul 3	22	28-37	31.5	0.35	1.12
	Aug 9	21	28-52	39.0	0.72	1.10
Goodell Creek	Aug 1	1	31	31	0.3	1.0
	9	2	30-32	31.0	0.40	1.35
	15	7	34-44	37.7	0.57	1.03
Diobsud Creek	Jul 25	2	32-34	33.0	0.40	1.11
	Aug 9	11	27-33	30.7	0.26	0.92
Bacon Creek	Jul 3	2	30-32	31.0	0.70	2.36
	18*	5	35-39	36.8	0.44	0.88
	25*	3	30-32	31.3	0.40	1.31
	Aug 1	3	29-31	30.3	0.33	1.22
	9	10	29-32	30.9	0.30	1.02
	15	5	30-36	32.6	-	-

*Fyke net samples

Table 8.58 Rainbow-steelhead fry catches at Skagit Basin sampling sites using electrofisher, 1976 brood.

	Skagit River at								
Date	County Line	Talc Mine	Marble-mount	Rock-port	Cascade River	Sauk River	Goodell Creek	Bacon Creek	Diobsud Creek
1976									
6/6 -6/12	-	-	-	-	-	-	-	-	-
6/13 -6/19	-	-	-	5	-	-	-	-	
6/20 -6/26	-	-	-	-	-	-	-	-	-
6/27 -7/3	-	-	-	-	-	-	8	-	-
7/4 -7/10	-	-	-		-	5	1	-	
7/11 -7/17	-	-	-		1	11	2	-	-
7/18 -7/24	-		1	2	-	40	5	-	-
7/25 -7/31	2		8	16	1	28	5	-	-
8/1 -8/7	20		11	27	4	30	3	1	4
8/8 -8/14	23	4	11	26	25	26	5	-	
8/15 -8/28	20	8	23	25	29	26	29	27	23
8/29 -9/11	33	15	29	47	31	30	25	33	28
9/12 -9/25	25	25	21		25	32		24	35
9/26 -10/9		5	5	8	5	5			
10/10-10/23	12	-	16	38	118	29	24	34	26
10/24-11/6	27	15	25	23	30	30	45	23	27
11/7 -11/20	-	2	8	15	10	10	10	12	13
11/21-12/4	6	7	15	16	17	47	16	17	20
12/5 -12/11	13	10	15	30	21	63	13	12	25
12/12-12/18	10	6	34	34	19	38	9	10	36
12/19-12/25	10	3	14	16	12	33	12	12	13
12/26-1/1	1	2	3	14	24	22	13	8	11
1977									
1/2 -1/8	-	5	6	8	20	10	11	5	-
1/9 -1/15	1	2	-	6	30	12	10	13	10
1/16 -1/22	-	-	5	9	16	8	11	10	18
1/23 -1/29	3	-	3	2	21	4	6	12	7
1/30 -2/5	4	3	2	5	10	11	5	18	5
2/6 -2/12	1	1	1	1	18	4	5	8	4
2/13 -2/19	-	-	-	-	16	2			
2/20 -2/26	4	-	-	-	11	8	2	11	1
2/27 -3/5	-		-	-	12	7	18	3	6
3/6 -3/12	-	1	-	-	13	2	6	2	5
3/13 -3/19	1	-	1	-	7	-	28	1	4
3/20 -3/26	-	-	-	-	1	2	7	-	2
3/27 -4/2	-	-	9	-	5	-	-	1	-
4/3 -4/9	3	2	2	-	4	2	5	5	2
4/10 -4/16	-	1	-	-	11	3	4	11	-
4/17 -4/23	-	6	5	-	16	2	3	3	1
4/24 -4/30	3	1	1	4	27	2	5	4	1
5/1 -5/7	1		1	-	10	6	3	4	1
5/8 -5/21	3	1	2	-	8	21	3	4	-
5/22 -6/4	6	1	4	14	15	9	4	2	-
6/5 -6/18	1	3	4	-	3	10	2	1	-
6/19 -7/2	-	-	-	1	-	1	-	-	-

Table 8.58 Rainbow-steelhead fry catches at Skagit Basin sampling sites using electrofisher, 1976 brood--continued.

Date	Skagit River at: Newhalem-County Line	Skagit River at: Talc Mine	Skagit River at: Marble-mount	Skagit River at: Rock-port	Cascade River	Sauk River	Goodell Creek	Bacon Creek	Diobsud Creek
1977									
7/3 -7/16	4	1	4	-	5	2	-	1	-
7/17 -7/30	-	-	2	1	2	-	1	1	-
7/31 -8/13	-	-	-	-	2	-	-	-	-
8/14 -8/27	-	-	-	-	2	-	-	-	-
8/28 -9/3	-	-	-	-	-	-			
9/20 -9/21	-	-	-	-	-	-			
10/19-10/22	-	-	-	-	-	-			
11/18-11/20	-	-	-	-	-	1			
12/15-12/20	-	-	-	1	-	-			

Note: Dash (-) signifies catch was zero.
Blank signifies sampling not conducted.

Table 8.59 Rainbow-steelhead fry catches at Skagit Basin sampling sites using electrofisher, 1977 brood.

Date	Skagit River at County Line	Skagit River at Talc Mine	Skagit River at Marble-mount	Skagit River at Rock-port	Cascade River	Sauk River	Goodell Creek	Bacon Creek	Diobsud Creek
1977									
5/22 -6/4	-	-	-	-	-	-	-	-	-
6/5 -6/18	3	1	2	8	7	8	-	-	-
6/19 -7/2	14	-	3	25	3	10	3	-	-
7/3 -7/16	12	-	5	57	2	24	1	-	-
7/17 -7/30	59	40	39	92	35	33	7	9	9
7/31 -8/13	63	25	27	127	27	30	13	13	12
8/14 -8/27	69	30	25	29	28	37	14	14	13
8/28 -9/3	75	30	26	69	41	36			
9/20 -9/21	59	38	41	43	35	41			
10/19-10/22	64	42	35	24	41	34			
11/18-11/20	34	30	29	29	34	35			
12/15-12/20	42	23	11	15	11	16			
1978									
1/11	21		2	-					
1/18 -1/22	19	25	4	-	20	13			
2/1	22		1	-					
2/10	6		-	-					
2/17	-		-	-					
2/24 -2/26	7	4	3	-	22	18			
3/3	8		-	-					
3/10	2		-	-					
3/17	36		-	-					
3/24 -3/27	-	-	-	-	13	2			
3/31	34		-	-					
4/7	26		2	-					
4/13	24		-	-					
4/21	4	-	-		-	5			
4/24 -4/25	13		3	-					
5/2	23		1	-					
5/9 -5/10	8		-	-					
5/16 -5/17	9		-	-					
5/23	11		-	-					
6/1	2		1	2					
6/6	25		36						
6/13	-		2	-					
6/20	7		7						
6/27	3		5	-					

Note: Dash (-) signifies catch was zero.
Blank signifies sampling not conducted.

and rainbow-steelhead fry of the 1977 brood continued to be caught at two of them.

8.4.5.2 Rainbow-Steelhead Trout Fry Size and Condition after Emergence. Some rainbow-steelhead fry from the 1974 brood were analysed for size and condition, but not enough samples were taken to exhibit distinct temporal trends or differences between stations (Table 8.57).

In the 1976 brood the general pattern seen in other salmonid fry in the Skagit Basin of an initial level period of fairly constant values followed by a period of increasing values was shown for rainbow-steelhead trout growth parameters (Figs. 8.48, 8.49, and 8.50). The divergence between the three sites during the increasing phase was not as pronounced as for coho but it did reflect the pattern of benthic insect density differences between the Skagit, Cascade, and Sauk rivers (Sec. 3). All three parameters showed a convergence of values at the three sites in late November and December, indicating that perhaps with favorable temperature conditions, Skagit fry were able to "catch up" with fry from the Sauk and Cascade rivers.

8.4.5.3 Rainbow-Steelhead Trout Fry Diet. The results of diet analysis for rainbow-steelhead fry of the 1976 brood in August and September 1976 are summarized in Table 8.60. Compared to chinook fry, few were found with unabsorbed yolk.

Chironomids were by far the most important component by numbers in the diet. For their first two months after emergence, rainbow-steelhead fry are tiny and hide in very shallow water. Chironomids are probably the right size for ingestion and available along the shallow shoreline.

Only 3% of the prey items found in Skagit River fry were plankton. This is a lower percentage than for chinook fry (Table 8.24) or coho fry (Table 8.56) in 1976. Only the first two months of steelhead fry development are summarized here.

8.4.6 Fry Stranding

8.4.6.1 Mortality Due to Stranding. The data for 1976 sampling are given in Table 8.61, including the approximate minimum flow reached and the flow reduction as measured at the Newhalem and Marblemount gaging stations (USGS). The flow lag time approximations used downriver from the Newhalem gage were 1 hr to County Line Bar, 2-3 hrs to Marblemount bars, and 5-6 hrs to Rockport Bar. The hourly flow patterns at Newhalem (USGS) for January through May 1976, are shown in Fig. 8.51. The variable nature of the timing, frequency, and magnitude of flow fluctuations can be discerned from this figure. The flow reductions that were sampled for stranded fry are indicated by arrows. A distance of 112,330 linear ft where stranding might occur was calculated from aerial photographs for the river between Gorge Powerhouse and the Sauk River. Extrapolating the fry mortality per linear foot to the estimated bar distance between Gorge Powerhouse and the mouth of the Sauk River where stranding might occur, we estimate a total mortality of 33,137 fry occurred on the five 1976

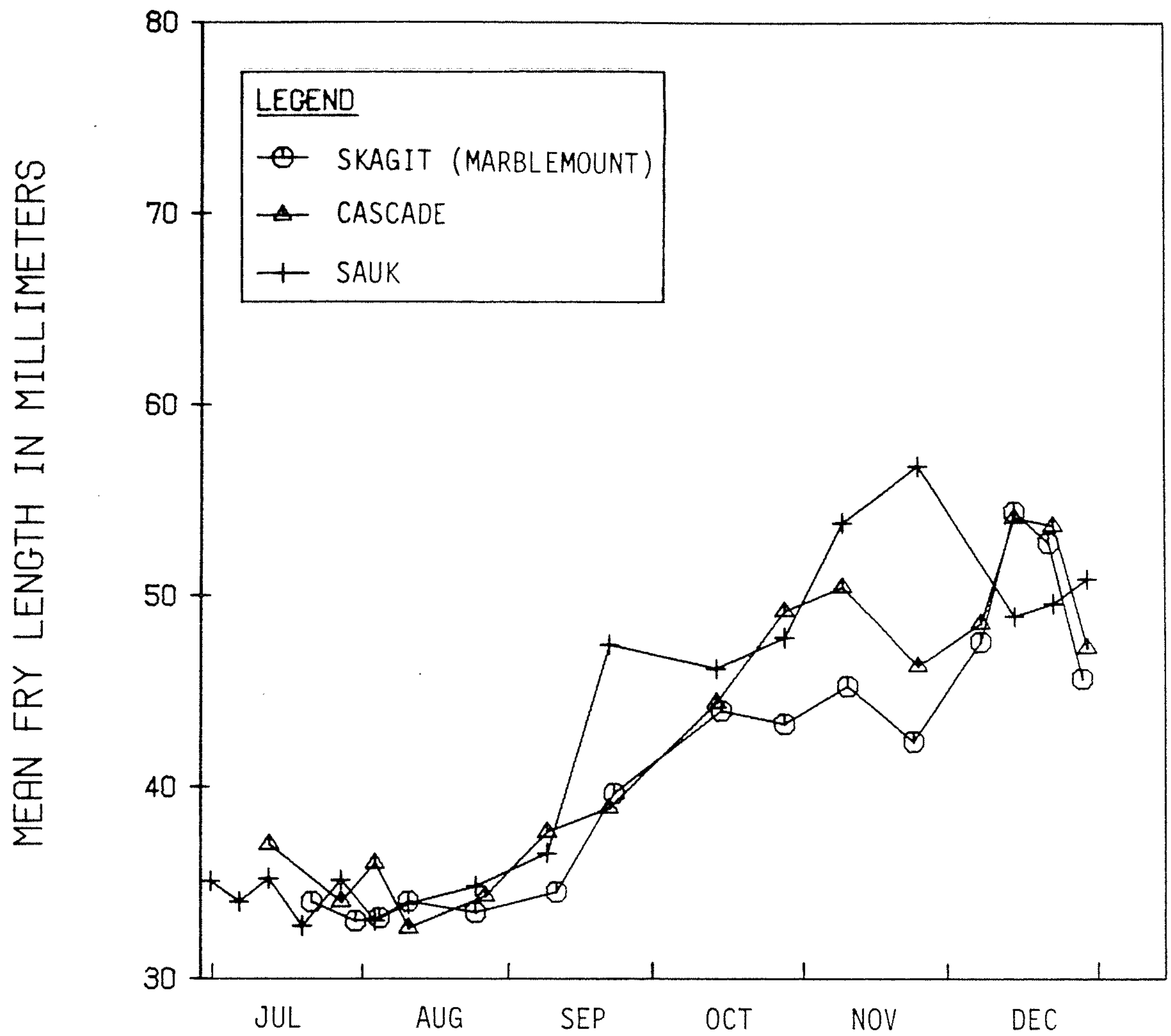

Fig. 8.48 Mean lengths of Skagit, Cascade, and Sauk rainbow-steelhead fry taken by electrofishing, 1976 brood.

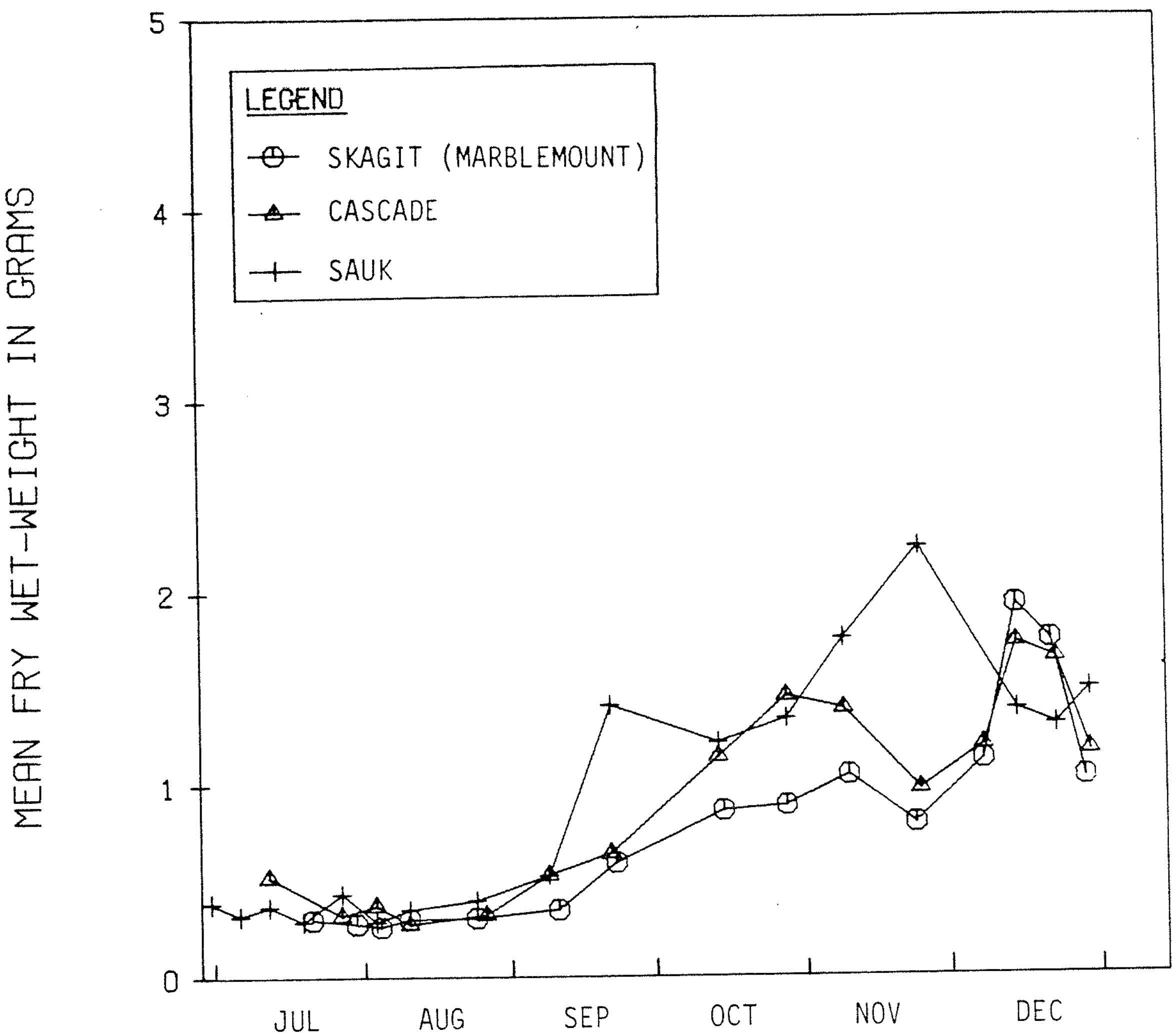

Fig. 8.49 Mean wet weights of Skagit, Cascade, and Sauk rainbow-steelhead fry taken by electrofishing, 1976 brood.

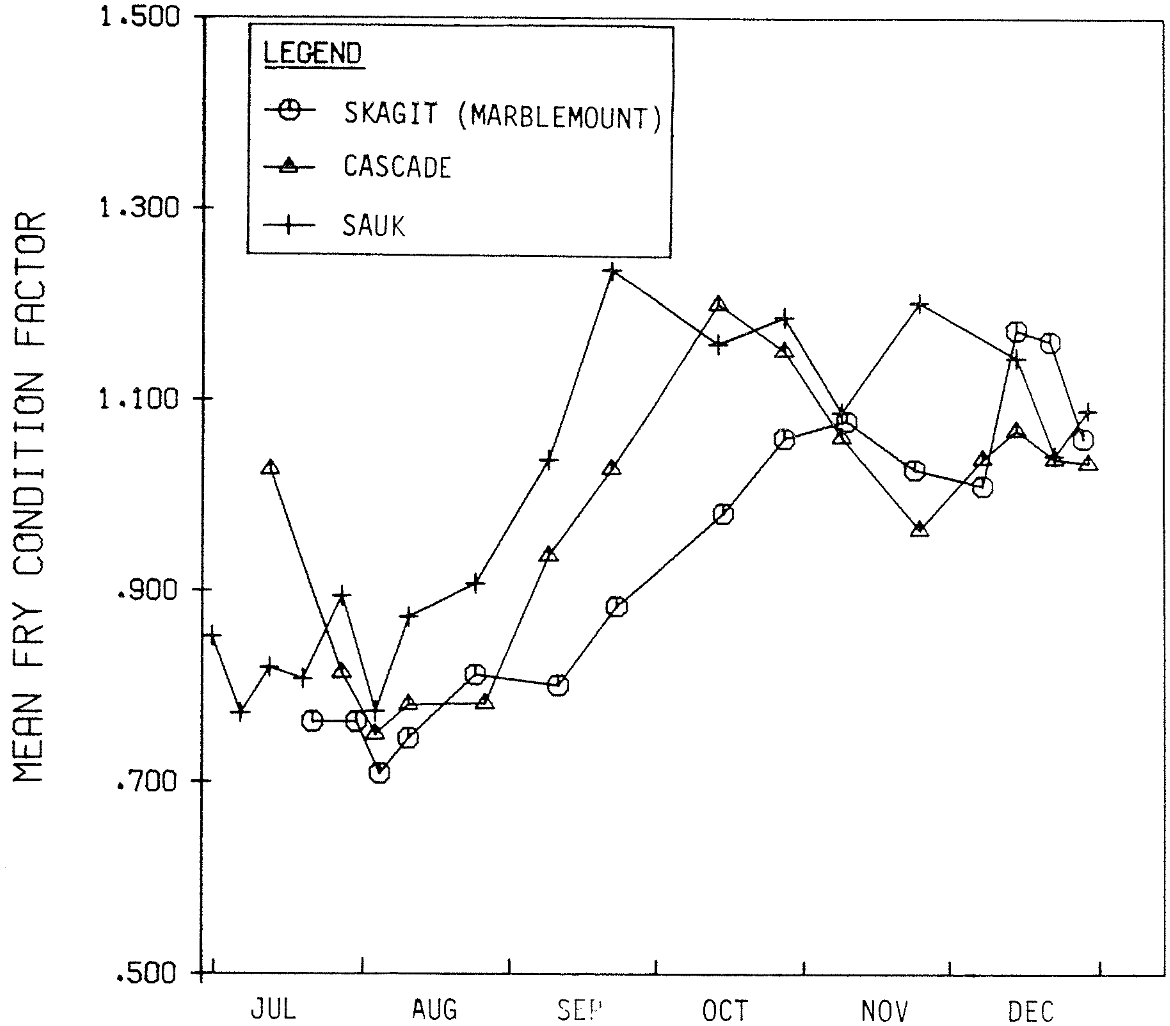

Fig. 8.50 Mean condition factors of Skagit, Cascade, and Sauk rainbow-steelhead fry taken by electrofishing, 1976 brood.

Table 8.60 Rainbow-steelhead fry stomach contents, 1976 brood, August and early-September 1976.

River	Cascade		Sauk		Skagit	
Number of stomachs examined	8		10		34	
Fry with empty gut and yolk	0		0		0	
Fry with non-empty gut and yolk	0		0		3	
Fry with empty gut and no yolk	0		0		0	
Fry with non-empty gut and no yolk	8		10		31	
Organism	**Total #**	**% occur.**	**Total #**	**% occur.**	**Total #**	**% occur.**
Diptera						
Chironomid larvae	94	43	194	89	327	53
Chironomid pupae	4	2			7	1
Chironomid adults	90	41	4	2	151	25
Other aquatic Diptera	6	3	4	2	19	3
Ephemeroptera nymphs	9	4	8	4	33	5
Plecoptera nymphs			2	< 1	13	2
Plecoptera adults					2	< 1
Trichoptera larvae	1	< 1	2	< 1	8	1
Diaptomus					4	< 1
Daphnia					16	3
Bosmina						
Collembola					4	< 1
Aphids	4	2			2	< 1
Mites			1	< 1	12	2
Other	1	< 1	1	< 1	6	< 1
Misc. and unknown	12	5	1	< 1	10	2

Table 8.61 Fry stranding observations, 1976.

Date	Location	Time surveyed	Area surveyed (sq.ft.)	Linear feet surveyed	No. of stranded fry	Mortality per 1,000 sq.ft.	Mortality per linear ft	Flow at Newhalem Minimum (cfs)	Flow at Newhalem Decrease (cfs)	Flow at Marblemount[e] Minimum (cfs)	Flow at Marblemount[e] Decrease (cfs)
Feb 5[a]	Rockport	0700	300	6	0	0	0	3,910	2,784		
Mar 5[a]	Rockport County line Marblemount	0600 0700	No area surveyed because of frozen substrate.								
Mar 17	Marblemount	0930	b	173[c]	8	--	0.046	3,535	945		
Mar 23	County line	1200-1255	353	38	11	31.2	0.289	4,769[d]	2,015		
Mar 23	Marblemount	1350-1500	b	173[c]	36[f]	--	0.208	3,430[d]	3,390	5,240	
Apr 22	Marblemount	0515-0545	386	22	0	0	0	3,595	3,317	5,300	
Apr 29	County line	0555	243	18	0	0	0	2,490	2,075		

[a]Ground too frozen for effective survey.

