Food Competition between Freshwater Sculpins (Genus *Cottus*) and Juvenile Coho Salmon (*Oncorhynchus kisutch*): an Experimental and Ecological Study in a British Columbia Coastal Stream

by Norman R. Ringstad

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FOOD COMPETITION BETWEEN FRESHWATER SCULPINS (GENUS COTTUS) AND JUVENILE COHO SALMON (ONCORHYNCHUS KISUTCH): AN EXPERIMENTAL AND ECOLOGICAL STUDY IN A BRITISH COLUMBIA COASTAL STREAM

by Norman R. Ringstad

(A thesis submitted in partial fulfilment of the requirements for the degree of Master of Science in the Department of Biology, University of Victoria, Victoria, B.C.)

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ABSTRACT

A system of experimental troughs was designed to examine food competition between sculpins and juvenile coho. Manipulation of sculpin densities showed that sculpins at higher than stream densities were able to crop down the benthos sufficiently to significantly reduce drift densities and thus coho growth. At close to natural stream densities sculpins did not limit coho growth. A detailed study of the autecology of the two sculpins *Cottus asper* and *Cottus aleuticus* occurring in Carnation Creek did not alter this conclusion. Juveniles of both sculpin species are found in the estuary. This results from either estuarine spawning or upstream spawning combined with downstream movement from March to July to the estuary, and subsequent metamorphosis of larvae. Upstream migration of young cottids takes place a year later from August to December. In the lowest 1500m of the stream *C. asper* tends to occupy areas with good cover and low current velocity, whereas *C. aleuticus* is restricted to the peripheral areas of *C. asper* habitat and riffles. In the lowest reaches of the stream the ratio of *C. aleuticus* to *C. asper* is 4:1. Above 1500m, in the absence of *C. asper*, *C. aleuticus* occupies all available habitat. *C. aleuticus* is smaller per age group than *C. asper* and the life span of both species is up to seven years. Both species are primarily bottom foragers feeding on aquatic insect larvae. Feeding increases throughout the night with maximal activity at or just before dawn. Some sexually mature adults of both species undertake a

downstream spawning migration in the spring. Most *C. asper* spawn in the estuary while *C. aleuticus* may undergo only local migrations and spawns primarily in freshwater.

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INTRODUCTION

Many small coastal streams in British Columbia which are important spawning and nursery areas for salmonids also contain resident populations of sculpins (Genus *Cottus*). As benthic foragers sculpins occupy space that is also accessible to salmon and trout. Although of no direct commercial value, high sculpin densities suggest an important role in stream ecosystems. Research on the ecological impact of cottids has been restricted to the Pacific Northwest United States and Alaska where they have been studied as potential predators on economically important salmon populations. A literature review (Ringstad and Narver, MS 1973) indicates that while members of this genus are capable of consuming large numbers of salmon eggs and fry, they are not a significant factor in salmon egg survival and thus fry production. Juvenile salmon and adult trout are more damaging predators on fry of their own species than cottids (Shapovalov and Taft, 1954).

In British Columbia the two most abundant sculpin species in coastal streams are the prickly sculpin *Cottus asper* (Richardson) and the Aleutian sculpin *Cottus aleuticus* (Gilbert). Krejsa (1966, 1967) has reviewed the nomenclatural history of both species and documented the complete life history of *C. asper*. Taylor (1966) studied the microhabitat preferences of both species. Both studies were undertaken in the Little Campbell River, a low gradient stream near White Rock in the Lower Fraser Valley.

The purpose of the present study is to evaluate interspecific food competition between sculpins and young coho salmon in a typical west coast Vancouver Island stream.

Preliminary examination of Carnation Creek showed coho (*Oncorhynchus kisutch*) fry to be abundant in pools and backwaters up to 3100 meters (see Fig. 9) where a physical barrier precludes further upstream movement. *Cottus asper* occupies benthic microhabitat in pools under logs, debris and rubble in the lowest 1500m. *C. aleuticus* occupies benthic habitat in riffles in the presence of *C. asper*, but is found in both pool and riffle niches in the absence of *C. asper* up to 3100m.