[b]Area measurements not taken.

[c]Shoreline between transects 3 and 4 examined.

[d]Flow dropping during observations, hence corresponding minimum at Newhalem difficult to estimate.

[e]Complete flow records not available during observation period.

[f]Includes one pink salmon fry.

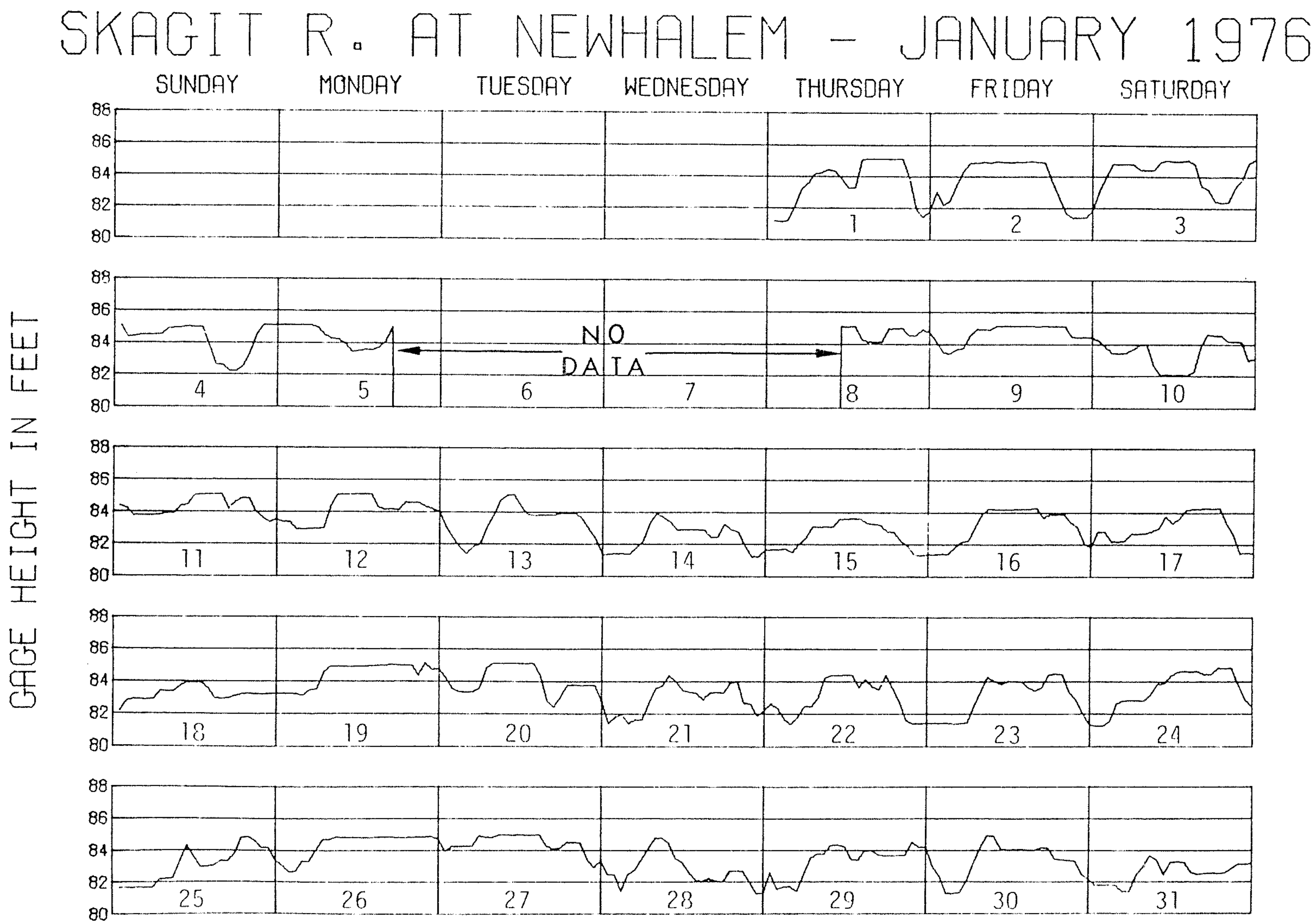

Fig. 8.51 Hourly gage height data for Skagit River at Newhalem (USGS), January-May, 1976.

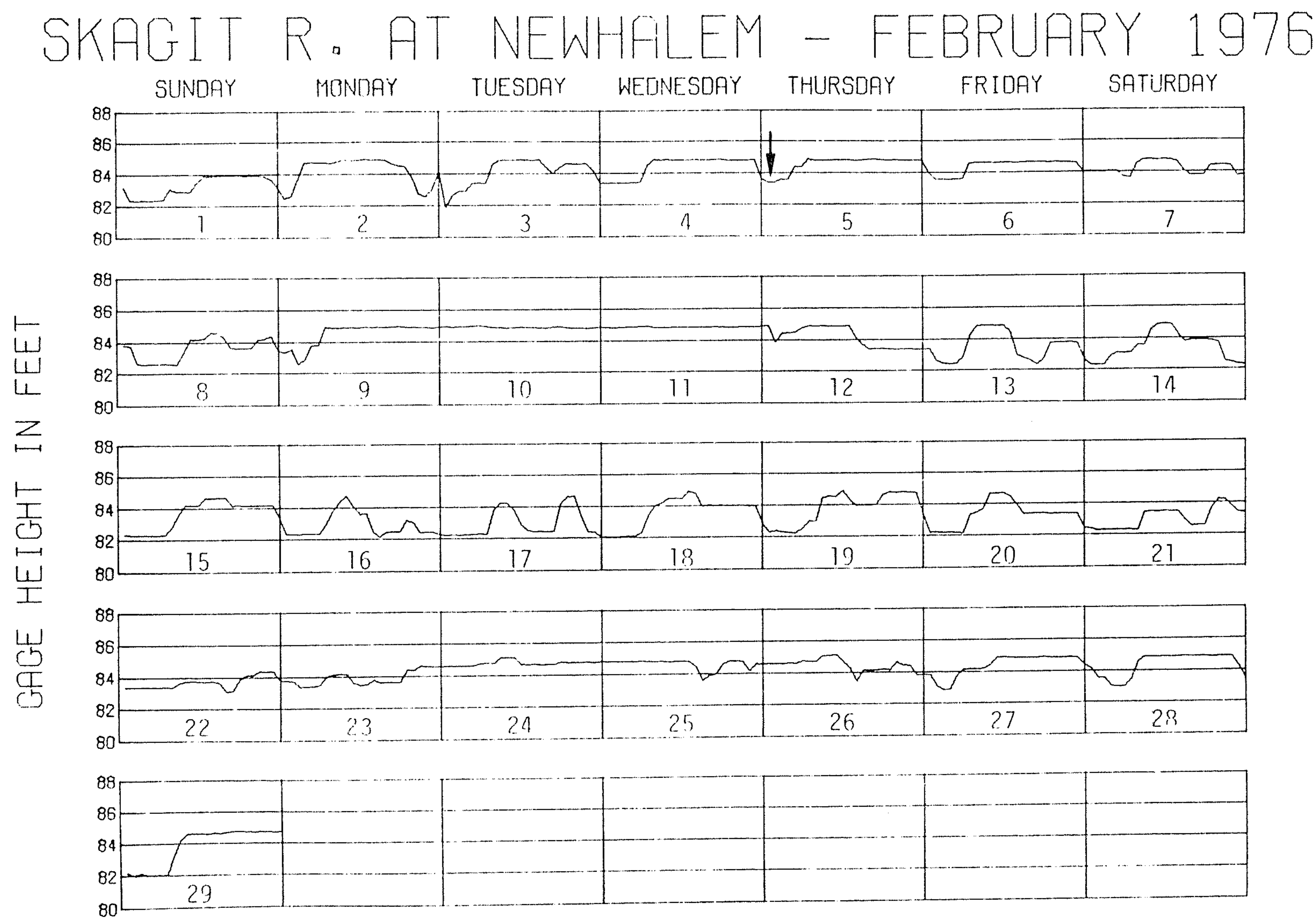

Fig. 3.51 Hourly gage height data for Skagit River at Newhalem (USGS), January-May, 1976 - continued.

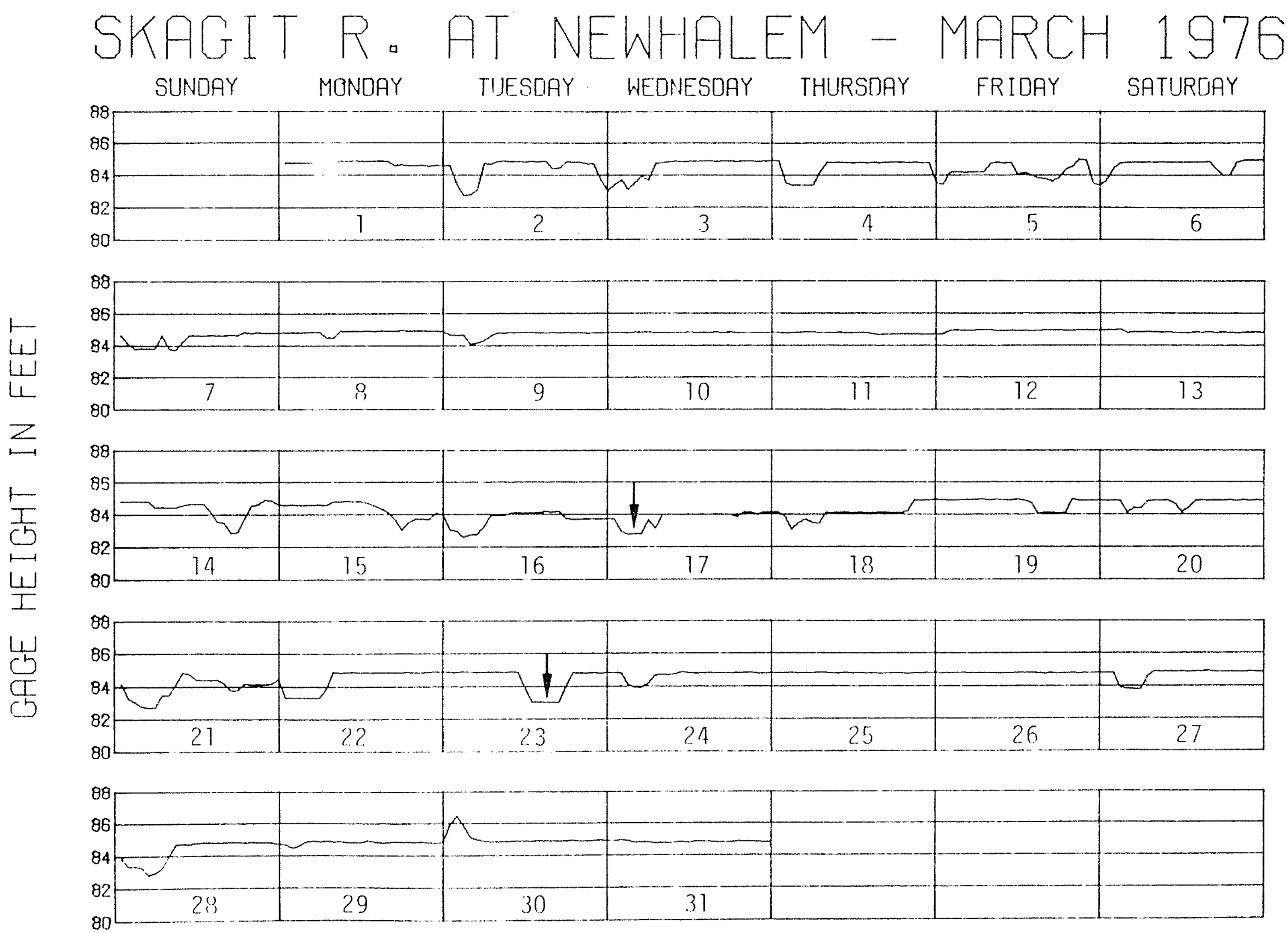

Fig. 8.51 Hourly gage height data for Skagit River at Newhalem (USGS), January-May, 1976 - continued.

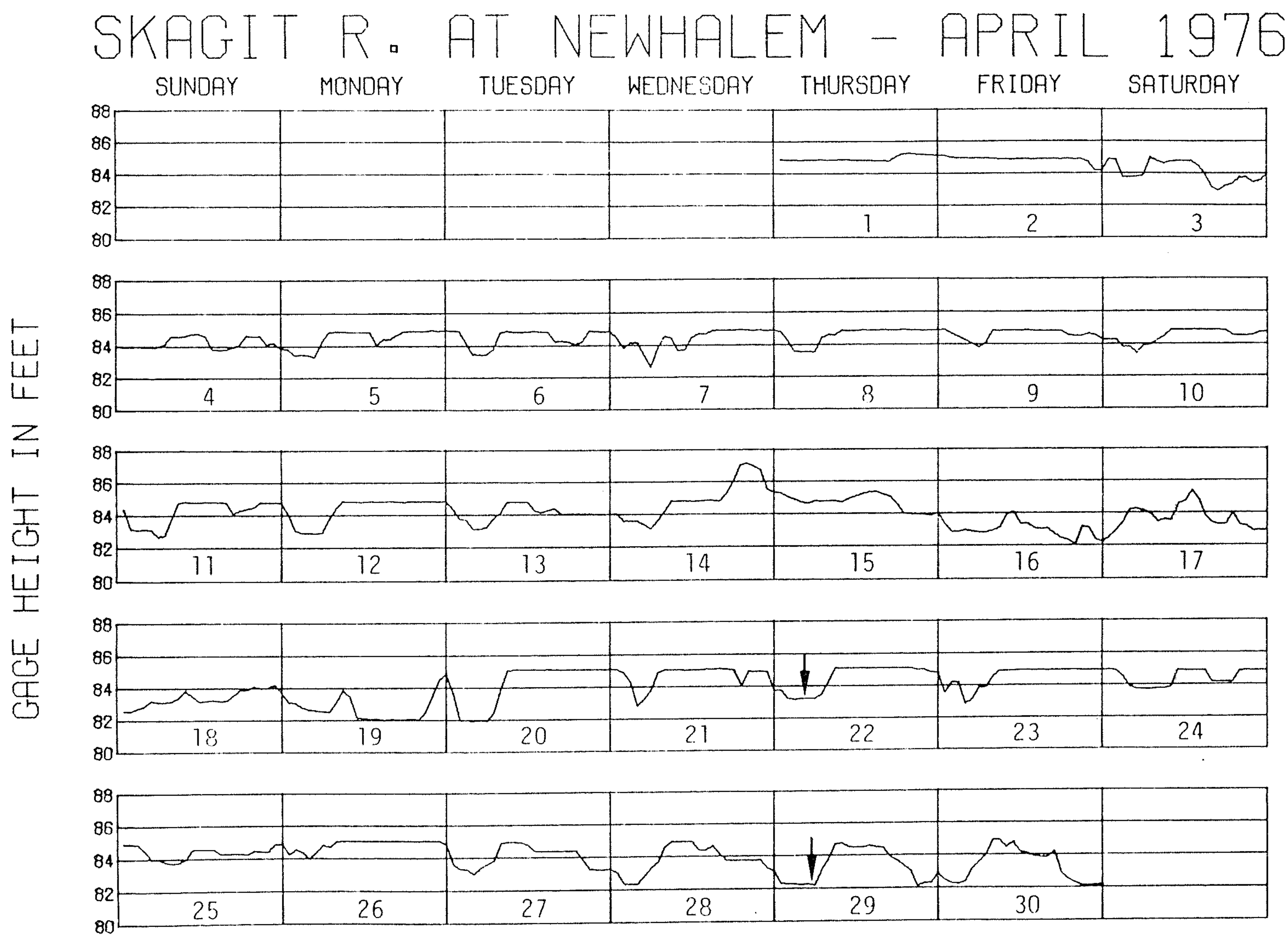

Fig. 8.51 Hourly gage height data for Skagit River at Newhalem (USGS), January-May, 1976 - continued.

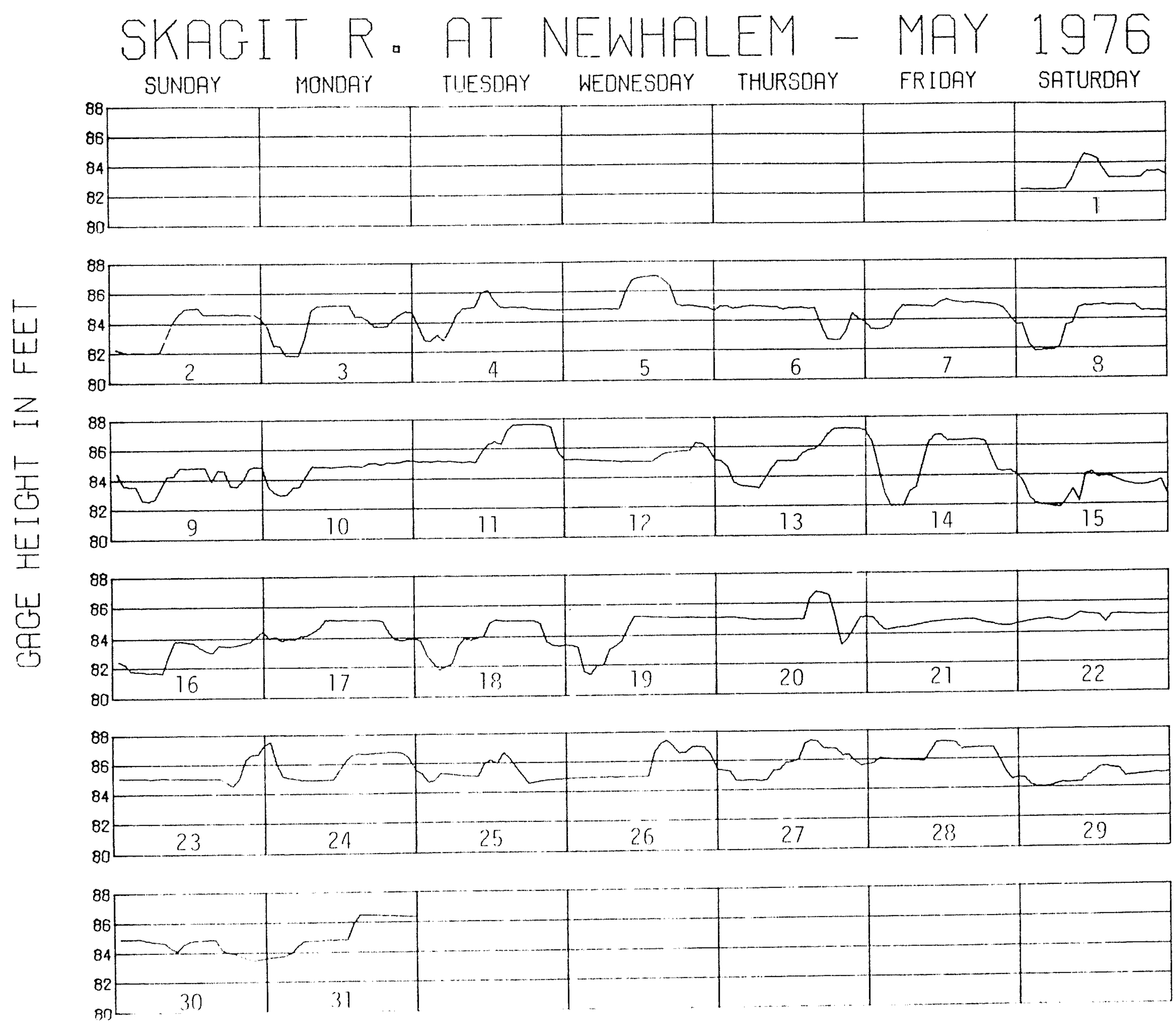

Fig. 8.51 Hourly gage height data for Skagit River at Newhalem (USGS), January-May, 1976 - continued.

observation days.[1] This extrapolation includes the assumptions that all dead fry were counted, that those considered freshly dead had been stranded during the current flow reduction, and that stranding was indeed the cause of mortality of dead fry observed.

The 1977 fry stranding observations were more extensive. Results are summarized in Table 8.62. The daily flow patterns at Newhalem (USGS) from January to mid-April are graphed in Fig. 8.52 with stranding observation dates indicated by arrows. The estimated total fry mortality due to stranding between Gorge Powerhouse and the Sauk River was 53,918 for the 11 observations in 1977.

Several of the minimum flows reached in the 1977 observations were in the vicinity of 2,300 cfs at Newhalem (Table 8.62), similar to the March 1973 test (Phinney 1974a). Mortalities per 1,000 ft^2 in all cases were less than encountered at corresponding bars in the March 17-18, 1973, tests of flow reduction to 2,304 cfs. However, the estimated chinook spawning escapement was also larger in 1972 than it was in 1976 (Table 5.3), and the ramping rates were lower for the surveys in 1977 under operational conditions than they were for scheduled tests conducted in 1973. Even so, it was apparent that flow fluctuation did cause mortality at higher discharges.

The majority of the fry mortalities estimated for the 1976 and 1977 surveys applied to chinook salmon fry, but included some pink and chum fry as well. One pink fry was found stranded during the 1976 surveys and one chum fry during 1977 surveys. The relatively short freshwater residence time for pink and chum fry following emergence (Sec. 8.4.2.1 and 8.4.3.1, respectively) makes them much less susceptible to stranding than chinook fry. The later emergence timing of chum fry (Table 7.10 and Sec. 8.4.3.1) probably reduces their susceptibility to stranding also, because of the generally higher streamflow with the commencement of "spring runoff".

While stranding observations were not made for rainbow-steelhead trout fry, they are also considered to be less susceptible to stranding than chinook fry for several reasons. First, spawner distribution was very low in upstream areas (Sec. 6.4.3.5) where the effects of flow reductions were greatest. Second, much rearing takes place in tributary streams, outside the influence of flow fluctuations in the mainstem Skagit River. Redistribution of fry into the mainstem Skagit probably does occur, but these fry would presumably be older and larger and may be less susceptible to stranding. Third, a large proportion of the emergence period coincided with the latter part of the high stream flow period in June, July, and early August.

Results of the classification of flow reductions according to minimum elevation reached and the number of feet dropped at the Newhalem gage (USGS) for the period from January 1 to April 21, 1977, are presented in Table 8.63. These analyses showed that we had fairly good distribution of

[1] The two mortality values for March 23 were averaged.

Table 8.62 Fry stranding observations, 1977.

Date	Location	Time surveyed	Area surveyed (sq.ft.)	Linear ft. surveyed	No. of stranded fry	Mortality per 1,000 sq.ft.	Mortality per linear ft	Flow at Newhalem Minimum (cfs)	Flow at Newhalem Decrease (cfs)	Flow at Marblemount Minimum (cfs)	Flow at Marblemount Decrease (cfs)
Feb 3	County line	1600-1700	480	32	0	0	0	3,550	3,293		
Feb 8	Marblemount	0725-0815	a	24	4	--	0.17	2,260	4,329	2,815	4,150
Feb 23	Marblemount	1600-1715	624	32	1	1.6	0.03	2,550	4,523	3,685	3,865
Mar 1	County line	1500-1600	1,228	48	5	4.1	0.10	2,730	2,660		
Mar 10	Marblemount	0630-0800	1,128	63	1	0.9	0.02	2,394	4,090	3,710	4,000
Mar 10	County line	1300-1400	748	32	1	1.3	0.03	2,730	2,679		
Mar 18	County line	1330-1430	688	40	0	0	0	3,475	3,093		
Mar 19	Rockport	0530-0600	96	8	0	0	0	5,637	1,206	6,650	740
Mar 22	Rockport	0600-0745	448	40	2	4.5	0.05	4,667	2,544	6,195	1,955
Mar 29	Marblemount	0515-0600	742	34	1[b]	1.3	0.03	2,382	4,375	3,394	4,036
Mar 30	County line	0515-0700	1,024	40	2	2.0	0.05	2,359	4,377		

[a] Area not recorded on one transect.

[b] Chum salmon fry.

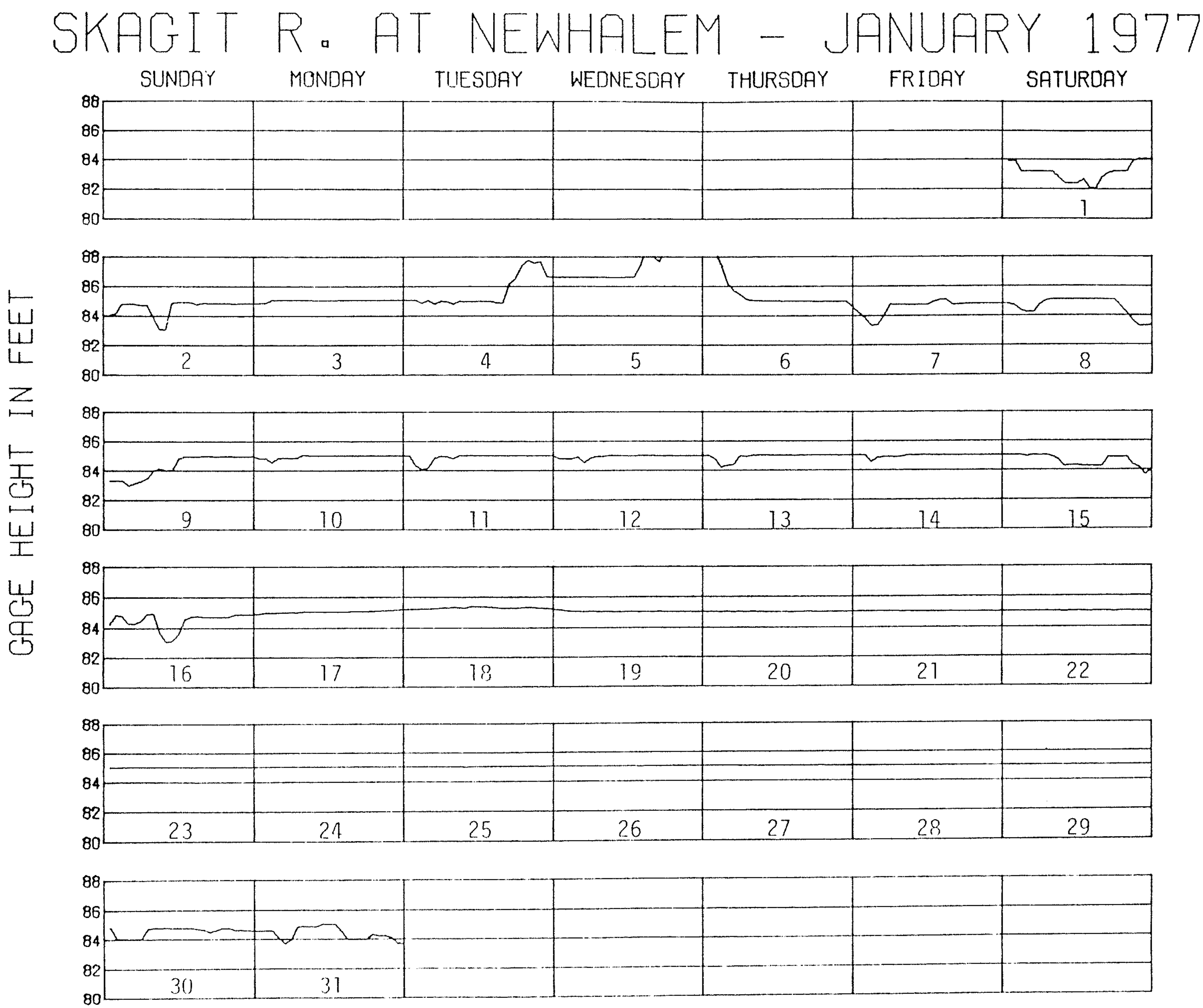

Fig. 8.52 Hourly gage height data for Skagit River at Newhalem (USGS), January-April 14, 1977.

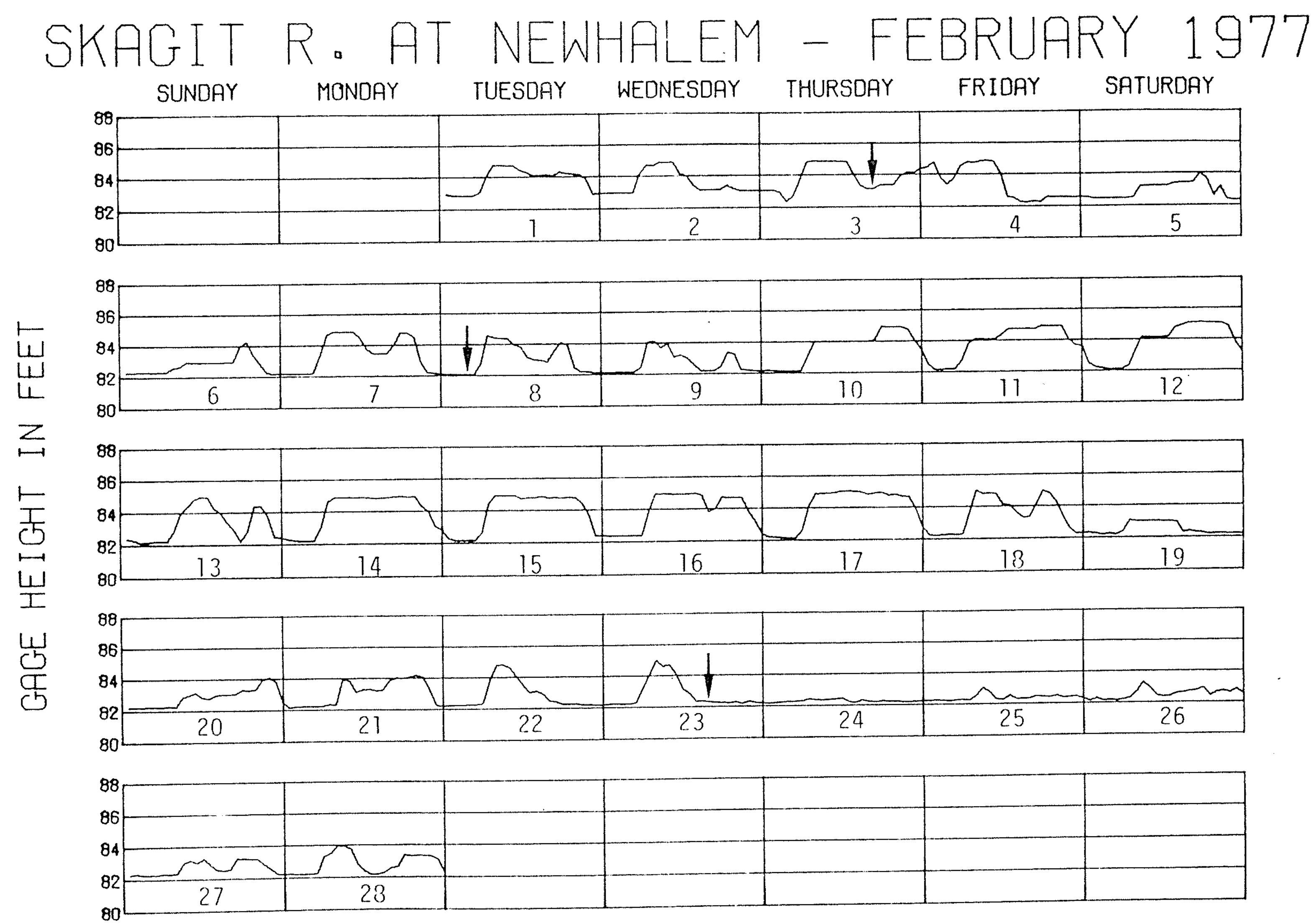

Fig. 8.52 Hourly gage height data for Skagit River at Newhalem (USGS), January-April 14, 1977 - continued.

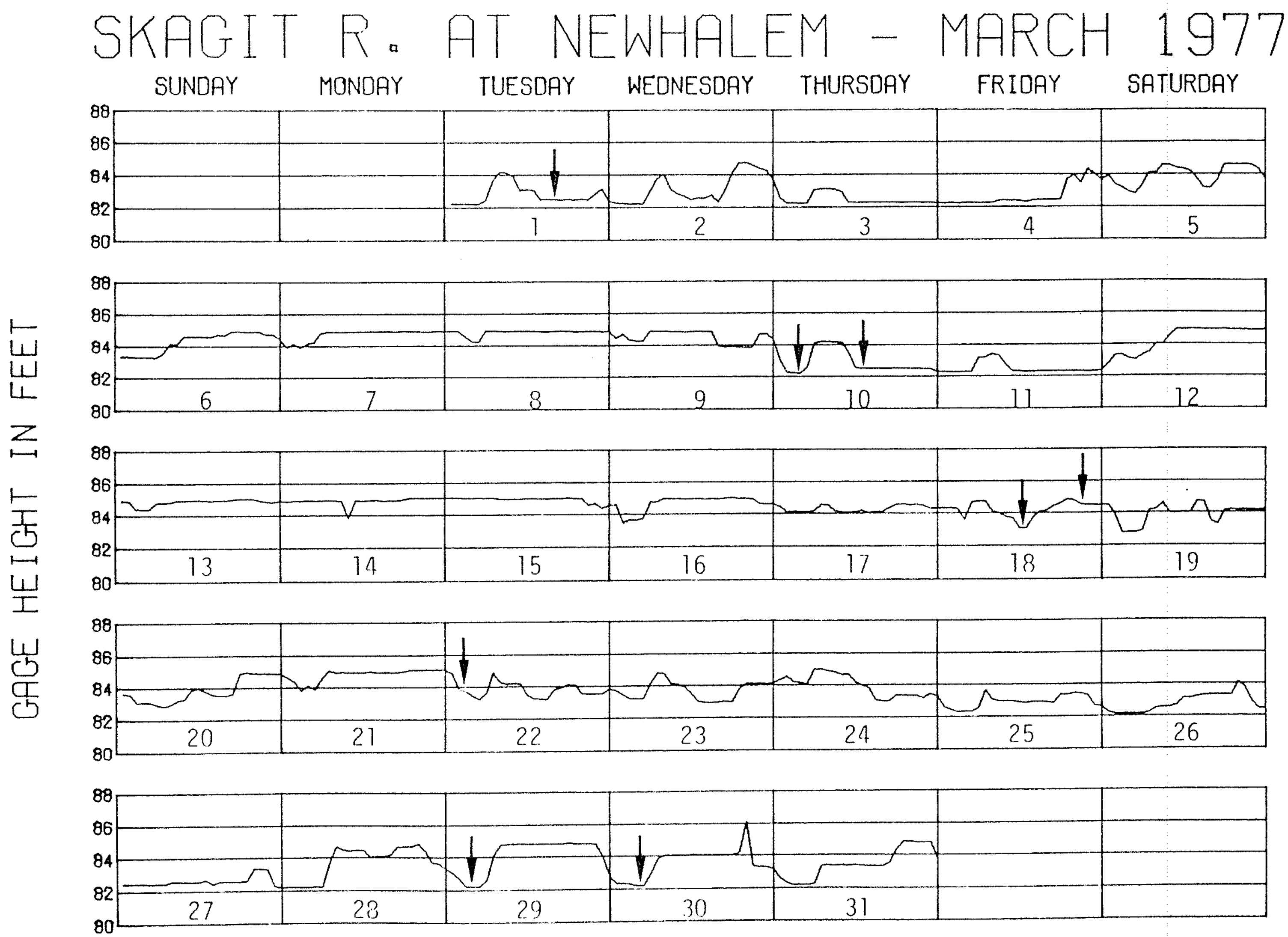

Fig. 8.52 Hourly gage height data for Skagit River at Newhalem (USGS), January-April 14, 1977 - continued.

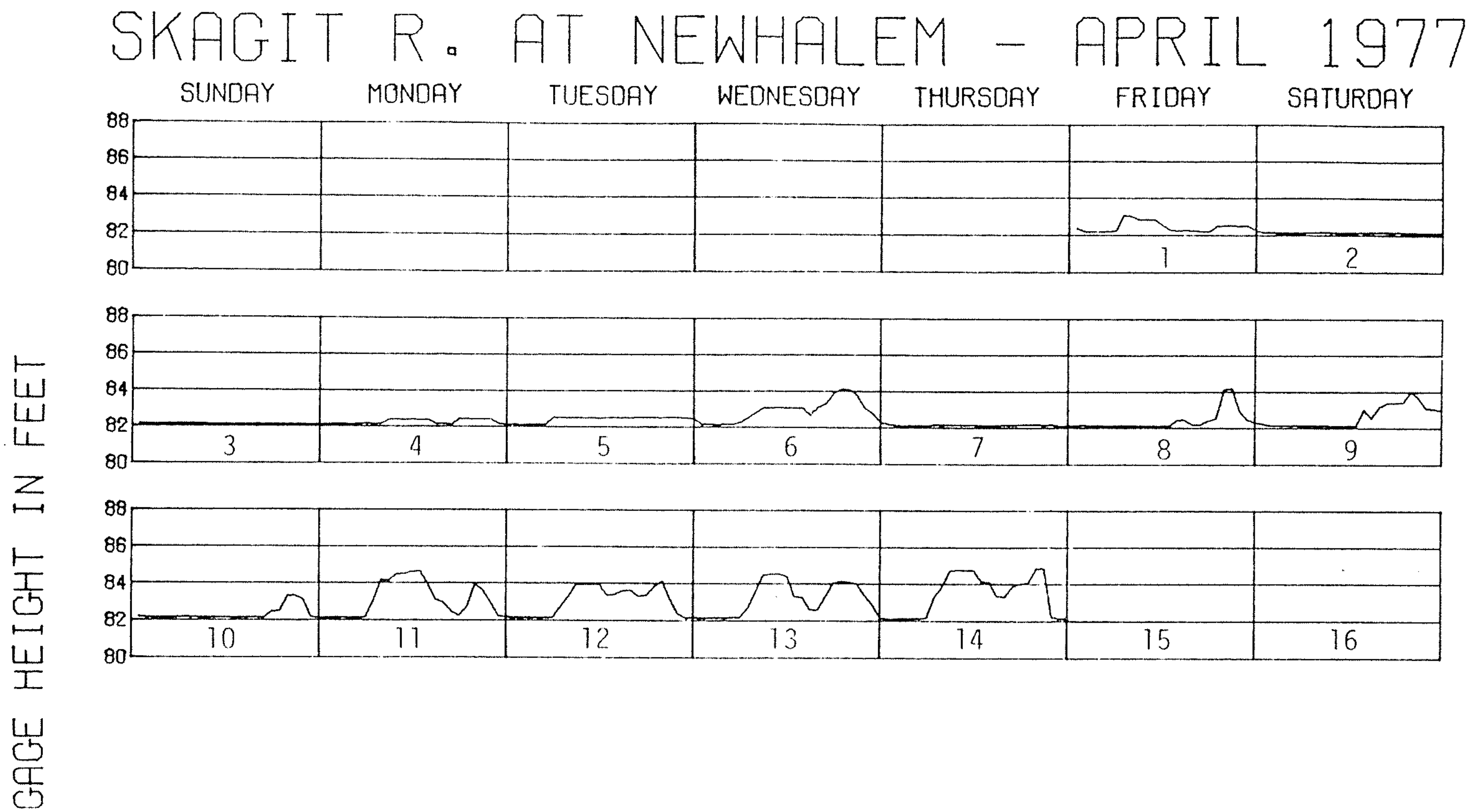

Fig. 8.52 Hourly gage height data for Skagit River at Newhalem (USGS), January-April 14, 1977 - continued.

Table 8.63 Classification of flow reductions for Skagit River at Newhalem (USGS) between January 1 and April 21, 1977, according to minimum elevation attained and number of feet dropped. Number of flow reductions surveyed for stranded fry are shown in parentheses.

Minimum elevation(ft)	Equivalent streamflow(cfs)		Number of occurrences	
84	~ 5,000		16	
83	~ 3,400		36	(4)
82	~ 2,200		56	(7)
81	~ 1,200		0	
		Total	108	(11)

Magnitude of reduction(ft)		Number of occurrences	
1		47	
2		43	(6)
3		18	(5)
	Total	108	(11)

sampling for flow reductions to 83- and 82-ft, but none for reductions to 84 ft. In terms of the number of feet dropped, we sampled proportionately more of the 3-ft drops than the 2-ft drops and none of the 1-ft drops.

Based on this classification system, we sampled approximately 10 percent (11/108) of the flow reductions during this period of 1977; and so a gross estimate of total fry killed due to stranding would be 54,000 x 10, or 540,000 for 1977.

We consider this to be an overestimate for several reasons. First, this calculation implies comparable mortality during January and April for which we have no stranding observations. Of the 108 flow reductions, 36 occurred in January and April. Our chinook abundance information (Fig. 8.3) indicated that fry were not as available on the bars in January and April as they were in February and March. This generally agrees with the estimate of emergence timing based on temperature unit requirements. Secondly, results from our stream channel stranding studies indicated that fry may be susceptible to stranding for a fairly short time and that this may be related to age or experience. Substantial increase in average size also occurs in April. Thirdly, we sampled a disproportionately high number of the larger magnitude fluctuations in 1977. For these reasons we consider a kill of 540,000 fry to be a worst case estimate for 1977. However, we do not have a good numerical basis for adjusting the figure downward.

8.4.6.2 Stranding Selectivity. Comparisons of stranded and unstranded chinook fry from 1976 and 1977 surveys indicated that stranded fry had significantly (at $\alpha = 0.05$) higher condition factors than the unstranded fry from the same locations and approximately the same date (Table 8.64).

The experiment simulating stranding resulted in a 1.53 percent loss in length and a 3.09 percent gain in weight of the rainbow-steelhead trout fry (Table 8.65). The loss in length was probably due to rigor mortis and the weight gain from absorption of water. Although the experiment on changes due to stranding (and handling) was conducted with rainbow-steelhead trout, it is reasonable to suggest similar changes in chinook fry. The stranded chinook fry samples were corrected by these percentages and again compared with the electroshocked samples (Table 8.64). The stranded chinook fry, adjusted for handling, were significantly (at $\alpha = 0.05$) longer than the unstranded fry. The new comparison of condition factors showed no significant (at $\alpha = 0.05$) difference between stranded and unstranded fry. In view of these results, it is not possible at this time to conclude that there are any significant differences between stranded and unstranded chinook fry.

8.4.6.3 Ramping Rate. Analyses were conducted to determine the relationship between fry stranding mortality and the rate of flow reduction or ramping rate. Stranding mortalities for County Line and Marblemount bars from 1973, 1976, and 1977 surveys when plotted against corresponding ramping rates showed poor correlation. However, when the data were grouped by the minimum elevation attained (Table 8.66), either

Table 8.64 Observed and corrected length, weight, and condition factors of stranded and unstranded chinook fry from surveys conducted in 1976 and 1977.

	Length groups:	36-40 mm				41-45 mm			
Date	Location	N	Length (mm)	Weight (g)	Condition factor	N	Length (mm)	Weight (g)	Condition factor
3/14/76[a]	Marblemount	9	39.6	0.466	0.750	17	42.0	0.542	0.732
3/17/76[b]	"	2	40.0	0.465	0.727	8	41.8	0.596	0.816
3/17/76[c]	"	2	40.6	0.451	0.674	8	42.4	0.578	0.758
3/19/76[a]	County Line	11	39.6	0.455	0.730	14	41.8	0.535	0.730
3/23/76[b]	"	6	39.7	0.475	0.759	13	41.5	0.538	0.751
3/23/76[c]	"	6	40.3	0.460	0.703	13	42.1	0.521	0.698
3/22/76[a]	Marblemount	11	39.7	0.449	0.718	14	42.1	0.542	0.726
3/23/76[b]	"	11	39.4	0.434	0.710	24	42.0	0.526	0.710
3/23/76[c]	"	11	40.0	0.421	0.658	24	42.6	0.510	0.660
4/19/76[a]	Talc Mine	5	39.6	0.486	0.783	23	42.2	0.647	0.861
4/19/76[b]	"	4	38.8	0.542	0.928	2	41.5	0.660	0.923
4/19/76[c]	"	4	39.4	0.525	0.858	2	42.1	0.640	0.858
3/22/77[a]	Rockport	9	39.1	0.454	0.760	16	42.1	0.522	0.700
3/22/77[b]	"	13	39.2	0.530	0.880	20	41.4	0.534	0.753
3/22/77[c]	"	13	39.8	0.514	0.815	20	42.0	0.518	0.699

a = Condition sample from electroshocking samples.
b = Stranding sample.
c = Stranding sample corrected for 1.53% loss in length and 3.09% gain in weight.

Table 8.65 The lengths, weights, and condition factors of 49 rainbow-steelhead trout fry measured fresh, "stranded" for two hours, and then soaked in water for one hour.

Length group	N	Mean length(mm)	Mean weight(g)	Condition factor
		Fresh rainbow-steelhead trout		
31-35	1	34	0.34	.87
36-40	26	38.6	0.5269	.92
41-45	15	43.1	0.7707	.96
46-50	6	46.8	1.0167	.99
51-55	1	55	1.61	.97
		"Stranded" rainbow-steelhead trout		
31-35	2	34.5	0.3600	0.88
36-40	26	38.3	0.5338	0.95
41-45	17	43.2	0.8053	1.00
46-50	3	47.7	1.1067	1.02
51-55	1	55	1.60	0.96
		"Soaked" rainbow-steelhead trout		
31-35	3	34.6	0.3967	0.95
36-40	26	38.4	0.5627	0.99
41-45	15	43.0	0.8287	1.04
46-50	4	46.8	1.1100	1.08
51-55	1	54	1.65	1.05

Table 8.66 Calculated ramping rate and time at maximum flow prior to flow reduction for flow reductions to approximately 82 and 83 ft at the Newhalem gaging station (USGS) for surveys conducted at County Line and Marblemount bars in 1973, 1976, 1977. Estimated mortality due to stranding is also shown.