Competition for space is probably not important. Throughout the warm months competition between coho fry and cottids is minimized by their respective midwater and benthic positions. In winter coho move into tributaries, side channels and backwaters seeking cover under logs, debris and cutbanks (Bustard, MS 1973), while most cottids seem to bury into the gravel and rubble substrate (personal observation).

Competition for food may be important however. In Carnation Creek cottids have been found to rely heavily on the benthic immature stages of the insect orders Ephemeroptera, Plecoptera, Trichoptera, and the families Simuliidae and Chironomidae of the order Diptera (Ringstad and Narver, MS 1973). Coho fry also feed heavily on drifting aquatic insect larvae, and in addition on terrestrial invertebrates. Thus while the feeding behaviour of coho and cottids differs, there may nevertheless be considerable overlap in the food species preferred and consumed.

The objectives of this study are: (1) to measure the effects of *C. aleuticus* density on the food availability and growth of coho fry in experimental troughs, and: (2) to describe the life history and ecology of *Cottus asper* and *Cottus aleuticus* with particular emphasis on temporal and spatial distribution, relative abundance, diel feeding, and growth.

The present work forms part of a co-operative study on the impact of logging and silvicultural practices on the productive capacity of salmon and trout streams. Logging of the Carnation Creek watershed is to begin in the fall of 1974. Since sculpins contribute to the natural stream productivity, including possibly the production level of juvenile coho, knowledge of their role as competitors with salmon was considered imperative prior to measuring the physical and biological effects of logging.

MATERIALS AND METHODS

I. Description of Study Area

Carnation Creek is located 8 kilometers from the mouth of Alberni Inlet in Barkley Sound on the west coast of Vancouver Island (Fig. 1). The watershed is approximately $29km^2$ and the creek 6.5km long, emptying into Numukamis Bay.

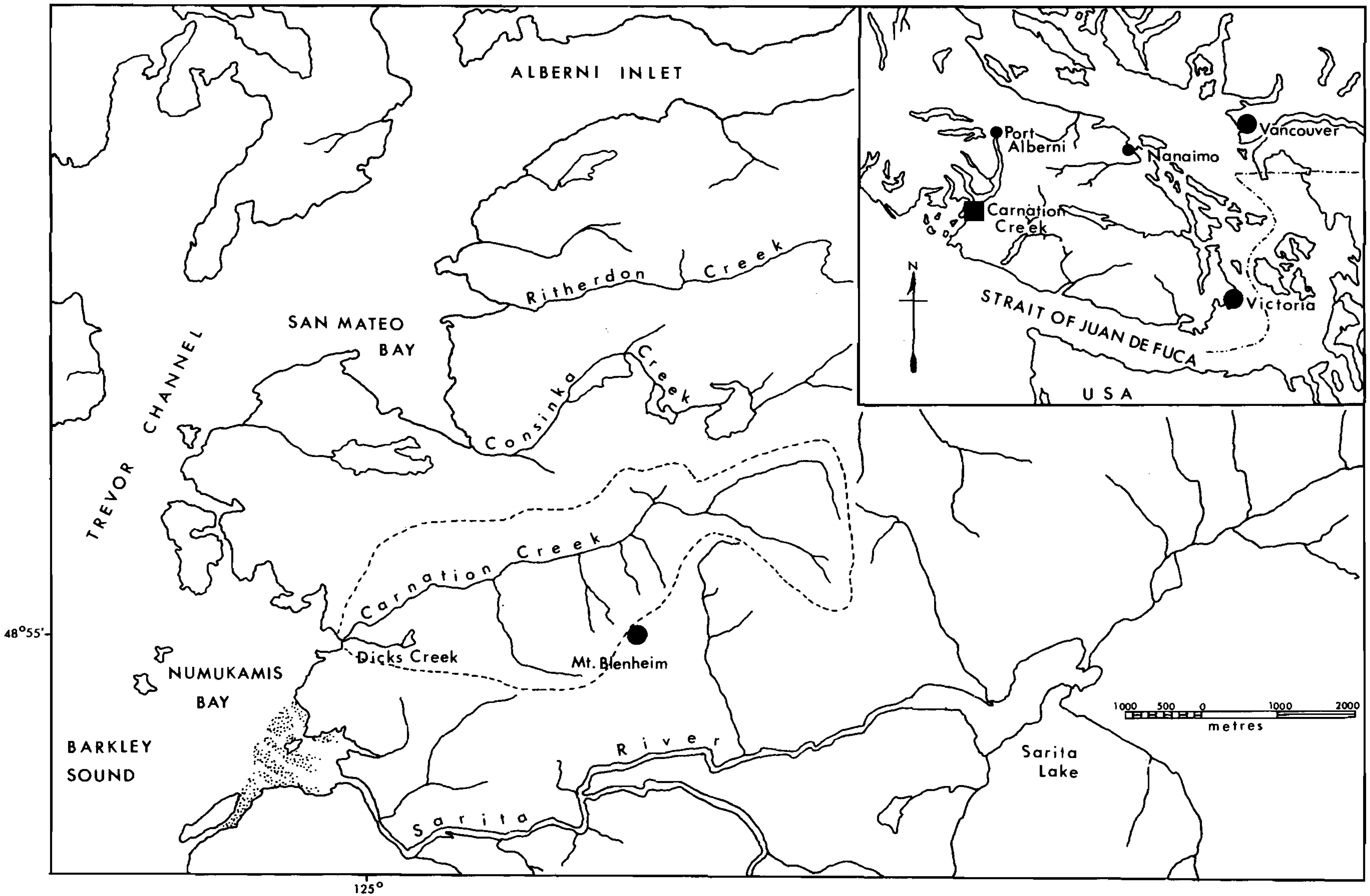
Carnation Creek, typical of most Vancouver Island west coast streams, consists of a high ratio pool to riffle complex. The lower reaches form a 200m long low gradient gravelly estuary and tidal mud flats. The stream has a highly variable discharge reaching a maximum of up to 28.31 cubic meters per second (1,000 cubic feet per second) during intense spring rainfall. In the late summer the discharge reaches a minimum of less than $0.02m^3$/sec (0.7 c.f.s.) at which time the flow in the lowest section (0 - 500m) and the upper section of the stream (2500 - 3100m) becomes subsurface, leaving large isolated pools.