Date	Ramping rate (cfs/hr)	Time at maximum flow prior to reduction (hr)	Stranding mortality (fry/lin.ft) County Line	Marblemount
Reductions to 82 ft				
3-17-73	1950	ND	0.92	0.13
3-18-73	2746	15	0.73	0.50
4-29-76	692	5	0	ND
2-8-77	2050	2	ND	0.17
2-23-77	1055	2	ND	0.03
3-1-77	665	4	0.10	ND
3-10-77	1630	1½	ND	0.02
3-29-77	636	3		0.03
3-30-77	1373	14	0.05	ND
Reductions to 83 ft				
3-17-76	1409	7	ND	0.046
3-23-76	3306	28	0.289	0.202
4-22-76	1175	3½	ND	0
2-3-77	1308	6	0	ND
3-10-77	1300	4	0.03	ND
3-18-77	618	2	0	ND

82 or 83 ft for Skagit River at Newhalem (USGS), the correlation coefficients indicated that there was at least a 95 percent probability of a linear relationship between stranding mortalities and ramping rates. For flow reductions to 82 ft with n = 11, the correlation coefficient (r) = 0.69 (Fig. 8.53). For flow reductions to 83 ft with n = 7, the correlation coefficient (r) = 0.96 (Fig. 8.54). The slope of the line for flow reductions to 82 ft was significantly steeper than the one for flow reduction to 83 ft (at 0.90 level). This suggests that the stranding mortality increases as the minimum level of flow drops and supports the idea that at lower flow levels the increased proportion of exposed bar area and the increased drying-up of potholes increases the mortality due to stranding.

These analyses indicated that for flow reductions to 83 ft or approximately 3,400 cfs, the expected stranding mortality would be zero for ramping rates at about 1,000 cfs/hr and less. For flow reductions to 82 ft or approximately 2,200 cfs, the expected stranding mortality would remain low or go to zero for ramping rates below about 500 cfs/hr.

Field observations in 1976 and 1977 had suggested that the duration of the maximum flow prior to flow reduction might be a factor influencing fry stranding mortality. It was observed that when the highest stranding mortality occurred, on March 23, 1976, the longest period of maximum flow prior to reduction (28 hrs) also occurred (Table 8.66). However, observations of other long periods of steady prior flow, such as March 30, 1977, showed that stranding mortalities can be relatively low. It can also be observed that on March 23, 1976, the ramping rate was very high, 3,306 cfs/hr. The evidence indicates that the ramping rate and not the duration of maximum flow prior to reduction may be the more important factor in causing stranding mortality.

8.4.6.4 Experimental Studies. The results of the chinook fry stranding trials conducted at Big Beef Creek Research Station during 1978 are summarized in Table 8.67. One of the factors studied which may influence fry susceptibility to stranding was the stability of flow prior to a flow reduction.

Observations by our field workers during 1976 and 1977 stranding surveys on the Skagit River led them to suggest that longer periods of steady flow may cause higher stranding rates. For example the highest stranding mortalities observed occurred on March 23, 1976, when 28 hrs of stable flow preceded the flow reduction (Table 8.66). The rationale was that the fry would have more time to move onto the bars and establish stations. Since they would have been associated with the station for a longer time they may be more reluctant to move offshore as the water drops. Therefore, they would be more likely to become stranded.

There was conflicting evidence from the experimental stranding trials that steady flow prior to reduction increases the stranding mortalities. For Group I the percent of fry stranded in the weekend trial with 64 hrs of steady flow prior to reduction was higher than those for the overnight trials with 16 hrs of steady flow, while for the other groups (II, III,

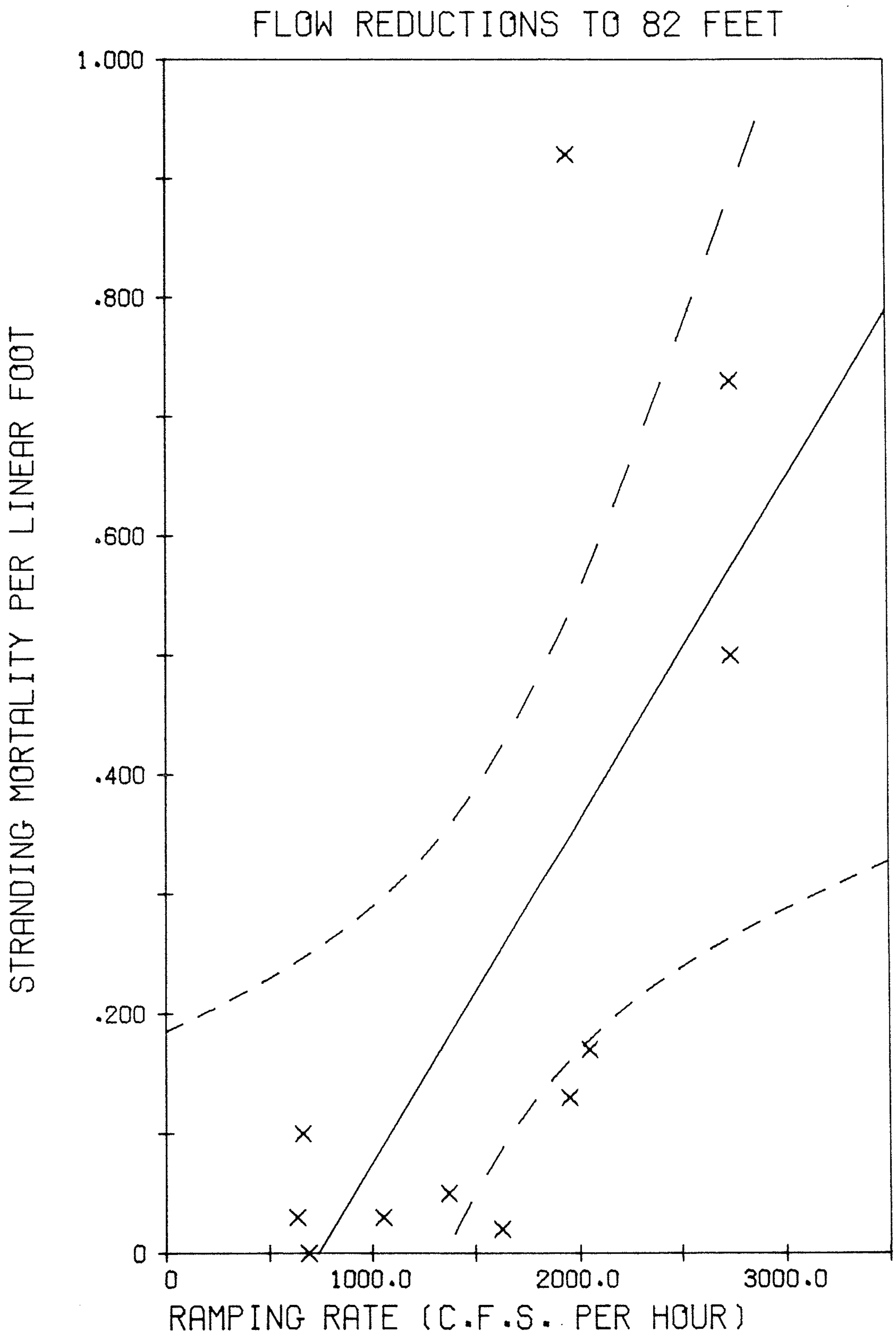

Fig. 8.53 Relationship between stranding mortality and ramping rate for flow reductions to 82 feet with 95 percent confidence intervals shown as dotted lines.

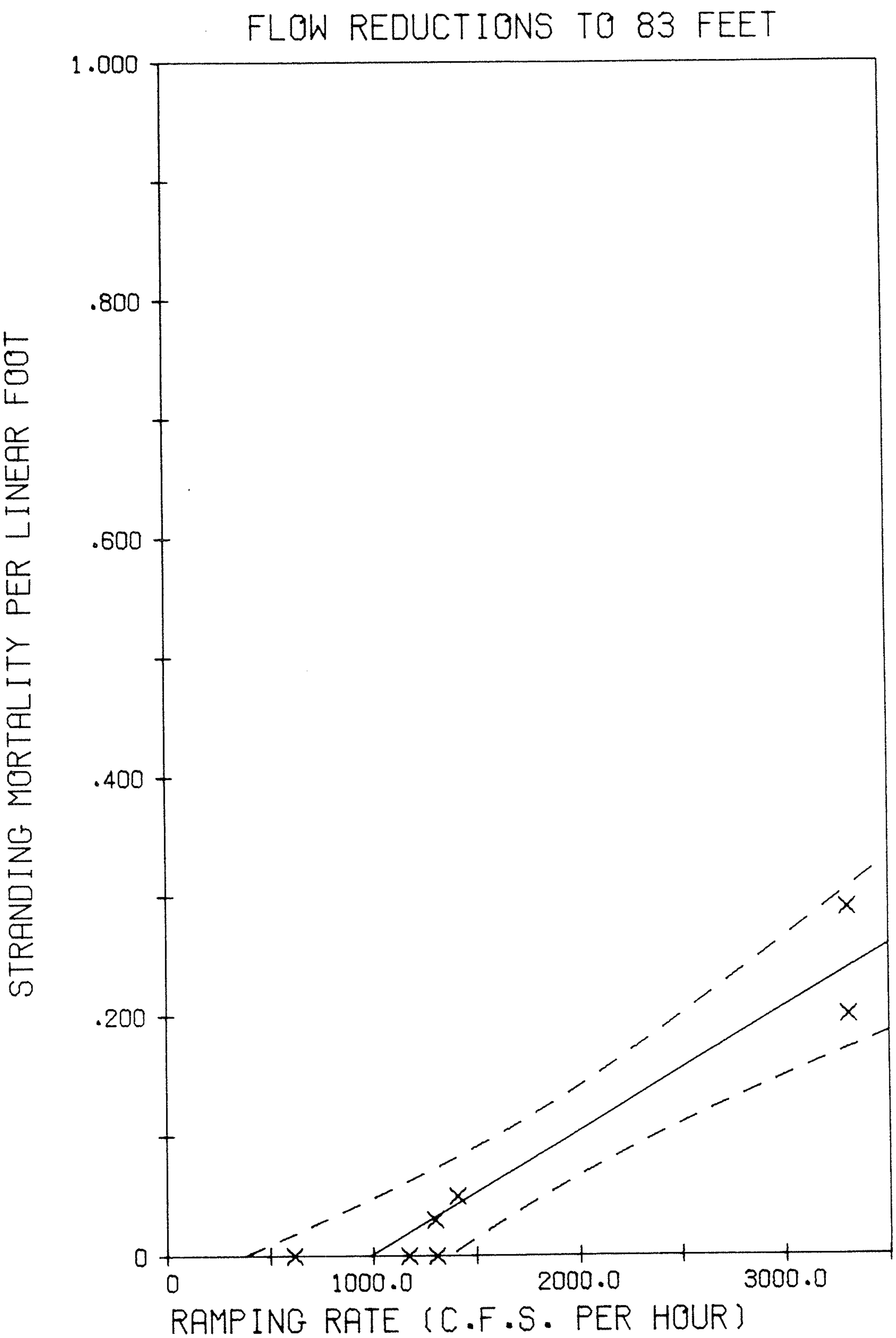

Fig. 8.54 Relationship between stranding mortality and ramping rate for flow reductions to 83 feet with 95 percent confidence intervals shown as dotted lines.

Table 8.67 Summary of chinook fry stranding trials conducted at Big Beef Creek Research Station during 1978.

Group no.	Capture date	Capture location	Length (mm)			Trial type	Percent stranded			Number stranded per trial
			$\bar{X}$	S^2	N		$\bar{X}$	S^2	N	
I	2/16	Skagit	41.4	2.31	30	Overnight	3	36	4	0,0,0,12[a]
						Overnight	4	-	1	4[b]
						Weekend	15	-	1	15
II	2/9	Skagit	42.0	5.24	44	Overnight	4.8	4.71	5	3,3,6,4,8
						Overnight	1.5	3.69	4	0,0,4,2
						Weekend	0	-	1	0
III	3/29	Skagit	42.9	8.34	30	Overnight	.8	1.2	5	0,2,0,2,0
						Overnight	.5	.67	4	0,1,0,1
						Weekend	.3	.33	3	1,0,0
IV	4/21	Lewis	42.5	11.95	33	Overnight	0	-	2	0,0
						Overnight	.5	-	2	1,0
						Weekend	1	-	1	1

a. Sample size of 50 fry and 6 were stranded.
b. Sample was selected from fry used in all previous 1st run trials.

and IV), the percent of fry stranded was similar or lower in the weekend trials than they were for overnight trials (Table 8.67).

Fry experience, age, and size, were other factors investigated experimentally which may affect fry susceptibility to stranding. Because flow reductions occur relatively frequently in the Skagit River, about once a day, it is possible that after several successful encounters with receding water levels the fry may "learn" to avoid stranding on subsequent reductions. Group II provided strong evidence supporting this statement. The mean stranding rate for the first and second trials of the same fry, dropped from 4.8 to 1.5 percent (t = 1.15, different at 80 percent confidence). Group III also showed a slight decrease in stranding rate from 0.8 to 0.5 percent between the first and second trials. Adequate data were not available for Groups I and IV to make comparisons between first and second trials.

If fry do "learn" to avoid stranding, then we would expect older fry to strand at a lower rate. The stranding rate between the first trials of Groups II and III (Group III fish were collected 20 days later then Group II fish and were significantly larger), dropped from 4.8 to 0.8 percent. This strongly suggested that older fry strand at a lower rate. The stranding rates between the first runs of Groups I and II (Group II fry were collected three weeks later and were significantly larger), however, were not significantly different. Because these two comparisons were inconclusive, chinook fry (Group IV) were collected from the Lewis River where the fish in this particular year had not experienced water level fluctuations (Hugh Fiscus, WDF, personal communication). The rate of stranding of Group IV was expected to be relatively high because the fish had no opportunity to "learn" about flow reductions. The stranding rate, however, was relatively low which suggested that experience was not a factor.

Lengths of stranded fish from Groups I, II, and III were compared to lengths of fish recovered alive from the channel. If experience is a factor, then the larger, and presumably older, fish would be less likely to become stranded. However, the stranded and recovered fish showed no significant difference in length.

Stranded: $\bar{x} = 42.2$, $S^2 = 5.8$, $N = 20$
Recovered: $\bar{x} = 41.7$, $S^2 = 4.8$, $N = 20$ $t = 0.15$

When FRI personnel compared the condition factors between stranded and nonstranded fish in the 1976 and 1977 studies on the Skagit River they also found no significant difference (Sec. 8.4.6.2). Studies by WDF on the Cowlitz River however, indicated that stranded fry were significantly shorter than unstranded fry (Bauersfeld 1978).

There were some observations of fry behavior in the experimental channel that were notable. The "wild" Skagit and Lewis river fish, when released in the experimental channel, would swim immediately for the upstream screen. The fry would then, over the next few hours, become evenly distributed throughout the channel. An examination of the location of the stranded fish shows a fairly even distribution, with a slight tendency to strand near the downstream screen (Fig. 8.55).

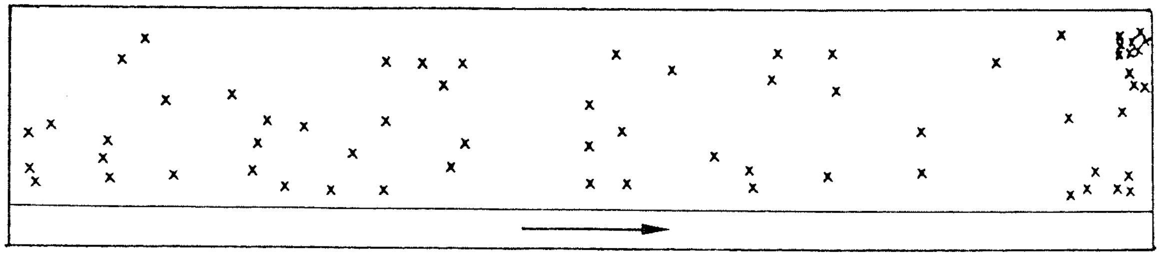

Fig. 8.55 Locations of stranded fish in experimental channel.

During the debugging of the channel, local Big Beef Hatchery fry were placed in the channel. These fish stayed together in a "knot" in the deep water and could not be stranded. A sample of incubation box fry was later obtained from the Skagit River. These fish initially associated more strongly with the gravel than the "wild" fry, but their stranding rate, 2 percent, was not significantly different from the "wild" fish.

While some of the group tests suggested that learning experience or size/age of chinook fry may influence stranding rate, there were contradictory or inconclusive results in other tests. It is clear, however, that as long as fry are within the nearshore areas they run the risk of being stranded. Analysis of dye-marking studies (in progress) may indicate the length of residency in nearshore areas.

9.0 OTHER FISHES

9.1 Introduction

Studies were conducted quarterly to survey the fishes other than salmon and adult steelhead trout residing in the mainstem Skagit River between Newhalem and Rockport. The fishes present included ones that were considered resident such as mountain whitefish (Prosopium williamsoni) and largescale sucker (Catostomus macrocheilus) and ones that can be either anadromous or resident, such as Dolly Varden char (Salvelinus malma) and rainbow-steelhead trout (Salmo gairdneri).

The objectives of the study were to determine species composition, relative abundance, and distribution of fishes other than salmon and adult steelhead trout in the mainstem Skagit River between Newhalem and Rockport and to assess the possible effects of the proposed Copper Creek Dam on these populations. Other species captured incidentally during sampling described in previous sections are also listed.

9.2 Study Sites

Three reaches of similar length were sampled in the mainstem Skagit River: (1) the Newhalem area from river mile (RM) 92.0 to RM 88.6, (2) the Marblemount area from RM 83.0 to RM 79.5, and (3) the Rockport area from RM 69.0 to RM 65.8 (Fig. 1.1)

9.3 Materials and Methods

The fish samples were obtained by electroshocking. The Coffelt designed electrofishing boat equipment using the VVP-15 shocker driven by 3.5 kw, 230 v. gas powered generator was modified to fit the project's 17-ft aluminum boat. Fiberglass booms on each side of the boat were extended 5-ft beyond the bow of the boat. Cables at the end of each boom and electrically connected to the electro-shocker extended several feet into the water and functioned as the anode. Two cables wired to the other pole of the shocker were hung over the sides of the boat near the stern and served as the cathode. The voltage was kept as high as possible (usually around 550 v. D.C.) to overcome the high resistance of the Skagit River water. The direct current was pulsed at a rate of about 120 pulses per second and pulse width of 50-60 percent was used.

The general procedure was to drift through the length of the study reach moving from side to side in the river to sample a variety of habitat types. The boat operator was responsible for the control of the shocking, while the other member of the team stood in the bow of the boat and dipnetted the fish which were attracted to the anode.

The captured fish were identified and counted and part of the catch (up to 40 whitefish, 10 largescale suckers, and any other fish which were caught) was taken to the field station. Fork lengths were measured to the nearest millimeter and weights were measured to the nearest hundredth of a gram (0.01 g) on the Mettler top loading balance for fish less than

1200 g. Fish weighing over 1200 g were weighed in a spring scale. Sex and maturity were determined for individual fish and the stomachs were removed and preserved in 10 percent formalin for later examination. The contents of the preserved stomachs were removed in the laboratory and examined with a binocular microscope. All identifiable contents were enumerated and the results compiled.

The sampling was conducted quarterly in June, August-September, and December, 1977, and March 1978.

9.4 Results and Discussion

9.4.1 Availability

Mountain whitefish (*Prosopium williamsoni*) was the most abundant species captured and over-all comprised about 89 percent of the catch (Table 9.1). Largescale sucker (*Calostomus macrocheilus*) was next in over-all abundance at about six percent of the catch, followed by Dolly Varden char (*Salvelinus malma*) and rainbow-steelhead trout (*Salmo gairdneri*) which comprised about three and two percent, respectively, of the over-all catch.

Mountain whitefish were readily available at the three sampling sites during June, August-September, and December, 1977. The significance of numerical differences in catch is not known since the sampling was not strictly quantitative. Factors such as discharge (Table 9.1) and conductivity probably affected sampling ability. However, there were no apparent trends to suggest that the distribution of mountain whitefish was other than proportional to river length during the 1977 sampling times.

During the March 1978 sampling period no whitefish were captured at the Newhalem and Marblemount areas and only 11 were taken at the Rockport site. Whitefish were observed visually, however, in a deep pool (near RM 87.5) below the Newhalem sampling area. These fish remained beyond the effective range of the shocker. Pettit and Wallace (1975) observed that whitefish moved downstream to overwinter in deep pools at the North Fork Clearwater River in Idaho. It is not known whether or not Skagit River whitefish move downstream after spawning, however, it was apparent that they do move into deeper water. It is also of interest that all of the whitefish taken in the Rockport area came from the confluence of the Sauk and Skagit rivers rather than the usual riffle areas.

Dolly Varden and rainbow-steelhead were generally captured at the three sites but in relatively low numbers (Table 9.1). Their distribution appeared to be fairly uniform between the three sites.

Largescale suckers were not captured at the upper two sites, but were consistently taken during the four sampling periods at the Rockport sampling site (Table 9.1).

Table 9.1 Catch of non-salmon fishes at three sites on the Skagit River during 1977-1978.

Date	Location	Discharge (cfs)	Catch: Mountain whitefish	Dolly Varden char	Rainbow-steelhead trout	Largescale sucker
6/9/77	Newhalem	2,110	46	1	0	0
6/15/77	Marblemount	3,960	38	1	1	0
6/15/77	Rockport	7,980	20	0	2	6
8/31/77	Newhalem	1,450	40	1	1	0
8/31/77	Marblemount	2,263	75	1	1	0
9/1/77	Rockport	3,845	49	1	2	11
12/1/77	Newhalem	4,991	58	2	2	0
12/2/77	Marblemount	16,650	40	1	1	0
12/5/77	Rockport	13,310	48	2	0	5
3/21/78	Newhalem	3,370	0	1	0	0
3/22/78	Marblemount	5,060	0	1	1	0
3/22/78	Rockport	6,670	11	3	0	6
	Total		425	15	11	28

9.4.2 Length and Weight

Length and weight data are presented in Table 9.2 for mountain whitefish and in Table 9.3 for rainbow-steelhead trout, Dolly Varden char, and largescale suckers captured at three locations in the mainstem Skagit between Newhalem and Rockport. Whitefish lengths ranged from 100 to 357 mm (mean = 237.5 mm) and weights ranged from 11.21 to 502.81 g (mean = 160.58 g). The mean length and weight of whitefish for the individual sampling periods in 1977 declined as the sampling progressed down river (Table 9.1). It is not known whether this was a real representation of the whitefish population or if it was an artifact introduced by sampling gear selectivity.

The captured rainbow-steelhead trout ranged in length from 72 to 385 mm (mean length = 150.3 mm) and in weight from 4.04 to 695.32 g (mean weight = 92.56 g) (Table 9.3). Dolly Varden ranged in length from 137 to 547 mm (mean length = 416.3 mm) and in weight from 25.0 to 1,985 g (mean weight = 925.26 g). It seemed probable that both anadromous and resident froms of these two species were present in the samples but no attempt was made to differentiate them.

Largescale suckers were, in general, more consistent in size than the two previously discussed species (Table 9.3) and ranged from 355 to 492 mm (mean length = 412.4 mm) in length and from 529.0 to 1,133.1 g (mean weight = 886.2 g) in weight.

9.4.3 Sexual Maturity

The sexual maturity data for mountain whitefish (Table 9.4) indicated that spawning took place in December. Information on the spawning times of the other species was sketchy due to the limited number of specimens captured in these studies. These fish probably spawn at times normal for their species: Dolly Varden char in the fall (September-November); rainbow-steelhead trout in the spring (April-June); and largescale suckers in the spring (April-June). Steelhead trout (anadromous form) have been observed to spawn in the mainstem Skagit between March and June (Sec. 6.4.2.5).

9.4.4 Diet

The results of stomach content analysis for 345 mountain whitefish collected in 1977 and 1978 at three sites on the mainstem Skagit River are presented in Tables 9.5, 9.6, and 9.7. The column labeled "Freq. occur." represents the percentage of non-empty stomachs in a sample group that contained a certain prey organism. The column, "Total no.", gives the total number of individuals of the prey counted in the sample group. The column, "Range", indicates the minimum and maximum numbers of a prey organism in individual stomachs for a sample group. The next column, "% occur.", is the percentage by numbers of the prey organism among all prey types encountered in the sample group.

Table 9.2 Length and weight of mountain whitefish captured at three locations in the mainstem Skagit River during quarterly sampling in 1977 and 1978.

Date	Location	Number sampled	Fork length(mm) min.	mean	max.	Weight(g) min.	mean	max.
6/ 9/77	Newhalem	36	193	251.5	331	72.20	168.84	355.10
6/15/77	Marblemount	38	142	235.0	357	41.70	161.47	502.81
6/15/77	Rockport	20	100	208.7	282	11.21	113.52	281.19
8/31/77	Newhalem	40	151	235.2	311	35.59	149.35	400.62
8/31/77	Marblemount	40	142	227.5	291	26.90	139.46	294.01
9/ 1/77	Rockport	40	140	214.3	345	26.76	124.24	486.40
12/1/77	Newhalem	40	194	256.2	338	65.42	209.52	496.13
12/2/77	Marblemount	40	165	251.5	303	46.97	189.41	308.58
12/5/77	Rockport	40	167	242.0	327	43.19	170.42	433.22
3/22/78	Rockport	11	200	245.3	291	73.09	147.21	261.72
	Total	345	100	237.5	357	11.21	160.58	502.81

Table 9.3 Length and weight data for fishes captured at three locations in the mainstem Skagit River during quarterly sampling in 1977 and 1978.

Date	Location	Species	Number sampled	Fork length(mm) min.	Fork length(mm) mean	Fork length(mm) max.	Weight(g) min.	Weight(g) mean	Weight(g) max.
6/ 9/77	Newhalem	DV	1	428	-	-	950	-	-
6/16/77	Marblemount	Rb-SH	1	82	-	-	6.42	-	-
		DV	1	471	-	-	1372.11	-	-
6/15/77	Rockport	Rb-SH	2	88	147	206	7.96	53.71	99.46
		LSS	6	412	428	440	843.32	971.42	1081.72
8/31/77	Newhalem	Rb-SH	1	145	-	-	33.17	-	-
		DV	1	380	-	-	502.86	-	-
8/31/77	Marblemount	Rb-SH	1	99	-	-	10.11	-	-
		DV	1	137	-	-	25.0	-	-
9/ 1/77	Rockport	Rb-SH	2	111	112	113	14.25	15.36	16.47
		DV	1	390	-	-	744.75	-	-
		LSS	10	355	404.4	455	529.0	816.21	1115.98
12/1/77	Newhalem	Rb-SH	2	72	228.5	385	4.04	349.68	695.32
		DV	2	356	406.5	457	593.97	795.34	996.70
12/2/77	Marblemount	Rb-SH	1	218	-	-	106.43	-	-
		DV	1	235	-	-	148.49	-	-
12/5/77	Rockport	DV	2	488	517.5	547	1220	1602.5	1985
		LSS	5	377	417.2	492	716.76	892.93	1009.0
3/21/78	Newhalem	DV	1	505	-	-	1130	-	-
3/22/78	Marblemount	Rb-SH	1	134	-	-	24.56	-	-
		DV	1	411	-	-	770.69	-	-
3/22/78	Rockport	DV	3	437	480	515	844.32	1146.44	1445
		LSS	6	387	406	419	768.17	912.02	1133.1
Total		Rb-SH	11	72	150.3	385	4.04	92.56	694.32
		DV	15	137	416.3	547	25.0	925.26	1985.0
		LSS	27	355	412.4	492	529.0	886.20	1133.1

Rb-SH = Rainbow-steelhead trout.
DV = Dolly Varden char.
LSS = Largescale sucker.

Table 9.4 Sexual maturity of Skagit River whitefish, 1977-78.

Date sampled		Number sampled	Development stages 1 N	1 %	2 N	2 %	3 N	3 %	4 N	4 %	5 N	5 %
6/9,15	M	30	30	100								
1977	F	60	60	100								
	Unident.	4										
8/31,9/1	M	58	8	14	50	86						
1977	F	62	15	24	47	76						
12/1,2,5	M	60	5	8			40	67	15	25		
1977	F	60	14	23	3	5	37	62	2	3	1	2
3/21,22	M	6	2	33			2	33			2	33
1978	F	5	2	40							3	60

Development stages:

1. Immature - Gonads very small, individual eggs not distinguishable.
2. Maturing - Gonads increasing in size, will probably spawn that season, individual eggs easily distinguished.
3. Mature - Gonads near maximum size, spawning imminent.
4. Ripe - Sexual products easily extruded.
5. Spent - Gonads deflated in appearance, residual eggs and milt may be present.

Table 9.5 Newhalem whitefish stomach contents.

Date	6-9-77				8-31-77				12-1-77				3-21-78				Combined		
	Freq. occur.	Total no.	Range	% occur.	Freq. occur.	Total no.	Range	% occur.	Freq. occur.	Total no.	Range	% occur.	Freq. occur.	Total no.	Range	% occur.	Freq. occur.	Total no.	% occur.
Sample size	35				40				39				0				114		
Ephemeroptera	97.1	1264	2-244	58.30	85.0	1693	1-443	44.41	53.8	141	1-70	21.73					78.0	3098	46.73
Plecoptera	51.4	62	1-14	2.86	77.5	712	1-129	18.68	74.4	102	1-47	15.72					68.4	876	13.21
Trichoptera	80.0	277	1-33	12.78	80.0	634	1-192	16.63	97.4	252	1-20	38.83					86.0	1163	17.54
Misc. Diptera	37.1	21	1-4	.97	17.5	27	1-17	.71	12.8	7	1-3	1.08					21.9	55	.83
Chironomidae	45.7	265	1-217	12.22	82.5	670	1-110	17.58	2.6	1	1	.15					43.9	936	14.12
Tipulidae	34.3	66	1-52	3.04	-	-	-	-	5.1	3	1-2	.46					12.3	69	1.04
Simuliidae	8.6	5	1-3	.23	2.5	4	4	.10	-	-	-	-					3.5	9	.14
Diaptomus	-	-	-	-	2.5	1	1	.03	-	-	-	-					.83	1	.02
Sphaeriidae	-	-	-	-	-	-	-	-	-	-	-	-					-	-	-
Misc. Aquatics	20.0	9	1-3	.42	30.0	33	1-11	.87	2.6	1	1	.15					17.6	43	.65
Misc. Terrestrials	40.0	70	1-23	3.23	-	-	-	-	12.8	6	1-2	.92					16.7	76	1.15
Salmon eggs	-	-	-	-	15.0	33	1-11	.87	48.7	67	1-19	10.32					21.9	100	1.51
Whitefish eggs	-	-	-	-	2.5	1	1	.03	35.9	20	1-4	3.08					13.2	21	.32
Unidentified eggs	17.1	124	1-74	5.72	-	-	-	-	-	-	-	-					5.7	124	1.87
Inanimate material	5.7	5	1-4	.23	2.5	4	4-4	.10	12.8	49	1-29	7.55					7.0	58	.87

Table 9.6 Marblemount whitefish stomach contents.

Date	6-15-77				8-31-77				12-2-77				3-21-78				Combined		
	Freq. occur.	Total no.	Range	% occur.	Freq. occur.	Total no.	Range	% occur.	Freq. occur.	Total no.	Range	% occur.	Freq. occur.	Total no.	Range	% occur.	Freq. occur.	Total no.	% occur.
Sample size	39				40				39				0				118		
Ephemeroptera	84.6	1950	1-251	52.85	97.5	2369	1-760	60.81	51.3	1048	1-399	51.83					78.0	5367	55.86
Plecoptera	43.6	82	1-27	2.22	75.0	284	1-45	7.29	41.0	22	1-3	1.09					53.4	388	4.04
Trichoptera	92.3	270	1-37	7.32	87.5	378	1-112	9.70	71.8	270	1-104	13.35					83.9	918	9.55
Misc. Diptera	10.3	7	1-4	.19	17.5	10	1-2	.26	17.9	9	1-2	.45					15.3	26	.27
Chironomidae	64.1	812	1-629	22.01	75.0	366	1-79	9.39	30.8	41	1-13	2.03					56.8	1219	12.69
Tipulidae	46.2	291	1-163	7.89	2.5	1	1	.03	15.4	10	1-3	.49					21.2	302	3.14
Simuliidae	20.5	17	1-5	.46	37.5	422	1-343	10.83	10.3	5	1-2	.25					22.9	444	4.62
Diaptomus	-	-	-	-	-	-	-	-	5.1	2	1	.10					1.7	2	.02
Sphaeriidae	5.1	19	1-18	.51	-	-	-	-	-	-	-	-					1.7	19	.20
Misc. Aquatics	23.1	13	1-5	.35	35.0	34	1-8	.87	12.8	8	1-2	.40					23.7	55	.57
Misc. Terrestrials	25.6	18	1-8	.49	7.5	4	1-2	.10	12.8	15	1-7	.74					15.2	37	.39
Salmon eggs	-	-	-	-	10.0	28	2-17	.72	84.7	490	1-32	24.23					31.4	518	5.39
Whitefish eggs	-	-	-	-	-	-	-	-	43.6	64	1-12	3.17					14.53	64	.67
Unidentified eggs	15.4	106	1-75	2.87	-	-	-	-	-	-	-	-					5.13	106	1.10
Inanimate material	43.6	105	1-21	2.85	-	-	-	-	20.5	38	2-7	1.88					21.2	143	1.49

Table 9.7 Rockport whitefish stomach contents.

Date	6-16-77				9-1-77				12-5-77				3-22-78				Combined		
	Freq. occur.	Total no.	Range	% occur.	Freq. occur.	Total no.	Range	% occur.	Freq. occur.	Total no.	Range	% occur.	Freq. occur.	Total no.	Range	% occur.	Freq. occur.	Total no.	% occur.
Sample size	20				40				42				11				113		
Ephemeroptera	100.0	1145	4-319	43.57	85.0	1853	1-315	42.19	52.4	162	1-89	13.15	100.0	70	1-12	1.71	77.0	3230	26.14
Plecoptera	45.0	17	1-5	.65	32.5	73	1-39	1.66	59.5	187	1-64	15.18	45.5	9	1-3	.22	46.0	286	2.31
Trichoptera	95.0	329	1-86	12.52	95.0	658	1-58	14.98	81.0	207	1-53	16.80	63.6	13	1-3	.32	86.7	1207	9.77
Misc. Diptera	15.0	3	1	.11	20.0	13	1-5	.30	31.0	25	1-3	2.03	-	-	-	-	21.3	41	.33
Chironomidae	80.0	421	1-145	16.02	90.0	1344	1-289	30.60	14.3	11	1-4	.89	100.0	3771	5-1119	91.89	61.1	5547	44.89
Tipulidae	65.0	120	1-76	4.57	12.5	8	1-2	.18	11.9	12	1-6	.97	18.2	3	1-2	.07	22.1	143	1.16
Simuliidae	65.0	546	1-507	20.78	32.5	405	1-248	9.22	2.4	1	1	.08	90.9	202	1-129	4.92	32.7	1154	9.34
Diaptomus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sphaeriidae	-	-	-	-	-	-	-	-	-	-	-	-	9.1	1	1	.02	.9	1	.01
Misc. Aquatics	25.0	10	1-5	.38	22.5	16	1-4	.36	2.4	1	1	.08	45.5	22	1-15	.54	17.7	49	.40
Misc. Terrestrials	20.0	14	1-11	.53	10.0	5	1-2	.11	73.8	160	1-21	12.99	9.1	1	1	.02	35.4	180	1.46
Salmon eggs					17.5	17	1-4	.39	-	-	-	-	-	-	-	-	6.2	17	.14
Whitefish eggs	-	-	-	-	-	-	-	-	57.1	56	1-7	4.55	-	-	-	-	21.2	56	.45
Unidentified eggs	15.0	12	3-5	.46	-	-	-	-	76.2	407	1-33	33.04	27.3	7	1-4	.17	33.6	426	3.45
Inanimate material	20.0	11	1-8	.42	-	-	-	-	4.8	3	2-2	.24	18.2	5	2-3	.12	7.1	19	.15

Aquatic insects accounted for about 90 percent or more of the total number of food items in the stomachs of mountain whitefish captured at three sites on the Skagit River. The remainder of the stomach contents were composites such as watermites and calanoid copepods, terrestrial insects, fish eggs, and particles of inanimate material such as wood and rocks. In general the most frequently occurring food items (Freq. occur.) were Trichoptera, Ephemeroptera, Chironomidae, and Plecoptera. Members of the order Ephermeroptera accounted for the largest combined number of food items found in stomachs of whitefish captured in the Newhalem and Marblemount reaches followed by Trichoptera and Chironomidae at Newhalem and by Chironomidae and Trichoptera at Marblemount.

For fish captured in the Rockport Reach, Chironomids were found in the largest numbers followed by Ephemeroptera, Trichoptera, and Simuliidae. The predominance of Chironomidae in the combined data for Rockport resulted from the heavy utilixation of this insect group shown by fish collected in March 1978, (91.89 percent). This shift was probably related to the observation that whitefish were captrued in pools near the mouth of the Sauk River in March 1978, and not in the usual riffles as during other sampling times. Pool conditions with sandy bottoms and slower currents should favor chironomid production hence, their availability for whitefish residing in the pools. Another seasonal difference was observed during the salmon sapwning season when fish eggs made up a sizable proportion of the whitefish diets. This was particularly noticeable during the December 1977 sampling period.

Dolly Varden showed a general preference for aquatic insects except during the salmon spawning season, when salmon eggs made up the majority of their diet (Table 9.8). This was evidenced at all three locations. Other items recovered from Dolly Varden stomachs included frogs, salamanders, and juvenile salmonids, and a sucker.

9.4.5 Incidental Species

Other fish species captured incidentally during other fisheries investigations wer were conducting in the study area are listed below:

(a) brook trout (<u>Salvelinus fontinalis</u>)
(b) threespine stickleback (<u>Gasterosteus aculeatus</u>)
(c) sculpins (Cottus sp.) - confirmed <u>Cottus asper</u>, but may be others
(d) longnose dace (<u>Rhinichthys cataractae</u>)
(e) brook lamprey

There was a noted absence of cutthroat trout (<u>Salmo clarki</u>) in te study area. This included smaller tributaries to the Skagit River upstream of the Cascade River (RM 78.1) where sampling ws conducted such as Newhalem, Goodell, Thornton, Sky, Damnation, Alma, Copper, and Diobsud creeks. Sampling conducted by Washington Department of Game (WDG) extending to lower Skagit tributaries found cutthroat trout only as far upstream as Miller Creek (RM 64.7) (WDG 1977, 1978).

Table 9.8 Dolly Varden stomach contents. Samples from Newhalem, Marblemount and Rockport combined.

Date:	June, 1977				September, 1977				December, 1977				March, 1978				Combined			
	Freq. occur.	Total no.	Range	% occur.	Freq. occur.	Total no.	Range	% occur.	Freq. occur.	Total no.	Range	% occur.	Freq. occur.	Total no.	Range	% occur.	Freq. occur.	Total no.	Range	% occur.
Sample size :		2				3				5				5				15		
Ephemeroptera	50.0	2	2	10.53	33.3	1	1	4.0					40.0	20	2-18	10.81	26.67	23	1-18	4.44
Plecoptera	50.0	1	1	5.26									20.0	85	85	45.95	13.33	86	1-85	16.60
Trichoptera	100.0	12	1-11	63.16									40.0	6	1-5	3.24	26.67	18	1-11	3.47
Diptera									20.0	1	1	.35	20.0	1	1	.54	13.33	2	1	.39
Annelida									40.0	16	5-11	5.54	20.0	2	2	1.08	20.0	18	2-11	3.47
Anura									40.0	4	1-3	1.38					13.33	4	1-3	.77
Caudata									20.0	3	3	1.04	20.0	1	1	.54	13.33	4	1-3	.77
Misc.																				
Terrestrials	100.0	2	1	10.53									20.0	1	1	.54	20.0	3	1	.58
Sucker													20.0	1	1	.54	6.67	1	1	.19
Salmonid juveniles	50.0	1	1	5.26	33.3	1	1	4.0	60.0	19	1-10	6.57					33.33	21	1-10	4.05
Salmon eggs					33.3	23	23	92.0	100.0	246	1-121	85.12					40.0	269	1-121	51.93
Unidentified fish eggs													20.0	62	62	33.51	6.67	62	62	11.97
Organic material	50.0	1	1	5.26									40.0	2	1	1.04	20.0	3	1	.58
Inorganic material													20.0	4	4	2.16	6.67	4	4	.77

10.0 SUMMARY AND CONCLUSIONS

10.1 Periphyton and Benthic Insects

10.1.1 Periphyton

Periphyton in the Skagit, Sauk, and Cascade rivers was sampled along transects perpendicular to water flow at six-week intervals from October 1976 to November 1977. Two different sampling methods were employed. Artificial substrates were used through March 1977, and periphyton was collected directly from streambed rocks on subsequent dates. Samples were analyzed to determine chlorophyll a content, and the percent exposure time during the six weeks prior to sampling was calculated for each sampler or sampling location.

Results indicated that exposure to desiccation during flow fluctuations reduced the periphyton standing crop in the Skagit along the stream margins. The amount of periphyton, as indicated by chlorophyll a content, on the artificial substrates during periods of hydroelectric peaking was related to the amount of time the substrates were exposed during dewatering, with a greater amount of periphyton on deeper, less frequently exposed substrates.

During the period of nearly stable flow in 1977, periphyton standing crop was usually greater in the Skagit than in the Sauk or Cascade rivers. The degree of water level fluctuation was similar in all three rivers and the higher standing crop in the Skagit was due to lower turbidity and possibly higher nutrient levels. Enhancement of periphyton growth below reservoirs due to turbidity reduction, discharge of nutrients from the hypolimnion, and stabilization of discharge has been noted frequently (Neel 1963). The stable flow regime during much of 1977, combined with the effects of turbidity reduction and any release of nutrients, resulted in optimal conditions for periphyton growth in the stream margins.

Reduced fluctuation under the stable flow regime was beneficial to the periphyton in shoreline areas of the Skagit. A controlled flow regime in the future would most likely result in a similarly high level of periphyton standing crop.

10.1.2 Benthic Insects

During 1976, benthic insects were sampled bimonthly in the Skagit, Sauk, and Cascade rivers from May through November. In 1977, samples were collected in the Skagit and Sauk in February and bimonthly from May to November. Samples were collected at three to four depths along permanent transects at the sampling stations using a modified Surber sampler. Insect density and community composition, as well as percent exposure time during the two weeks prior to sampling, were determined for each location on the transect.

As a result of exposure during flow fluctuation, the density of benthic insects in exposed shoreline areas of the Skagit was reduced, and the degree of reduction was related to exposure time. During the fluctuating flow regime of 1976, density at unexposed locations in the Skagit was similar to density in Sauk and Cascade in July. However, density at unexposed locations was lower in the Skagit in September.

Community composition in shoreline areas of the Skagit was also affected by flow fluctuation. Species susceptible to stranding or intolerant to exposure to desiccation were eliminated or reduced in the marginal areas of the river. The resulting community composition was dissimilar to composition in deeper, unexposed areas of the Skagit and to composition in the Sauk and Cascade rivers.

During the period of nearly stable flow from late April to mid-November 1977, density at the Skagit River stations was always greater than at the Sauk River stations. Benthic insect abundance at the Skagit Lower Station during July and September 1977 was six to nine times greater than at unexposed sample locations in July and September 1976, indicating that the reduction in flow fluctuation was extremely beneficial to the benthic insect community. During the stable flow period, stranding mortality and drift losses were reduced, and the benthic insect community in the shoreline areas was unexposed for long periods. The enhanced periphyton standing crop may have also contributed to increased insect abundance.

A reduction in water level fluctuation, either by manipulation of flow with existing hydroelectric facilities or by the proposed Copper Creek Dam, would be likely to have the same beneficial effect on benthic insect standing crop.

10.1.3 Experimental Studies

Three species of aquatic insects from the Skagit River, representing the orders Ephemeroptera, Plecoptera, and Trichoptera, were tested in a series of experiments designed to determine their ability to avoid becoming stranded during flow reduction and to survive desiccation on dewatered substrate. The density and composition of aquatic insect communities subjected to fluctuating and non-fluctuating flow regimes in an artificial stream were also compared.

Results from the stranding experiments indicated that substantial numbers of insects, particularly mayflies (Ephemeroptera), may be stranded during flow reductions in the Skagit. The mayfly species tested was also more susceptible to desiccation on exposed substrate, indicating that mayflies are highly vulnerable to the effects of flow fluctuation.

10.2 Plankton Drift

Because of the large number of unbroken, viable specimens collected in the tailrace stations and in the Skagit River below Gorge Dam, it was evident that crustacean zooplankton survived passage through the hydropower dams on the Skagit.

There was zooplankton production in Diablo Reservoir in addition to zooplankton received from Ross Reservoir. However, because of the rapid flush time, Gorge Lake apparently added little to the plankton it received from Diablo Lake.

Diablo Lake was probably the source of most of the zooplankton in the Skagit River below Gorge Powerhouse in 1977. Seasonal plankton abundance fluctuations at the Gorge Forebay Station and the stations downstream reflected the bimodal seasonal fluctuations of Diaptomus, Bosmina, and Daphnia densities in Diablo Lake more than they reflected the unimodal fluctuation of total crustacea observed in Ross Lake in 1972 and 1973 (SCL 1974). However, discharge from Ross Lake was low most of the year and especially low from June through September. In a typical generation year, Ross Lake is probably the primary source of zooplankton at the river stations.