The dominant vegetation of the watershed consists of overmature stands of western hemlock (*Tsuga heterophyla*), amabilis fir (*Abies amabilis*), western red cedar (*Thuja plicata*), and sitka spruce (*Picea sitchensis*). Red alder (*Alnus rubra*), comprises most of the trees along the stream channel (Oswald, 1973). Streamside shrubs include salmonberry (*Rubus spectabilis*), stink current (*Ribes bracteosum*), blueberry (*Vaccinium ovalifolium*), and salal (*Gaultheria shallon*). Oswald (1973) has documented the soil types and geology of the watershed.

The Department of the Environment has been monitoring the physical, chemical, and biological parameters of Carnation Creek since 1970.

FIGURE 1

Map of Carnation Creek watershed
with Vancouver Island inset.



ALBERNI INLET
Ritherdon Creek
SAN MATEO BAY
Consinka Creek
TREVOR CHANNEL
Carnation Creek
Dicks Creek
Mt. Blenheim
48°55'
NUMUKAMIS BAY
BARKLEY SOUND
Sarita River
Sarita Lake
125°
1000 500 0 1000 2000
metres
Port Alberni
Nanaimo
Vancouver
Carnation Creek
N
STRAIT OF JUAN DE FUCA
Victoria
USA

Annual rainfall ranges between 277.5 - 375cm. The mean summer discharge is 0.184m^3/sec (6.5 c.f.s.). Stream temperatures range from 1.5 - 13^{o}c, with a mean summer range of 10 - 12^{o}c. Total dissolved solids range between 15 - 40 mg/l. Primary production is very low but there is considerable periphyton growth in areas exposed to prolonged sunlight.

In order of abundance (numbers) the main stream insect orders are the Ephemeroptera (mayflies), Plecoptera (stoneflies), and the family Chironomidae of the order Diptera. The dominant genera of mayflies in order of abundance are: *Cinygmula, Baetis, Paraleptophlebia, Iron, Ephemerella* (Needhami and Walkeri Groups) and *Ameletus* which is rare. Stoneflies comprise up to 30 per cent of the benthos biomass. The genera in relative abundance are: *Alloperla* (5 species), *Capnia* (2 sp.), *Nemoura, Paraleptra* (2 sp.), and *Kathroperla.* There are three families of chironomids. Other stream insects include the families Limnephilidae and Rhyacophilidae of the order Trichoptera, and the families Simuliidae (blackflies), Tipulidae (craneflies), and Ceratopogonidae (no see-ums) of the Diptera. The stream also contains populations of oligochaetes (Scrivener, personal communication).