The Diaptomus, Bosmina, and Daphnia densities at the upper river sites had peaks in May or June and another in the fall or winter. At the lower stations, this bimodal trend was damped out. In 1977, the timing of the peak utilization of zooplankton by Skagit chinook fry corresponded with the timing of peak plankton densities observed in 1976 while in 1975 and 1976 they did not. The peak occurrence of zooplankton in coho stomach samples occurred in August in 1976. Feeding on zooplankton by salmonid fry appeared sporadic and opportunistic. Zooplankton was available to salmonid fry as far downriver as the Concrete Station, about 37 river miles downstream of Gorge Powerhouse.

10.3 Spawning

10.3.1 Spawning Depths and Velocities

Depth and velocity were measured over active salmon and steelhead trout redds to determine the preferred spawning ranges. The 80-percent ranges of preferred spawning depths and velocities for Skagit River salmon and steelhead trout were: chinook between 1.7-4.2 ft for depth and 1.8-3.7 ft/sec for velocity; pink between 0.9-2.5 ft for depth and 1.2-3.2 ft/sec for velocity; chum between 1.4-4.4 ft for depth and 0.2-3.0 ft/sec for velocity; steelhead between 0.9-2.9 ft for depth and 1.5-3.0 ft/sec for velocity. By comparison to literature values Skagit River chinook and pink salmon appeared to spawn in both deeper and faster water than the same species in most smaller streams. Depth seemed to be the less critical of the two criteria.

The velocity range for Skagit River chum salmon compared favorably with that reported by another researcher while the depth range was higher and wider. For Skagit River steelhead trout the depth and velocity ranges were similar to those reported in the literature.

10.3.2 Timing of Spawning

Boat and aerial surveys were conducted to determine the timing of spawning for Skagit River chinook, pink, and chum salmon, and steelhead trout. Summer-fall chinook salmon spawned from the last week of August through the end of October with peak spawning between September 4 and September 10. In comparison to other chinook populations in other systems, it appears that the timing of spawning for Skagit River chinook salmon was similar. Upon reviewing historical spawning records, no evidence was found that the spawning timing has undergone a change.

Pink salmon spawned from the last week of September until the last week of October with peak spawning in the first two weeks of October. Chum salmon spawned from early November until late December with peak spawning during the first two weeks of December. Steelhead trout spawned from March to June, but peak spawning was not well defined. Skagit system coho salmon spawned from mid-October to mid-January (Williams et al., 1975).

Boat surveys of chinook spawning areas indicated that redds remained visible after construction for approximately 26 days on the average.

10.3.3 Spawner Distribution

Aerial surveys were conducted over various river sections to determine the spawner distribution of Skagit River chinook (summer-fall) and pink salmon and steelhead trout. For the mainstem Skagit upstream of the Sauk River, the most heavily utilized section on a per-mile-basis was between Copper Creek Dam site and Cascade River for summer-fall chinook and pink salmon. The most heavily utilized section for steelhead upstream of the Sauk River was the section between the Cascade and Sauk rivers. These patterns, particularly for chinook and steelhead, were probably due in part to the influence of nearby fish hatchery and rearing facilities.

Based on Washington Department of Fisheries (WDF) carcass recoveries, the most heavily utilized section for chum salmon spawning was between the Cascade and Sauk rivers.

About 27.5 and 39.5 percent of chinook and pink salmon spawning, respectively, above the Sauk River took place above the Copper Creek Dam site. The 10.2 river miles above the dam site comprised 37.5 percent of the river miles. Approximately 11 and 2 percent of chum salmon and steelhead trout spawning, respectively, above the Baker River, took place above Copper Creek dam site which comprised 27 percent of the river miles.

The relatively high pink salmon utilization of the river section immediately downstream of Newhalem may be attributable to the presence of the Skagit dams. Through their operation, the peak flood flows were reduced which presumably increased the survival of incubating eggs and alevins.

The spawner distribution upstream of Copper Creek Dam site as a proportion of that for the Skagit system was estimated using the above data for chinook, pink, and chum salmon and using other distribution data provided by WDF. An estimated 14, 30, and 7 percent of chinook, pink, and chum salmon spawning in the Skagit system took place above the Copper

Creek Dam site. Based on accessible length of Skagit system tributaries and mainstem areas, a maximum utilization above the project site of 2.4 percent was estimated for coho salmon. Based on peak redd counts from four years, less than 1 percent of the steelhead redds in the mainstem Skagit and Sauk rivers were observed above Copper Creek Dam site.

10.3.4 Low Flow Observations

Fluctuating low flows were observed to drive adult chinook salmon off their redds. The exposed chinook redds that were examined always had residual water in them beneath their surfaces.

10.3.5 Relationship of Spawnable Area to Discharge

Detailed surveys of depth and velocity were conducted in four reference reaches over a range of stream flows. Each measurement of depth and velocity was classified with respect to the 80-percent preferred spawning ranges for each species. The areas that fell within these ranges were designated the estimated spawnable area. The calculated peak spawning flow was defined as the flow that provided the maximum amount of estimated spawnable area.

The peak spawning discharge in the Skagit River upstream of Sauk River was 3,417 cfs for chinook salmon. The peak spawning discharge for pink and chum salmon and steelhead trout was 1,824 cfs. Theoretically these peak flows describe maximized conditions for spawning fish particularly if spawning area was limiting. However, we observed some areas in our Skagit River reference reaches that were potentially spawnable based on depth and velocity, but were not utilized by spawning fish.

The estimates made in this study of spawnable area were based on the two hydraulic parameters of depth and velocity. They did not include other such possibly influential and recognized factors as substrate size, light intensity, intragravel flow, upwelling, dissolved oxygen, and temperature (Bell 1973). Nevertheless, as key criteria, depth and velocity have been among the most widely used determinants of preferred spawning areas (Stalnaker and Arnette 1976) and have often been thought of as two of the most important (Chambers et al. 1955; sams and Pearson 1963).

10.3.6 Potential Spawnable Area

Detailed surveys of depth and velocity were conducted at 20 sample transects for estimation of potential spawning area available to chinook, pink, and chum salmon, and steelhead trout in the upper Skagit.

It was estimated that there were 2,678 $ft^2 \times 10^3$ of potential spawnable area for chinook salmon at a medium flow, 1,843 $ft^2 \times 10^3$ of potential spawnable area for pink salmon at a low flow, 3,841 $ft^2 \times 10^3$ of potential spawnable area for chum salmon at a low flow, and 1,224 $ft^2 \times 10^3$ of potential spawnable area for steelhead trout at a low flow above the Copper Creek Dam site. Between the dam site and the Baker River it was estimated that there were 15,379 $ft^2 \times 10^3$ of potential spawnable area for chinook salmon at a medium flow, 7,104 $ft^2 \times 10^3$ of potential spawnable area for pink salmon at a low flow, 22,483 $ft^2 \times 10^3$ of potential spawnable area for chum salmon at a low flow, and 8,375 $ft^2 \times 10^3$ of potential spawnable area for steelhead trout at a low flow.

Fifteen percent at a medium flow, 21 percent at a low flow, 15 percent at a low flow, and 13 percent at a low flow, of the potential estimated spawnable area on the mainstem Skagit above the Baker River for chinook, pink, and chum salmon, and steelhead trout, respectively, occurred above the Copper Creek Dam site.

The Skagit above the proposed dam site contained 9.3 $ft^2 \times 10^3$, 7.1 $ft^2 \times 10^3$, 14.8 $ft^2 \times 10^3$, and 4.7 $ft^2 \times 10^3$ of spawnable area per acre of wetted area for chinook, pink, and chum salmon, and steelhead trout, respectively. The Skagit between the dam site and the Baker River contained 11.8 $ft^2 \times 10^3$, 6.2 $ft^2 \times 10^3$, and 19.6 $ft^2 \times 10^3$, and 7.3 $ft^2 \times 10^3$, of spawnable area per acre of wetted area for chinook, pink, and chum salmon, and steelhead trout, respectively.

The Skagit River above the Copper Creek Dam site was estimated to contain 263 $ft^2 \times 10^3$/mi of potential chinook salmon spawnable area at a medium flow, 181 $ft^2 \times 10^3$/mi of potential pink salmon spawnable area at a low flow, 377 $ft^2 \times 10^3$/mi of potential chum salmon spawnable area at a low flow and 120 $ft^2 \times 10^3$/mi of potential steehead trout spawnable area at a low flow. Between the dam site and the Baker River, it was estimated that there were 559 $ft^2 \times 10^3$/mi of potential chinook salmon spawnable area at a medium flow, 258 $ft^2 \times 10^3$/mi of potential pink salmon spawnable area at a low flow, 818 $ft^2 \times 10^3$/mi of potential chum salmon spawnable area at a low flow, and 305 $ft^2 \times 10^3$/mi of potential steelhead trout spawnable area at a low flow.

Based upon the amount of potential spawnable area involved, it was concluded that the section of the Skagit River above the proposed Copper Creek Dam site was an important spawning area for the four spwcies discussed. However, for its relative length, the Skagit River above the project site usually contained less potential spawnable area for chinook, pink, and chum salmon, and steelhead trout per river mile than did the other sections of the Skagit between the Copper Creek site and the Baker River. This uneven distribution was most pronounced for chinook and chum salmon, and steelhead trout, with 15, 15, and 13 percent, respectively, of their total estimated spawnable area above the Baker River occurring upstream of the proposed dam. It was less pronounced, though still apparent, with the distribution of the pink salmon spawnable area of which 23 percent of the estimated total occurred above the dam site. This was in spite of the fact that the river above the project site contained 27 percent of the total river miles studied.

The method precludes making statements about the degree of significance of the numerical differences discussed. For chinook and pink salmon, however, the comparisons between potential and observed distribution data were generally good.

Comparisons were not made for chum salmon because dissimilar river sections were used for the two sets of data and agreement of these data was poor for steelhead trout.

The findings of this investigation did not preclude the possibility that the 10.2 mi of river above the Copper Creek Dam site might provide a relatively superior quality and quantity of preferred spawnable area when compared to other sections of the Skagit River not examined in this study. Nor did the study findings preclude the possibility that fry production could be reduced in the Skagit below the Sauk River because of the excessive turbidity, even though the amount of potential spawnable area available to the adult salmon was large.

10.4 Incubation and Emergence

The Skagit River temperature regime has undergone a change as a result of dam construction, but the magnitude of the change is not precisely known. The present temperature regime is warmer than the estimated pre-dam regime, during the fall and early winter when salmon eggs and alevins are incubating in the river gravels.

Under present temperature conditions embryonic development of chinook salmon in the Skagit River occurred from late August to May. An estimated 981 temperature units (TU) were required to mean hatching and about 1,930 TU's were required to mean yolk absorption. While completion of yolk absorption and emergence are not necessarily synonymous, their timing appeared to be similar under natural conditions.

Emergence was calculated to have occurred from mid-December or early January to late April or mid-May depending on temperature with peak emergence occurring from late January to early February. It appears that chinook fry do not delay in the gravel after yolk absorption because: 1) emergent fry were caught by electroshocking in early January; 2) fry held in incubation boxes past yolk absorption had lower condition factors than natural fry; and 3) a portion of the fry caught in emergent nets over natural redds still contained egg yolk.

The developmental rate and TU requirments to hatching and yolk absorption were shown to be influenced by mean incubation temperature and egg size. The relationship with egg size was that the larger and heavier eggs required more TU's to yolk absorption than did the smaller and lighter eggs. Egg size and fry size were shown to be related; the larger the egg the larger the resulting fry. For eggs of similar size from a single female chinook the TU requirements were shown to be highly correlated to mean temperature during the incubation period. Confounding effects are possible when both factors vary simultaneously. The observed effects of mean incubation temperature suggests that the developmental rate was altered by a compensating mechanism so that at higher temperature more TU's were required and at a lower temperature less TU's were required. Such a mechanism would presumably improve fish survival by tending to maintain their emergence at a specific time of year when environmental conditions, food resources, etc., are more favorable.

It does not appear that TU adjustment with higher temperature has been sufficient to shift emergence timing of Skagit River chinooks to that under pre-dam conditions since the first appearance of Skagit River chinook fry precedes that of Sauk and Cascade river fry by about one month. It is likely, however, that by TU adjustment the effect of temperature increases resulting from dam construction on the Skagit River has been dampened.

Condition factor of chinook fry at or near mean yolk absorption ranged from 0.64 to 0.72 and compared favorably with the minimum of those egressing from two Columbia River spawning channels.

During the evolutionary development of these organisms the timing of emergence was presumably set to coincide with conditions favorable to their survival subsequent to emergence. Two of these factors, water temperature and food resource, are related to growth (Baldwin 1956, Brett et al. 1969, Brocksen and Bugge 1974), and presumably to survival. The apparent early emergence of Skagit chinook fry under the present regime appeared to present less favorable conditions, at least in terms of water temperature. Water temperature was still dropping when fry began to emerge in December 1976, and reached its minimum in early March 1977, when an estimated 80-90 percent of fry had already emerged.

The relationship between emergence timing and food resource was not clear. Abundance of aquatic insects was at or near its minimum during the beginning of emergence in December 1976, then increased in February 1977. However, under natural flow conditions, such as in the Sauk River, emergence occurred during a period of generally declining aquatic insect density. Considering the generally low water temperature through this period food resource levels represented by aquatic insects may be of minor importance. Later emergence would seem to better coincide with improving temperature conditions and presumably would improve survival.

A later emergence time than presently observed for Skagit chinook salmon could potentially reduce the losses due to fry stranding. Improved rearing conditions for later emerging fry may shorten the freshwater residence time or at least may allow the onset of growth at an earlier time. Either or both of these would probably reduce stranding losses. A more detailed discussion of factors influencing growth and fry stranding are presented in Sec. 8.0.

The incubation period under the post-dam elevated temperature regime was predicted to be from 4 to 11 weeks shorter for pink salmon, no change to 5 weeks shorter for chum salmon and 10 days shorter to 8 days longer for steelhead trout depending on which model (Burt 1973, or Sauk-Cascade) was used for pre-dam conditions. Coho salmon were not considered since spawning and incubation occurs primarily in tributary streams, out of the influence of the Skagit Project.

The maximum potential temperature effects on incubation period caused by Copper Creek Dam would be to lengthen the incubation period by about two weeks for chinook and pink salmon, and to effect little change for chum salmon and steelhead trout.

10.5 Fry Rearing

10.5.1 Fry Availability

No fry population estimates have been made because of the difficulties of working with an open population. The interacting factors of emergence timing, immigration from tributaries and upstream mortality, and downriver migration, determine fry abundance at the study sites.

The temperature regime during incubation strongly affects the timing of first emergence. Warmer temperatures like those of 1976-1977 advance emergence.

Fry of summer-fall chinook begin emergence in December or January. Peak emergence is in January or February and emergence continues into May. Peak abundance on the bars is normally March or April. Emigration occurs as early as March and upriver abundance declines in May and June. Chinook fry are nearly absent from the study area by August.

Fry of pink salmon begin emergence as early as January. Highest abundance is in April. Pink fry are more abundant in the mainstem Skagit than the tributaries. They were absent from the sampling sites by late May.

Fry of chum salmon are present at the sampling sites from March to early June. They were most abundant in April and May. Nearly all were caught in the mainstem Skagit.

Coho fry are present at the sampling sites all year. They first emerge from February to early April in the tributaries and appear in the Skagit River sites by April. They reside in the study area for about 12 months.

Fry of rainbow-steelhead trout first emerge from June to July. The fry remain in the study area for perhaps two years before emigrating. Some remain as residents, especially in the tributaries.

10.5.2 Fry Size and Condition after Emergence

For chinook, rainbow-steelhead, and coho fry in our study area, there generally was an initial period after first emergence with little increase or even decline in mean length, weight, and condition factors. Within each species, the size and condition at all sites were similar during this period. This initial level period is thought to be partially due to continual emergence of fry from the gravel through this period.

The end of the initial level period, when mean length, weight, and condition factors started to increase, may be when most of the fry population have emerged from the gravel. This point would be somewhat after peak emergence. This would place peak emergence of chinook, coho, and rainbow-steelhead before March, June, and August, respectively. Warmer temperatures during incubation, however, can advance the timing of first emergence and peak emergence, as seen in the 1976 brood of chinook fry.

After the initial level period, there was a tendency for the Sauk River chinook, coho, and rainbow-steelhead fry to be larger and have higher condition factors than the fry from the Cascade or Skagit River during the same week except for the 1976 brood of chinook and for rainbow-steelhead and coho fry in the fall and winter. Fry from the Skagit River tended to be smallest and have the lowest condition factor. Several possible explanations for the divergence between the river sites in chinook, coho, and rainbow-steelhead fry size and condition are suggested.

1. Higher temperatures in the Sauk than in the other systems during the rearing period may differentially promote growth in the Sauk. The Skagit Riverwas cooler than the Sauk River from about March through September 1976, through the chinook fry rearing period and the early part of the coho and rainbow-steelhead fry rearing period. For the rest of the year, the Skagit was warmer than the Sauk. Impoundments on the Skagit have probably increased the temperature of the Skagit at Alma Creek throughout the year, but especially from August through January, compared to pre-dam temperatures (Burt 1973). Rainbow-steelhead fry from the Skagit caught up in size and condition with the fry from the Sauk River during this period when the Skagit River was warmer while coho fry from the Skagit converged in condition factor only. In 1977, there was less difference in temperature between the Sauk and Skagit rivers through the chinook rearing period and less difference in the size and condition of chinook fry in the two rivers than in 1976 except for the last three samples of very large fry from the Sauk River in 1977. Although the Cascade River temperatures were generally lower than the Skagit River temperatures in 1976 and 1977 except for February, March, and April, 1976; chinook, coho, and rainbow-steelhead fry from the Cascade River were generally larger after peak emergence than fry from the Skagit. In the fall, when Cascade River temperatures were much lower than Skagit temperatures, coho and rainbow-steelhead fry from the Skagit River tended to catch up in size and condition to the fry from the Cascade River, but other factors in addition to temperature appeared to keep Skagit fry size and condition low.

2. The food supply in the Skagit River may be reduced due to fluctuations and the resulting increased substrate exposure. Dam-related fluctuations clearly reduce periphyton and benthic insect standing crop in the Skagit River. The reduced flow fluctuations in 1977 may have resulted, in part, in the improved size and condition of chinook fry from the Skagit River in relation to Sauk and Cascade river chinook in 1977 compared to 1976. A lower percentage of empty stomachs in chinook fry

stomach samples from the Skagit in 1977 than in 1976 suggests that more food was available in 1977. Reduced flow fluctuations were not in effect until late April 1977, several months into the chinook rearing period. Analysis of samples of coho and rainbow-steelhead fry which experienced reduced flow fluctuations during the early part of their rearing periods will be helpful in determining the effect of reduced flow fluctuations.

3. There was probably movement of spring chinook fry from tributaries of the Sauk into or through the mainstem Sauk River sampling areas. The initiation of growth may be earlier for spring chinook fry since they probably emerge earlier than summer-fall chinook fry. The extent and timing of migration and the growth pattern for spring chinook fry are not well defined.

4. Water quality may be more favorable to rearing in the Sauk, perhaps related to such parameters as pH and alkalinity. However, higher turbidity in the Sauk in 1977 appeared to play a role in decreased size and condition of chinook fry by reducing benthic production and probably by reducing feeding efficiency.

5. The interaction of several of the above factors may be responsible for the divergence in fry size and condition between sites.

Pink and chum salmon fry were also sampled for size and condition, but the small sizes of the catches prevent the development of strong inferences of peak emergence timing and differences between sites.

10.5.3 Fry Diet

Aquatic insects are the most important component by number in chinook, chum, coho, and rainbow-steelhead fry diets in the Skagit River below Gorge Dam, the Sauk River, and the Cascade River. Chironomids and Ephemeroptera nymphs are the two most important groups of aquatic insects.

Zooplankton utilization by chinook fry in the Skagit River was lower in 1977 when increased solar radiation and decreased flow fluctuations stimulated higher benthic insect production than in 1976. A higher percentage of the chinook fry diet in samples from the Skagit River in 1977 compared to 1976 consisted of Simuliidae larvae, Ephemeroptera nymphs, and Plecoptera nymphs. Despite higher fry densities in the Skagit in 1977, a smaller percentage of empty chinook fry stomachs were found in 1977 than in 1976. The apparently better feeding conditions, as well as warmer temperatures during incubation and rearing, may have caused improved size and condition factors of Skagit chinook fry in 1977. However, despite improved size and condition factor through the rearing period of chinook fry captured in the Cascade River in 1977, there was a larger percentage of empty stomachs in 1977 in the small sample examined.

10.5.4 Fry Stranding

Water level fluctuations caused by fluctuations in power generation at Gorge Dam can result in the stranding of salmon fry in the upper Skagit

River. The estimated total fry mortality due to stranding between Gorge Powerhouse and the Sauk River for 1977 was 540,000. For several reasons, we consider this an overestimate.

Comparisons of stranded fry and unstranded fry from 1976 and 1977 surveys indicated that stranding was selective for fry with higher condition factor. However, when the data were adjusted for changes in the fry due to stranding and handling, no significant differences in condition factor between stranded and unstranded fry were found.

Of the many factors involved in stranding, the rate of flow reduction (ramping rate) and the level of minimum flow were suspected as being most important. Analyses of these factors indicated a correlation between stranding mortality and both ramping rate and the level of minimum flow.

Experiments in a controlled flow channel suggested that learning experience, or the age of fry, may influence the stranding rate. The experiments failed to find evidence linking the duration of steady flow prior to flow reduction to stranding rate or to find evidence that stranding is size selective.

10.6 Other Fishes

Quarterly sampling was conducted in the mainstem Skagit for fishes other than salmon and adult steelhead trout. Mountain whitefish was the most abundant species captured comprising about 89 percent of the catch followed by largescale sucker (6 percent), Dolly Varden char (3 percent), and rainbow-steelhead trout (2 percent). The distribution of mountain whitefish appeared to be proportional to river length except during winter when they were captured only at the Rockport site. However, they were observed visually in upstream areas during winter but were outside the effective range of our sampling gear. They may exhibit a downstream migration pattern in winter or at least a movement to deeper areas in the river. Distribution of Dolly Varden char and rainbow-steelhead trout appeared fairly uniform while largescale suckers were captured at the Rockport site only.

The sexual maturity data indicated that whitefish spawning occurred in December. Spawning times were not determined for the other species but they probably spawn at times normal for their species.

Aquatic insects accounted for the majority of food items in the stomachs of mountain whitefish. They showed a tendency to consume proportionately more chironomids during the winter probably related to a change in habitat at that time. Fish eggs were consumed by whitefish particularly during the fall salmon spawning season. Dolly Varden char primarily utilized aquatic insects except during the fall when salmon eggs dominated their diets. Juvenile salmonids and a sucker also appeared in the stomach contents of Dolly Varden.

Other species captured incidentally to other sampling were (1) brook trout, (2) threespine stickleback, (3) sculpin, (4) brook lamprey, and (5) longnose dace. There was a noted absence of cutthroat trout in Skagit tributaries within the study area.

11.0 IMPACT

11.1 Copper Creek Project

11.1.1 Periphyton and Benthic Insects

The Skagit Lower Station was representative of the river between the proposed Copper Creek Dam site and the mouth of the Sauk River. Environmental conditions were different below the Sauk, due to increased turbidity and smaller substrate size. The Skagit Upper Station, located about 1 mi above the Copper Creek Dam site, was representative of the river above the proposed dam, except for the river immediately below Gorge Powerhouse.

Based on data from these two Skagit stations, mean annual standing crop per-unit-area was equal above and below the dam site in 1977. Mean chlorophyll *a* content of samples collected during May through November 1977, was 3.12 mg/m^2 at the upper station and 3.17 mg/m^2 at the lower station. Standing crop per-unit-area was higher at the lower station during May and June, but higher at the upper station during July, September, and November.

Mean annual standing crop above and below Copper Creek was estimated by two methods, resulting in minimum and maximum estimates (Table 11.1). Areas of the river deeper than 1.5 ft could not be sampled. It was assumed that standing crop in these areas could be as low as zero grams chlorophyll *a* per-unit-area, but no greater than standing crop in areas 1.5-ft deep. The minimum estimates (method 1) were derived by multiplying wetted area between 0.0- and 1.5-ft deep by the appropriate standing crop per-unit-area value, 3.12 mg/m^2 for river sections above Copper Creek, and 3.17 mg/m^2 for sections below. Standing crop in areas deeper than 1.5 ft was assumed to be zero. The maximum standing crop value for a particular section of the river was the sum of the minimum value and an estimate of standing crop in areas deeper than 1.5 ft (method 2). This estimate was derived by multiplying wetted area deeper than 1.5 ft by the mean annual chlorophyll *a* content of samples collected at locations 1.5-ft deep.

The amount of periphyton that would be lost varied with the discharge level and method of calculation. It ranged from a minimum of 0.63-0.98 kg chlorophyll *a* to a maximum of 3.26-4.27 kg. Standing crop calculated by the second method was mainly a function of total wetted area, or discharge. However, standing crop calculated by the first method was a function of the wetted area between 0.0- and 1.5-ft deep, which depended on the shape of the riverbed and did not necessarily increase with increasing discharge. When calculated by the first method, maximum chlorophyll *a* was available at low discharge above Copper Creek and at medium discharge below Copper Creek.

Table 11.1 Mean annual (1977) periphyton standing crop, as indicated by amount of chlorophyll *a*, in the Skagit River between Gorge Powerhouse and the Sauk River at low (L), medium (M), and high (H) discharge. The percentage of the total standing crop above and below Copper Creek is also shown for each discharge level. Two methods were used to calculate standing crop and results are shown separately as minimum and maximum estimates.

Estimate	River section	Chlorophyll *a* (kg) L	Chlorophyll *a* (kg) M	Chlorophyll *a* (kg) H	Percent of total standing crop L	Percent of total standing crop M	Percent of total standing crop H
Minimum	Gorge Powerhouse - Copper Creek	0.98	0.83	0.63	42	35	35
	Copper Creek - Cascade River	0.45	0.37	0.35			
	Copper Creek - Sauk River	1.38	1.57	1.18	58	65	65
	TOTAL (Gorge Powerhouse - Sauk River)	2.36	2.40	1.81			
Maximum	Gorge Powerhouse - Copper Creek	3.26	3.63	4.27	35	35	37
	Copper Creek - Cascade River	1.75	1.83	2.13			
	Copper Creek - Sauk River	6.13	6.77	7.29	65	65	63
	TOTAL (Gorge Powerhouse - Sauk River)	9.39	10.40	11.56			

The percentage of total standing crop above and below Copper Creek indicated the changes in relative productivity at different flows. Of the total river mileage between Gorge Powerhouse and the Sauk River, 37.5 percent lies above Copper Creek and 62.5 percent below. The first method indicates that the section above Copper Creek is more productive per river mile than the section below at low discharge, since it contains 42 percent of the standing crop, but only 37.5 percent of the length. At other discharges, and at all discharges using the second calculation method, the section below Copper Creek is relatively more productive.

Benthic insect standing crop per-unit-area was slightly higher in the river below Copper Creek than above during 1977. Mean density during May through November was 4,951 insects/m^2 at the upper station and 6,252 insects/m^2 at the lower station.

Mean annual benthic insect standing crops (Table 11.2) were estimated using the same procedure used for calculation of the periphyton standing crops. Benthic insect density values were simply substituted for the chlorophyll per-unit-area values.

There is evidence that benthic macroinvertebrate density decreases with increasing water depth and velocity. Needham and Usinger (1956) found that the abundance of most aquatic insect genera was several times greater in shallow, slower moving water of an unregulated stream than in the deeper, faster moving water at midstream. Kennedy (1967) reported that benthic macroinvertebrate density in Convict Creek, California, was highest at depths of 4-5 inches (686 organisms/ft^2) and decreased steadily as depth increased. Density was lowest at 11-12 inches (114 organisms/ft^2), the deepest location sampled. During July and September 1977, when discharge was relatively stable, benthic insect density was always highest at the 6-inch deep locations at both Skagit River stations. Density decreased with increasing depth, and was usually lowest at 1.5 ft. This trend of declining density probably continued beyond depths of 1.5 ft, resulting in much lower density in midstream areas than in the shoreline areas that were 1.5 ft deep. Therefore, the actual standing crop is probably closer to the minimum estimate in Table 11.2 than to the maximum.

The estimated standing crop of benthic insects that would be lost due to construction of the proposed Copper Creek Dam is shown in Table 11.2. Predicted losses ranged from a minimum of 1.57×10^9 - 1.00×10^9 to a maximum of 4.28×10^9 - 5.35×10^9 insects. When calculated by the first method, standing crop above Copper Creek and between Copper Creek and the Cascade River was highest at low flow. In the section below Copper Creek, standing crop was greatest at medium flow. The section of river below Copper Creek was as productive, or more productive per river mile than the section above Copper Creek, regardless of the method of estimation.

The capacity for benthic insect production below Copper Creek is related to the type of flow pattern. Benthic insect standing crop was reduced under the fluctuating flow regime in 1976 and enhanced during the relatively stable flow period in 1977. Benthic insect density in areas

Table 11.2 Mean annual (1977) benthic insect standing crop in the Skagit River between Gorge Powerhouse and the Sauk River at low (L), medium (M), and high (H) discharge. The percentage of the total standing crop above and below Copper Creek is also shown for each discharge level. Two methods were used to estimate standing crop, and results are shown separately as minimum and maximum estimates.

Estimate	River section	Standing crop (Individuals x 10^9) L	M	H	Percent of total standing crop L	M	H
Minimum	Gorge Powerhouse - Copper Creek	1.57	1.33	1.00	37	30	30
	Copper Creek - Cascade River	0.89	0.73	0.69			
	Copper Creek - Sauk River	2.73	3.10	2.32	63	70	70
	TOTAL (Gorge Powerhouse - Sauk River)	4.30	4.43	3.32			
Maximum	Gorge Powerhouse - Copper Creek	4.28	4.67	5.35	29	29	30
	Copper Creek - Cascade River	3.03	3.13	3.62			
	Copper Creek - Sauk River	10.56	11.66	12.40	71	71	70
	TOTAL (Gorge Powerhouse - Sauk River)	14.84	16.33	17.45			

unexposed during th two week period prior to sampling was as high as 1236 insects/m^2 during 1976. Density in exposed areas was always lower than in the unexposed areas. When this maximum density value for fluctuating flow conditions was multiplied by the wetted area 0-1.5 ft deep between Copper Creek and the mouth of the Sauk River, total standing crop estimates of 0.54×10^9, 0.61×10^9, and 0.46×10^9 insects were obtained for low, medium, and high flows, respectively. These estimates are considerably lower than the minimum estimates for stable flow conditions of 2.32×10^9 to 3.10×10^9 insects shown in Table 11.2.

The benefits of flow control in the Skagit were evident during the period of relatively stable flow from late April to mid-November. Both periphyton and benthic standing crops were high when compared with standing crops in the Sauk and Cascade. Benthic insect standing crop in unexposed areas of the river was higher under stable flow conditions in 1977 than under fluctuating flow in 1976. Controlled flows in the future would most likely have the same effect.

11.1.2 Plankton Drift

Copper Creek Reservoir will be similar in volume and retention time to Diablo Reservoir (Table 2.4). The extent of stratification could be as high as that found in Diablo Reservoir. During moderate to low flows in August, September, and October (Table 11.3), fairly long retention times were predicted and would allow plankton production in addition to the biomass received from upstream as in Diablo Reservoir.

Preliminary drawings of Copper Creek Dam indicate power tunnel intakes 110 ft below the full pool elevation, compared to 125 ft in Diablo Dam. If Copper Creek Reservoir stratifies, it is likely that zooplankton will be concentrated in the epilimnion, and avoid entrainment to some degree, extending the plankton retention time longer than the average water retention time and allowing more plankton development.

Like the other reservoirs, some zooplankton will probably be released from Copper Creek Reservoir which could augment the diet of salmonid fry downstream. The amount and seasonal timing is difficult to predict from the data collected in the atypical, low-flow year of 1977.

11.1.3 Spawning Area

Construction of Copper Creek Dam will remove the 10.2 mi of the mainstem Skagit and associated tributaries upstream of the site from access to adult anadromous salmonids. Based on recent escapement levels and observed spawner distribution data, the estimated loss of that portion of the spawning population from the Skagit Basin would amount to 14 percent for chinook salmon, 30 percent for pink salmon, 7 percent for chum salmon, and less than 1 percent for steelhead trout. A maximum estimate of loss for coho salmon was 2.4 percent based on accessible length data. Based on average escapement this would translate to approximately 2,000 adult chinook, 100,000 adult pinks, 2,600 adult chum,

Table 11.3 Predicted average monthly discharge from proposed Copper Creek Reservoir in acre-ft based on USGS records of Skagit River discharge at Alma Creek, 1951-1976, and average retention time in days calculated from full pool storage capacity of 123,000 acre-ft.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
discharge (acre-ft)	357,738	307,862	303,515	298,996	356,754	504,004	508,673	291,307	211,123	279,750	334,715	366,954
retention time (days)	10.66	11.29	12.56	12.34	10.69	7.32	7.50	13.09	17.48	13.63	11.02	10.39

and 37 adult coho. Escapement estimates are not available for steelhead trout.

Chinook, coho, and steelhead production is probably not limited by spawning area in the Skagit River. This is based on the observed densities in our reference reaches and in the Skagit River as a whole and upon the early life history of the juveniles which rear in the Skagit for a period of time before migrating to salt water. For summer-fall chinook salmon it is unlikely that a racially distinct stock was present above the Copper Creek site, but we have no evidence either way.

The river sections downstream of the project site could probably accommodate those chinook, coho, and steelhead adults which would have spawned above the project site.

Because pink and chum juveniles do not rear for an extended period in fresh water, spawning area may be limiting for the adults. This is especially true in the upstream areas for pink salmon which utilized it so heavily.

Because of the partial protection provided by the present dams, the area immediately downstream of Newhalem acts as a buffer against flood flows. As natural inflow is added progressively downstream, this protection is reduced. A significant portion of this would be lost with construction of Copper Creek Dam.

11.1.4 Incubation and Emergence

It was predicted that the downstream temperature regime resulting from construction of Copper Creek Dam and Reservoir would either change very little or shift slightly toward predicted pre-dam condition. The maximum potential effects would be to lengthen the incubation period by about two weeks for chinook and pink salmon and to effect little change for chum salmon and steelhead trout.

11.1.5 Fry Rearing. Copper Creek Dam would inundate potential rearing areas along 10.2 mi of the mainstem Skagit River, in the mouths of tributaries between Newhalem and Copper Creek Dam site, in the Newhalem Ponds, and in the County Line Ponds.

Freshwater rearing area is not an important consideration in the production of pink and chum salmon fry. These two species spend little time in upstream areas after emergence. However, chinook, coho, and rainbow-steelhead spend a considerable portion of their early life feeding in freshwater.

Zillges (1977) used several methods to estimate production of coho smolts in different types of freshwater environments. In streams less than 6 yd wide, the number of potential smolts was calculated by multiplying the available rearing area in yd^2 by 0.42 smolts/yd^2, the highest density found by Chapman (1965) in small Oregon streams. In larger streams, the smolt production was calculated by multiplying the accessible length in yards by 2.5 smolts/linear yd, the figure found by Lister and Walker (1966) for the Big Qualicum River. For lakes and reservoirs accessible to coho, the smolt production was calculated by multiplying the yards of shoreline by 1.25, the number of smolts per linear yard on one river bank. Using Zillges′ (1977) methodology, we estimated the coho smolt production potential for the area above river mile (RM) 84 to be 58,887 smolts (Table 11.4). This is 4.0 percent of the potential smolt production we estimated by this methodology for the whole Skagit Basin, including production from the Baker River and its tributaries that were appended in an errata sheet to Zillges (1977).

The lower fry rearing value of the lower Skagit, due to turbidity and siltation, and of the Skagit near Gorge Dam, which is more exposed to dam-related flow fluctuations, is not considered in this simplistic analysis, but the two biases may tend to cancel. However, the 4.0 percent figure may be considered a minimum figure because of the large extent of areas of lower fry rearing value in the lower Skagit.

From standardized electrofishing effort in 1978, coho fry densities at the County Line Station on the mainstem Skagit River reached 1.80 fry/yd of one river bank in June, but were usually much lower. Although standardized electrofishing was discontinued in June 1978, catches of age-0 coho fry remained high in 1976 and 1977 in the mainstem Skagit sites into August, suggesting peak densities may occur later than June. Most coho spawning occurs in the tributaries and coho fry densities may be higher there than in the mainstem Skagit. However, because of considerable mortality of the young salmon from many sources, eventual smolt production should be considerably lower than fry densities. It appears that the smolt production of at least some areas fell short of the maximum production potential estimated by Zillges′ (1977) method.

Coho adult escapements in recent years may have been too low to saturate the fry rearing environment. Zillges (1977) calculated the number of females necessary to produce the potential smolts by dividing the number of smolts by 100, found from the average fry rearing potential and optimum escapement at Minter Creek (Salo and Bayliff 1978). Total desired escapement was then roughly calculated as 2 to 2.5 times the number of females. By these calculations, the estimated smolt production potential of the Skagit drainage, 1,455,191, would require the parentage of 14,552 female spawners, or at the least, 29,104 total spawners. Estimated coho escapements other than hatchery returns from 1965 to 1977 averaged only 15,385 and never reached 29,104 (Table 4.2).

Lister and Walker (1966) found that chinook smolt production in the Big Qualicum River tended to be 0.31 smolts/yd^2 or 4.67 smolts/accessible yd, despite more variable adult escapements. These figures were applied in analysis similar to the one above used for estimating coho smolt potential from Zillges (1977) to streams in the Skagit Basin known to be used by chinook for rearing, spawning, or migration (Williams et al., 1975). The results (Tables 11.5 and 11.6) indicated that 4.4 percent of the potential chinook smolt production would be lost after

Table 11.4 Estimated coho smolt production potential above the proposed Copper Creek Dam site at RM 84.0. Adapted from Zillges (1977), Table 4 and Errata sheet.

Location	Computation	Smolt potential
Newhalem Creek	1,760 yds^2 x .42	739
Goodell Creek	3,168 yds accessible x 2.5	7,920
Martin Creek	1,056 yds^2 x .42	443
Newhalem Ponds, two	2,300 yds perimeter x 1.25	2,875
Thornton Creek	704 yds^2 x .42	296
County Line Ponds, three	1,033 yds perimeter x 1.25	1,291
Damnation Creek	1,056 yds^2 x .42	443
10.2 miles of Skagit R.	17,952 yds accessible x 2.5	44,880
		58,887

$$\frac{\text{Estimated smolt production potential above RM 84.0} = 58,887}{\text{Estimated smolt production potential for Skagit Basin} = 1,455,191} = 4.0\% \text{ smolt prod. pot. lost}$$

Table 11.5 Estimated chinook smolt production potential below the proposed Copper Creek Dam site at RM 84.0. Adapted from Zillges (1977), and Williams et al. (1975).

Stream no.	Name	Accessible length (mi)	Average width (yds)	Chinook smolt potential x 1000
176	Skagit, below Copper Cr.	84.0	-	690.4
177	Tom Moore Slough	2.8	-	23.0
178	Unnamed	1.0	-	8.2
213	Freshwater Slough	3.0	-	24.7
215	N. Fork Skagit	7.3	-	60.0
275	Unnamed	.9	1.0	.5
278	Shiyou Slough	2.2	-	18.1
298	Day Creek Slough	1.5	-	12.3
299	Day	5.0	-	41.1
359	Alder	4.4	2.5	6.0
377	Grandy	4.0	-	32.9
392	Finney	11.7	-	96.2
667	McCleod Slough	2.4	-	19.7
673	Sauk	35.0	-	287.7
677	Unnamed	0.9	1.0	.5
710	Suiattle	45.0	-	369.9
723	Big	0.6	-	4.9
761	Tenas	1.6	4.0	3.5
797	Straight	1.9	2.0	2.1
813	Buck	1.5	-	12.3
897	Lime	1.0	4.0	2.2
919	Downey	1.2	-	9.9
973	Sulpher	1.2	-	9.9
1022	Milk	5.8	-	47.7
1078	Unnamed	2.2	-	18.1
1079	Dan	3.4	4.0	7.4
1092	Unnamed	1.0	1.0	.6
1174	Unnamed	.2	-	1.6
1176	Unnamed	.7	1.0	.4
1204	S. Fork Sauk	12.0	-	98.6
1346	Illabot	2.5	-	20.6
1411	Cascade	18.5	-	152.1
1412	Jordan	.5	3.0	.8
1750	Diobsud	1.7	4.0	3.7
1774	Bacon	6.0	-	49.3
1774	Upper Bacon	2.3	3.0	3.8
1780	Falls	0.3	3.0	.5
			Total	2141.2

Table 11.6 Estimated chinook smolt production potential above the proposed Copper Creek Dam site at RM 84.0 and its comparison with the estimated production potential of the total accessible Skagit drainage. Adapted from Zillges (1977), and Williams et al. (1975).

Stream no.	Name	Accessible length (mi)	Average width (yds)	Chinook smolt potential x 1000
176	Skagit, above Copper Cr.	10.2	-	83.8
1827	Alma	0.3	2	.3
1867	Goodell	1.8	-	14.8
			Total	98.9

$$\frac{\text{Estimated chinook smolt production potential above RM 84.0} = 98.9 \times 10^3}{\text{Estimated chinook smolt production potential for Skagit Basin} = 2240 \times 10^3} = 4.4[illegible]$$

construction of Copper Creek Dam at RM 84.0. The upstream areas of the Skagit River are probably more important for fry rearing than this analysis indicated and, as with coho, this estimate of lost smolt production may be a minimum figure. Washington Department of Fisheries (WDF) data for 1973 to 1976 indicated that 66.4 percent of the mainstem Skagit adult chinook escapement was attributed to the river section upstream of the Sauk River (Sec. 6.4.3.1). In 1978, WDF had difficulty capturing chinook fry for wire tagging at stations on the Skagit River below the mouth of the Sauk until May and fry captured at the downstream stations were larger than those captured above the mouth of the Sauk River (Don Hendricks, WDF, personal communication). These findings suggest that the lower reaches are more important for fry migration than for fry rearing.

Chinook returns in some years were probably large enough to produce fry densities near the carrying capacity. For example, using an egg to smolt survival for chinook salmon of 5 percent from findings of Lister and Walker (1966), a fecundity of 6,400 eggs/female found from spawners captured near Marblemount in 1973, and a sex ratio of 1.5:1 males to females (Russ Orrell, WDF, personal communication), we calculate that an adult return of 17,391 could fill the estimated production potential for the Skagit Basin of 2,24 million chinook smolts. The average return to natural spawning areas from 1965 to 1977 of summer-fall chinook spawners and spring chinook was 14,428 and 2,022, respectively. Slight improvements of the egg to smolt survival figure due to decreased density dependent mortality or environmental factors would allow even average adult returns to fill the fry rearing environment by this estimate. It appears that rearing area is more of a limiting factor than spawning area for chinook in the Skagit Basin, especially since a disproportionate amount of fry production appears to be packed into the mainstem Skagit above the Sauk. Redistribution of overcrowded fry downstream as observed in chinook fry by Lister and Walker (1966) and improved rearing environment below Copper Creek Dam due to reduced flow fluctuations could help mitigate the effects of the loss of rearing area.

Because rainbow-steelhead fry rearing areas are similar to chinook and coho rearing areas, there would probably be about a 4 percent reduction in rainbow-steelhead rearing potential also.

It is more difficult to estimate the extent of fry crowding based on adult returns for rainbow-steelhead fry than for chinook or coho fry because the escapement sizes are not known for rainbow-steelhead adults. Sport catches of winter-run steelhead from the Skagit system averaged 12,378 from 1961-1962 to 1975-1976, but from 1973-1974 to 1975-1976 averaged 6,494. Lucas Slough releases contributed between 30 and 39 percent of the 1963-1964 and 1964-1965 catch (Gary Engman, Washington Department of Game (WDG), personal communication).

Total rainbow-steelhead redd counts from WDG aerial surveys of the Skagit and Sauk rivers averaged 705 from 1975 to 1978. These redd counts are considerably lower than one would expect if rainbow-steelhead escapements were of the size of the coho and chinook returns to the Skagit system in recent years.

Bjornn (1978) found that migrant rainbow-steelhead production from Big Springs Creek in Idaho was limited to 0.56 subyearlings and 0.52 yearling per yd^2 and that the number of migrants were reduced when chinook salmon were added to the stream. This is comparable to the production figures used for coho and chinook smolts. It appears that with recent escapement sizes the steehead fry may be less limited by rearing area than chinook and coho fry.

11.1.6 Other Fishes

Skagit River fishes other than salmon and adult steelhead trout will be affected by the alteration of 10 mi of upriver habitat if Copper Creek Dam is installed. Mountain whitefish are known to reside in lakes and reservoirs and probably could survive in the proposed Copper Creek Reservoir. However, if the Skagit whitefish population exhibits a migration pattern similar to that discussed by Pettit and Wallace (1975) then Copper Creek Dam would block access to upstream spawning grounds. However, no data are available for migration behavior of the Skagit whitefish. Largescale suckers were not observed upstream of the proposed dam site. The species composition of the new reservoir can reasonably be expected to match that of the upstream reservoirs. These reservoirs have fish populations composed predominantly of rainbow trout, but also includes: cutthroat trout, Dolly Varden char, and brook trout.

Downstream of the dam site these fishes will probably not be greatly affected by modified flow fluctuation except as it might affect benthic insect production. Whitefish and Dolly Varden rely heavily on aquatic insects. We have not observed these species stranded from flow fluctuation.

12.0 REFERENCES

12.1 Physical Environment

Burt, W. V. 1973. Natural flow water temperatures in the upper Skagit River. Water Res. Assoc., Corvallis, Oregon. 4 pp.

United States Geological Survey. 1955. Compilation of records of surface waters of the United States through September 1950. Water-supply paper 1316.