Coho (*Oncorhynchus kisutch*) and chum salmon (*O. keta*) spawn in the lower reaches of Carnation Creek. The stream also supports a small run of winter steelhead (*Salmo gairdneri*). During low summer flow the stream has a total carrying capacity of approximately 11,000 coho fry and yearlings, and 2,000 rainbow-steelhead of ages 0 - 2 (Narver, personal communication).

II. Experimental Study

A. Hypothesis: The presence of *Cottus aleuticus* does not significantly affect the growth of coho fry (*Oncorhynchus kisutch*) in artificial stream troughs.

B. Site Location

Dicks Creek, a 1000m long tributary stream emptying into the intertidal area of Carnation Creek was chosen for the site of a series of experimental stream troughs. Fed by a 1.2 acre lake, Dicks Creek offered the advantages of a stable flow and a grade of benthos comparable to Carnation Creek (Narver, personal communication).

C. Experimental Trough Design

Figure 2 shows the experimental trough system. Because of a restricted water supply the eight troughs consisted of four upper troughs in tandem with four lower troughs. A walkway separated the troughs into left and right sides.

The water supply originated from the top of a 6.5m high falls on Dicks Creek and a wooden flume carried the water to a common wooden headbox. Figure 3 shows the schematics of the experimental design. Each trough was divided into an upper riffle and lower pool area. The riffle areas were filled with gravel taken from Dicks Creek. Finer material was placed on the bottom of the riffle with coarser gravel and rocks placed on top. The gravel depth in the riffle was between 8 - 15cm. From 3 - 5cm of gravel was placed in the bottom of each pool.

The trough system, including the flume was covered with plastic to eliminate terrestrial insects as a food source and to keep out falling

FIGURE 2

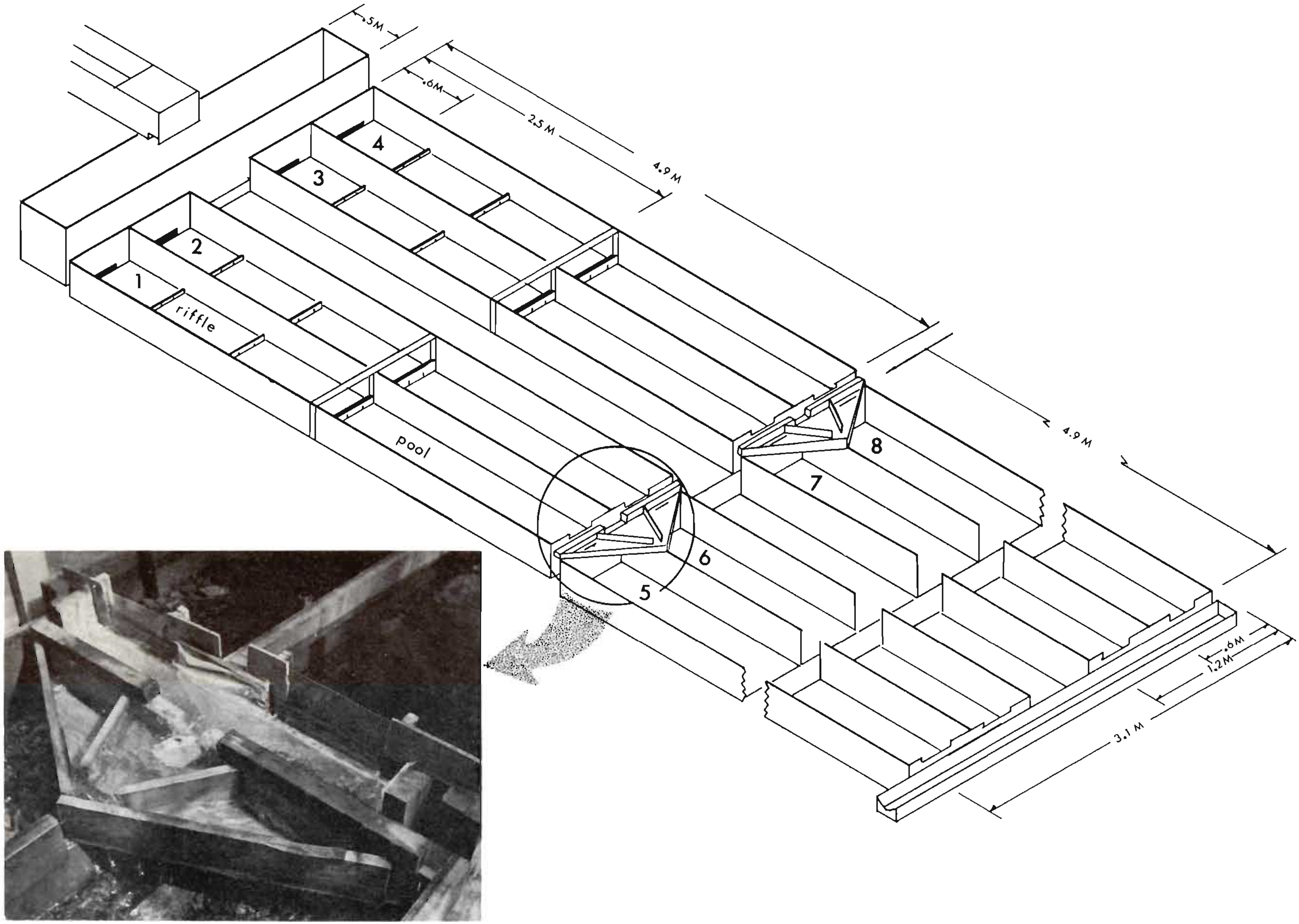
Photograph of experimental
trough system in Dicks Creek.