United States Geological Survey. 1964. Compilation of records of surface waters of the United States, October 1950 to September 1960. Water-supply paper 1736.

United States Geological Survey. 1971. Surface water supply of the United States, 1961-65. Water-supply paper 1932.

United States Geological Survey. 1974. Surface water supply of the United States, 1966-70. Water-supply paper 2132.

United States Geological Survey. 1970-1977. Water resources data for Washington. Yearly volumes.

12.2 Periphyton and Benthic Insects

American Public Health Association (APHA). 1971. Standard methods for the examination of water and wastewater. 13th ed. Amer. Public Health Assoc., New York. 874 pp.

Brusven, M. A., C. MacPhee, and R. Biggam. 1974. Effects of water fluctuation on benthic insects. Pages 67-79 in Anatomy of a river. Pac. N.W. River Basins Comm., Vancouver, Washington.

Brusven, M. A., and K. V. Prather. 1974. Influence of stream sediments on distribution of macrobenthos. J. Entomol. Soc. British Columbia 71:25-32.

Coleman, M. J., and H. B. N. Hynes. 1970. The vertical distribution of the invertebrate fauna in the bed of a stream. Limnol. Oceanogr. 15:31-40.

Cordone, A. J., and D. W. Kelley. 1961. The influence of inorganic sediment on the aquatic life of streams. California Fish Game 47:189-228.

Fisher, S. G., and A. LaVoy. 1972. Differences in littoral fauna due to fluctuating water levels below a hydroelectric dam. J. Fish. Res. Board Can. 29:1472-1476.

Gaufin, A. 1959. Production of bottom fauna in the Provo River, Utah. Iowa State Coll. J. Sci. 33:395-419.

Hynes, H. B. N. 1961. The invertebrate fauna of a Welsh mountain stream. Arch. Hydrobiol. 57:344-388.

Kennedy, H. D. 1967. Seasonal abundance of aquatic invertebrates and their utilization by hatchery-reared rainbow trout. Dept. Interior, Bur. Sport Fish. Wildl. Tech. Pap. 12. 41 pp.

Kroger, R. L. 1973. Biological effects of fluctuating water levels in the Snake River, Grand Teton National Park, Wyoming. Amer. Midl. Nat. 89:478-481.

MacPhee, C., and M. A. Brusven. 1973. The effects of river fluctuations resulting from hydroelectric peaking on selected aquatic invertebrates. Idaho Water Resour. Res. Inst., Moscow, Idaho. 20 pp.

Malick, J. G. 1977. Ecology of benthic insects of the Cedar River, Washington. Ph.D. Thesis, Univ. Washington. 188 pp.

Mason, W. T., J. B. Anderson, and G. E. Morrison. 1967. A limestone-filled artificial substrate sampler-float unit for collecting macroinvertebrates in large streams. Prog. Fish-Cult. 29:74.

McConnell, W. J., and W. F. Sigler. 1959. Chlorophyll and productivity in a mountain river. Limnol. Oceanogr. 4:335-351.

McIntire, C. D., and H. K. Phinney. 1965. Laboratory studies of periphyton production and community metabolism in lotic environments. Ecol. Monogr. 5:237-258.

McIntire, C. D. 1966. Some effects of current velocity on periphyton communities in laboratory streams. Hydrobiologia 27:559-570.

Needham, P. R., and R. L. Usinger. 1956. Variability in the macrofauna of a single riffle in Prosser Creek, California, as indicated by the Surber sampler. Hilgardia. 24:383-409.

Neel, J. K. 1963. Impact of reservoirs. Pages 575-593 in D. G. Frey, ed. Limnology in North America. Univ. Wisconsin Press, Madison.

Nuttal, P. M. 1972. The effects of sand deposition upon the macroinvertebrate fauna of the River Camel, Cornwall. Freshwater Biol. 2:181-186.

Pearson, W. D., R. H. Kramer, and D. R. Franklin. 1968. Macroinvertebrates in the Green River below Flaming Gorge Dam, 1964-65 and 1967. Proc. Utah Acad. Sci. Arts. Lett. 45:148-167.

Pfitzer, D. W. 1954. Investigations of waters below storage reservoirs in Tennessee. Trans. N. Amer. Wildl. Conf. 19:271-282.

Powell, G. C. 1958. Evaluation of the effects of a power dam water release pattern upon the downstream fishery. Quart. Rep. Colorado Coop. Fish. Res. Unit 4:31-37.

Radford, D. S., and R. Hartland-Rowe. 1971. A preliminary investigation of bottom fauna and invertebrate drift in an unregulated and regulated stream in Alberta. J. App. Ecol. 8:883-903.

Spence, J. A., and H. B. N. Hynes. 1971. Differences in benthos upstream and downstream of an impoundment. J. Fish. Res. Board Can. 28:35-43.

Stockner, J. G., and K. R. S. Shortreed. 1976. Autotrophic production in Carnation Creek, a coastal rainforest stream on Vancouver Island, British Columbia. J. Fish. Res. Board Can. 33:1553-1563.

Surber, E. W. 1937. Rainbow trout and bottom fauna production in one mile of stream. Trans. Amer. Fish. Soc. 66:193-202.

Trotzky, H. M., and R. W. Gregory. 1974. The effects of water flow manipulation below a hydroelectric power dam on the bottom fauna of the upper Kennebec River, Maine. Trans. Amer. Fish. Soc. 103:318-324.

Ward, J. V. 1974. A temperature-stressed ecosystem below a hypolimnial release mountain reservoir. Arch. Hydrobiol. 74:247-275.

Ward, J. V. 1976a. Effects of flow patterns below large dams on stream benthos: a review. Pages 235-253 in J. F. Orsborn and C. H. Allman, eds. Instream flow needs symposium, Vol. II. Amer. Fish. Soc.

Ward, J. V. 1976b. Comparative limnology of differentially regulated sections of a Colorado mountain river. Arch. Hydrobiol. 78:319-342.

Waters, T. F. 1961. Notes on the chlorophyll method of estimating the photosynthetic capacity of stream periphyton. Limnol. Oceanogr. 6:486-488.

Waters, T. F. 1964. Recolonization of denuded stream bottom areas by drift. Trans. Amer. Fish. Soc. 93:311-325.

12.3 Plankton Drift

Armitage, P. D., and M. H. Capper. 1976. The numbers, biomass and transport downstream of microcrustaceans and *Hydra* from Cow Green Reservoir (Upper Teesdale). Freshwater Biol. 6:425-432.

Axelson, J. 1961. Zooplankton and impoundment of two lakes in northern Sweden (Ransaren and Kultsjon) Rep. Inst. Freshwater Res. Drottningholm 42:84-168.

Briggs, J. C. 1948. The quantitative effects of a dam upon the bottom fauna of a small California stream. Trans. Amer. Fish. Soc. 78:70-81.

Brook, A. J., and W. B. Woodward 1956. Some observations on the effects of water inflow and outflow on the plankton of small lakes. J. Animal Ecol. 25:22-35.

Burgner, R. L. 1977. The aquatic environment and fish populations of Diablo and Gorge reservoirs. Report to City of Seattle, Dept. Lighting. 8 pp.

Chandler, D. C. 1937. Fate of typical lake plankton in streams. Ecol. Monogr. 7:447-479.

Cowell, B. 1967. The copepoda and cladocera of a Missouri River reservoir: a comparison of sampling in the reservoir and the discharge. Limnol. Oceanogr. 12:125-136.

Cushing, C. E. 1963. Filter-feeding insect distribution and planktonic food in the Montreal River. Trans. Amer. Fish. Soc. 92:216-219.

Edmondson, W. T., and G. G. Winberg. 1971. A manual on methods for the assessment of secondary productivity in fresh water. I.B.P. Handbook No. 17. Blackwell Sci. Publ., Oxford and Edinburgh. 358 pp.

Gibson, R. J., and D. Galbraith. 1975. The relationships between invertebrate drift and salmonid populations in the Matamek River, Quebec, below a lake. Trans. Amer. Fish. Soc. 104:529-535.

Johnson, W. E. 1964. Quantitative aspects of the pelagic, entromostracon zooplankton of a multibasis lake system over a 6-year period. Verh. Intern. Verein. Limnol. 15:727-734.

King, I. P., and G. T. Orlob. 1973. Final report on the temperature effects of Ross Dam, Skagit River, Washington. Prepared for the Dept. Lighting, City of Seattle, by Water Resources Engineers, Walnut Creek, CA.

Malick, J. G. 1977. Ecology of benthic insects of the Cedar River, Washington. Ph.D. Dissertation, Univ. Washington, Seattle. 188 pp.

Rodhe, W. 1964. Effects of impoundment on water chemistry and plankton in Lake Ransaren (Swedish Lappland). Verh. Intern. Verein. Limnol. 15:437-443.

Seattle City Light. 1973. The aquatic environment, fishes, and fishery, Ross Lake and the Canadian Skagit River. Interim Rep. No. 2, Vol. I, City of Seattle, Dept. Lighting. 378 pp.

Seattle City Light. 1974. The aquatic environment, fishes and fishery, Ross Lake and the Canadian Skagit River. Interim Rep. No. 3, Vol. I. City of Seattle, Dept. Lighting. 207 pp.

Tonolli, V. 1955. The migration currents of zooplankton organisms carried by lacustrine outflow waters. Verh. Intern. Verein. Limnol. 12:412-420.

Ward, J. V. 1975. Downstream fate of zooplankton from a hypolimnial release mountain reservoir. Verh. Intern. Verein. Limnol. 18:1798-1804.

12.4 Salmon and Steelhead

Ames, J., and D. E. Phinney. 1977. 1977 Puget Sound summer-fall chinook methodology: Escapement estimates and goals, run size forecasts, and in-season run size updates. Wash. Dept. Fish., Tech. Rep. 29. 70 pp.

Coleman, P., R. Foster, and V. Fletcher. [In press.] 1977 hatcheries statistical report of production and plantings. Wash. Dept. Fish.

Foster, R., V. Fletcher, and B. Kiser. 1977. 1976 hatcheries statistical report of production and plantings. Wash. Dept. Fish., Prog. Rep. 30.

Foster, R., R. Kolb, and V. Fletcher. 1975. 1974 hatcheries statistical report of production and plantings. Wash. Dept. Fish.

Foster, R., R. Rogers, B. Kiser, and V. Fletcher. 1976. 1975 hatcheries statistical report of production and plantings. Wash. Dept. Fish.

Kolb, R., R. Hager, and V. Fletcher. 1976. Hatchery stream plantings, 1952-1974. 2nd ed. Hatchery Statistical Records Rep. 1, Wash. Dept. Fish.

Kolb, R., R. Hager, B. McMillan, and V. Fletcher. 1975. Hatchery plantings, production by hatchery, 1952-1974. Hatchery Statistical Records Rep. 2, Wash. Dept. Fish.

Orrell, R. F. 1976. Skagit chinook race differentiation study. Wash. Dept. Fish., Proj. Compl. Rep. 53 pp.

Orrell, R. F., Biologist. Personal communication, Wash. Dept. Fish.

Reed, D., ed. 1971. 1970 Annual report. Wash. Dept. Fish.

Washington Department of Game. Hatcheries fish planting records. Seattle Reg. Off. [Unpublished]

Zillges, G. 1977. Methodology for determining Puget Sound coho escapement goals, escapement estimates, pre-season run size prediction, and in-season run assessment. Wash. Dept. Fish., Tech. Rep. 28. 60 pp.

12.5 Spawning

Ames, J., and D. E. Phinney. 1977. 1977 Puget Sound summer-fall chinook methodology: Escapement estimates and goals, run size forecasts, and in-season run size updates. Wash. Dept. Fish., Tech. Rep. 29. 70 pp.

Bell, M. C. 1973. Fisheries handbook of engineering requirements and biological criteria. Fish. Eng. Res. Prog. U.S. Army Corps Eng., N. Pac. Div., Portland, Oregon.

Chambers, J. S., G. H. Allen, and R. T. Pressey. 1955. Research relating to study of spawning grounds in natural areas. Annu. Rep. 1955. Rep. to U.S. Army Corps Eng. by Wash. Dept. Fish. 175 pp.

Collings, M. R. 1974. Generalization of spawning and rearing discharges for several Pacific salmon species in western Washington. U.S. Geol. Surv. Open-File Rep. 39 pp.

Corbett, D. M. 1962. Stream-gaging procedure. U.S. Geol. Surv. Water-Suppl. Paper 888. P. 245.

Curtis, B. 1959. Changes in a river's physical characteristics under substantial reductions in flow due to hydroelectric diversion. California Fish Game 45:181-188.

Dougenik, J. A., and D. E. Sheehan. 1977. SYMAP user's reference manual. 5th ed. Lab. Computer Graphics Spatial Anal., Harvard Univ. September 1975, revised February 1977. 187 pp.

Engman, R. G., personal communication. Fish. Biol., Wash. Dept. Game.

Graybill, J. P. 1974. Effects of discharge in the Cedar River on sockeye salmon spawning area. M.S. Thesis, Univ. Washington, Seattle, Washington. 60 pp.

Heiser, D. W. 1971. Spawning depths and velocities of chum and pink salmon in western Washington. Pages 42-50 in Pink and chum salmon investigations, 1969. Puget Sound Stream Studies, Suppl. Prog. Rep., Wash. Dept. Fish.

Hooper, D. R. 1973. Evaluation of the effects of flows on trout stream ecology. Pacific Gas Elec. Co., Emeryville, California. 97 pp.

Hunter, J. W. 1973. A discussion of game fish in the State of Washington as related to water requirements. Wash. Dept. Game, Olympia, Washington. [Unpublished Manuscript.] 66 pp.

Meekin, T. K. 1967. Observations of exposed fall chinook redds below Chief Joseph Dam during periods of low flow, October 1966 through January 1967. Wash. Dept. Fish., Res. Div. 23 pp.

Miller, J. W. 1976. An analysis of the relationship between sockeye fish production and streamflow levels on the Cedar River. M.S. Thesis, Univ. Washington, Seattle, Washington. 45 pp.

Oppermann, A. Fish. Biol., Wash. Dept. Game. Personal communication.

Orrell, R. F. Fish. Biol., Wash. Dept. Fish. Personal communication.

Sams, R. E., and L. S. Pearson. 1963. A study to develop methods for determining spawning flows for anadromous salmonids. Oregon Fish Comm. [Unpublished manuscript.] 56 pp.

Smith, A. K. 1973. Development and application of spawning velocity and depth criteria for Oregon salmonids. Trans. Amer. Fish. Soc. 102(2): 312-316.

Stalnaker, C. B., and J. L. Arnette. 1976. Methodologies for the determination of stream resource flow requirements: An assessment. Prepared for U.S. Fish Wildl. Serv., Off. Biol. Serv., Western Water Allocation by Utah State Univ., Logan, Utah. 199 p.

Stober, Q. J., and J. P. Graybill. 1974. Effects of discharge in the Cedar River on sockeye salmon spawning area. Univ. Washington, Fish. Res. Inst., Final Rep. FRI-UW-7407. 39 pp.

Thompson, K. E. 1972. Determining stream flows for fish life. Pages 31-46 and 85-103 in Instream flow requirement workshop. Pac. N.W. River Basins Comm.

United States Geological Survey. 1943-1960. Water supply papers. Yearly volumes.

United States Geological Survey. 1961-1977. Water resources data for Washington. Yearly volumes.

Williams, R. W., R. M. Laramie, and J. J. Ames. 1975. A catalog of Washington streams and salmon utilization, Vol. 1, Puget Sound region. Wash. Dept. Fish.

Zillges, G. 1977. Methodology for determining Puget Sound coho escapement goals, escapement estimates, 1977 pre-season run size prediction and in-season run assessment. Wash. Dept. Fish., Tech. Rep. 28. 65 pp.

12.6 Incubation and Emergence

Allen, R. L., and A. C. Moser. 1963-1965, 1967-1969. Rocky Reach chinook salmon spawning channel. Wash. Dept. Fish., Res. Div. Annu. Reps. 61-62, 62-63, 63-64, 65-66, 66-67, 67-68.

Allen, R. L., B. D. Turner, and J. E. Moore. 1969-1972. Wells summer chinook salmon spawning channel. Wash. Dept. Fish., Res. Div. Douglas County Publ. Util. Dist. Contract 022-4204, Annu. Reps. 68-69.

Baldwin, N. S. 1956. Food consumption and growth of brook trout at different temperatures. Trans. Amer. Fish. Soc. 86:323-328.

Brannon, E. 1974. General husbandry and growth. College of Fisheries, Univ. Washington. [Unpublished manuscript.]

Brett, J. R., J. E. Shelbourn, and C. T. Shoop. 1969. Growth rate and body composition of fingerling sockeye salmon, Oncorhynchus nerka, in relation to temperature and ration size. J. Fish. Res. Board Can. 26(9):2363-2393.

Brocksen, R. W., and J. P. Bugge. 1974. Preliminary investigations on the influence of temperature on food assimilation by rainbow trout, Salmo gairdneri Richardson. J. Fish. Biol. 6:93-97.

Burgner, R. L. 1974. Testimony before the Federal Power Commission. Subject: In the Matter of City of Seattle Project No. 553. Held in Washington, D. C. Official Stenographer's Report 28:4403.

Burt, W. V. 1971. Water temperature forecasts for the Skagit River below proposed High Ross Dam with maximum surface elevation of 1,725 feet above sea level. Water Res. Assoc., Corvallis, Oregon. 30 pp.

Burt, W. V. 1973. Natural flow water temperatures in the upper Skagit River. Water Res. Assoc., Corvallis, Oregon. 30 pp.

Chambers, J. S. 1963. Propagation of fall chinook salmon in McNary Dam experimental spawning channel. Summary Rep. 1957-1963, Wash. Dept. Fish., Res. Div. 38 pp.

Gebhards, S. V. 1961. Emergence and mortality of chinook salmon fry in a natural redd. The Progr. Fish-Cult. 23:91.

Johnson, R. C. 1974. Testimony before the Federal Power Commisssion. Subject: In the Matter of City of Seattle Project No. 553. Held at Washington, D.C. Official Stenographer's Report 28:5067, 5080.

Orrell, R. F. 1976. Skagit chinook race differentiation study. Wash. Dept. Fish., Proj. Compl. Rep. 53 pp.

Phillips, R. W., and K V. Koski. 1969. A fry trap method for estimating salmonid survival from egg deposition to fry emergence. J. Fish. Res. Board Can. 26(1):133-141.

Reimers, P. E., and R. E. Loeffel. 1967. The length of residence of juvenile fall chinook salmon in selected Columbia River tributaries. Oregon Fish. Comm. Res. Briefs 13(1):5-19.

Seymour, A. H. 1956. Effects of temperature upon young chinook salmon. Ph.D. Thesis, Univ. Washington, Seattle. 127 pp.

Sheridan, W. L. 1962. Relation of stream temperatures to timing of pink salmon escapements in southeast Alaska. Pages 87-102 in Symposium on pink salmon. H. R. MacMillan Lectures in Fish., Univ. British Columbia, Vancouver, Canada.

Wales, J. H., and M. Coots. 1954. Efficiency of chinook salmon spawning in Fall Creek, California. Trans. Amer. Fish. Soc. 84:137-149.

12.7 Fry Rearing

Bauersfeld, K. 1978. Stranding of juvenile salmon by flow reductions at Mayfield Dam on the Cowlitz River, 1976. Wash. Dept. Fish., Tech. Rep. No. 36. 36 pp.

Bjornn, T. C. 1978. Survival, production, and yield of trout and chinook salmon in the Lemhi River, Idaho. Final Report, Federal Aid to Fish Restoration, Project F-49-R, Salmon and Steelhead Invest. Bull. No. 27, Univ. Idaho. Idaho Dept. of Fish and Game, 57 pp.

Burt, W. V. 1973. Natural flow water temperatures in the upper Skagit River. Water Res. Assoc., Corvallis, Oregon. 4 pp.

Chapman, D. W. 1965. Net production of juvenile coho salmon in three Oregon streams. Trans. Amer. Fish. Soc. 94(1):40-52.

Congleton, J. L., Assist. Professor, U. W., Cooperative Fisheries Research Unit, personal communication.

Engman, G., Fish. Biol., Wash. Dept. Game, personal communication.

Fiscus, H., Fish. Biol., Wash. Dept. Fish., personal communication.

Hendricks, D., Fish. Biol., Wash. Dept. Fish, personal communication.

Lister, D. B., and C. E. Walker. 1966. The effect of flow control on freshwater survival of chum, coho, and chinook salmon in the Big Qualicum River. Canad. Fish. Cult. 37:3-25.

McPhail, J. D., and C. C. Lindsey. 1970. Freshwater fishes of Northwestern Canada and Alaska. Fish. Res. Board Can. Bull. 173. 381 pp.

Noggle, C. C. 1978. Behavioral, physiological and lethal effects of suspended sediment on juvenile salmonids. M.S. thesis, Univ. Washington, Seattle. 87 pp.

Orrell, R. F. 1976. Skagit chinook race differentiation study. Wash. Dept. Fish., Proj. Compl. Rep. 53 pp.

Orrell, R. F., Fish. Biol., Wash. Dept. Fish., personal communication.

Phinney, L. A. 1974a. Further observations of juvenile salmon strandings in the Skagit River, March 1973. Wash. Dept. Fish. 34 pp.

Phinney, L. A. 1974b. Direct examination testimony, Official Stenographers Rep. FPC/City of Seattle, Project No. 553, at Washington, D.C., pp. 4892.

Salo, E. and W. H. Bayliff. 1958. Artificial and natural production of silver salmon (*Oncorhynchus kisutch*), at Minter Creek, Washington. Wash. Dept. Fish., Res. Bull. No. 4, 76 pp.

Seattle City Light. 1974. The aquatic environment, fishes and fishery, Ross Lake and the Canadian Skagit River. Int. Rep. No. 3. City of Seattle, Dept. of Lighting.

Thompson J. S. 1970. The effect of water flow regulation at Gorge Dam on stranding of salmon fry in the Skagit River, 1969-1970. Wash. Dept. Fish., Suppl. Prog. Rep., Power Dam Studies, Management and Research Div. 46 pp.

Williams, R. W., R. M. Laramie, and J. J. Ames. 1975. A catalog of Washington streams and salmon utilization. Vol. 1. Puget Sound region. Wash. Dept. Fish.

Zillges, G. 1977. Methodology for determining Puget Sound coho escapement estimates, 1977 preseason run size prediction and in-season run assessment. Wash. Dept. Fish., Tech. Rep. No. 28, 65 pp.

12.8 Other Fishes

Pettit, S. W. and R. L. Wallace. 1975. Age, growth, and movement of mountain whitefish, *Prosopium williamsoni* (Girard), in the North Fork Clearwater River, Idaho. Trans. Amer. Fish. Soc. 104(1):68-76.

Washington Department of Game. 1977. Skagit River studies. Progress Rep.- December 31, 1977, Cooperative aggreement 14-16-0001-5776 FS and 14-16-0001-6345 IFC. Pp. 48-84.

Washington Department of Game. 1978. Skagit River studies. Progress Rep.- March 31, 1978, Cooperative agreement 14-16-0001-6345 IFC. Pp. 31-60.