FIGURE 3

Schematics of experimental trough system.

FIGURE 4

Photograph of water mixer
for experimental troughs.


.5M
.6M
2.5 M
4.9 M
4
3
2
1
riffle
pool
8
7
6
5
4.9 M
.6M
1.2M
3.1 M

debris which would clog screening and complicate the sorting of drift samples. During the experiment the water intake was also screened so that fish in the troughs depended mostly on in situ production of benthos and drift.

Each riffle was inoculated with stream benthos collected from Carnation Creek by placing a 40cm square mouth, 400μ mesh size plankton net in the stream and disturbing the substrate immediately upstream. Natural inoculation from Dicks Creek also took place. The system was left to equilibrate from April 30 to July 30. During this time monitoring and calibration of the following parameters were undertaken.

i. Stream Temperature: taken in the outflow flume daily and recorded in degrees centigrade. Periodically the temperature was taken in the inflow flume and pools to check for a temperature gradient.

ii. Minimum-Maximum Air Temperature: Recorded daily in degrees centigrade.

iii. Discharge Volume From Individual Troughs: Taken daily with a stop watch and a calibrated five-gallon bucket from the outflows of the four lower troughs. Between April and July the water passing from the upper to the lower set of troughs was not mixed, thus discharge measured from the outflow of a trough was also the discharge for the trough immediately above it. From this preliminary data plus daily readings of the water level in the outflow flume a discharge graph was constructed. Beginning August 1, 1973, the water passing from the upper two troughs of one side was thoroughly mixed then split equally into the lower troughs immediately below (Fig. 4, refer to Fig. 3). Discharge measurements from this time on were checked against the discharge curve.

iv. Food Potential: A series of drift (in this study refers to immature and emerging aquatic insects originating from the benthos) samples was taken from the ends of individual riffles on June 15 and June 23, 1973. Samples were collected by inserting a 100μ mesh size, 237mm wide mouth drift net into a wooden collar which spanned the width of the riffle. The collar insured passage of all water through the drift net. The nets sampled for 24 hours at the end of which time benthos from each sampler was was washed into individual jars containing 5 per cent formalin. During the sampling period a 400μ mesh size plankton net was placed in the inflow flume to eliminate Dicks Creek drift. Thus the drift collected in the trough nets originated from the riffle immediately upstream. In the lab each drift sample was divided into quarters with a Folsom Plankton Splitter, and an estimate of the total number of organisms was made by analysing one of the quarter samples. Subsampling gave estimates within 5 per cent when checked against 6 full samples. Organisms were mostly identified to order and a few to family. The object of these counts was to examine the similarity of the food grade among troughs.

All other parameters were assumed to have an equal effect on all troughs.

By the second week in July the discharge in Dicks Creek became critically low (less than $0.006m^3$/sec). The position of Dicks Lake allowed the construction of a siphon system. The siphon consisted of three plastic irrigation pipes (2 @ 6.5cm and 1 @ 7.6cm) suspended from a raft in the middle of the lake and extending 154 meters emptying water in the stream channel. This system was in operation from July 23 to the end of the experiment in September.

One week before the experiment began, the stream 20m above the flume entrance was channeled through a 40cm square mouth, 400μ mesh size plankton net to eliminate lake drift, terrestrial food input, and excess drifting benthos.

D. Trough Experiment Procedures

The experiment consisted of replicating four treatments in which the effects of increasing densities of *Cottus aleuticus* on the growth of a constant density of coho fry was determined. Increasing sculpin densities would be expected to reduce the standing crop of benthos in trough riffles in turn lowering the drift available as food for coho in the trough pools. Each treatment was replicated once. The tandem arrangement of troughs meant that food originating in the upper troughs drifted into the lower troughs. To permit assessment of this effect a full complement of treatments randomly occupied the upper troughs and another complement the lower troughs.

Cottus aleuticus of the age groups 1+, 2+, 3+ (40 - 65mm range) and age 0 coho ($\bar{X}$ = 48 ± 0.5mm) comprised the fish populations. These size ranges were chosen for two reasons: they approximated the size distribution found in Carnation Creek in August and since both species are approximately the same size this increased the probability of food competition.

The number of fish assigned to each trough was determined from density estimates of fish in Carnation Creek. Table 1 summarizes the fish densities and treatment arrangement of the experimental design.

TABLE 1. SUMMARY OF TREATMENTS IN EXPERIMENTAL TROUGHS

	Troughs (see Fig. 3)	SCULPINS No./ Riffle[2]	SCULPINS Density Fish/m^2	SCULPINS No./ Pool	COHO No./ Pool[3]	COHO Density Fish/m^2
[1]Tr. 1	4, 5	0	0	4	4	2.63
Tr. 2	2, 8	3	1.97	4	4	2.63
Tr. 3	1, 7	8	5.26	4	4	2.63
Tr. 4	3, 6	13	8.55	4	4	2.63

Footnotes

[1]Treatment [2]Riffle area 1.52m^2 [3]Pool area 1.52m^2

Population data from 1971 and 1972 indicated *C. aleuticus* densities ranging from 0.01 to 3.0 fish/m^2 and coho fry, 0.76 to 0.82 fish/m^2. Densities of coho fry in pools of Carnation Creek during June of 1972 reached 4.3 fish/m^2. This corresponds to 3.4 fish per trough pool. Since preliminary analysis of drifting trough benthos showed populations of mayflies (Genera *Paraleptophlebia* and *Ameletus*) occurring in the pool habitats, four sculpins (representative of the size range) were placed in each pool to crop this potential food supply. The assumption was made that the effects of the pool sculpins was the same in all eight troughs.

Fish were introduced on August 1, 1973. All fish were weighed to 0.01gm and measured to 0.5mm prior to placement in the troughs. Lengths and weights on coho fry were taken three times between August 1 - September 23, 1973. *Cottus aleuticus* were measured again only at the end of the experiment, September 23. Coho were captured from individual trough pools at night with a hand-dip net and a spotlamp, and held overnight in buckets to insure digestion of food recently ingested.

At the beginning of the experiment trough 7 (treatment 3) was electroshocked to remove several sculpins placed in by mistake. When sculpins were removed at the end of the experiment only three of the expected eight were found in this trough. Preliminary electroshocking was assumed to have killed the other five fish.

To measure the effect sculpins had on the coho food supply, drift samples were taken from the end of each pool on August 15 - 16, August 29 - 30, and September 21 - 22, 1973. The lower four troughs were sampled the first evening and the top four, the second evening of each sampling period.

The high drift densities in the lower troughs on September 21, 1973 (refer to Fig. 14) was the result of an overnight freshet which washed large numbers of Ephemeroptera nymphs from the wooden inflow flume. The drift samples from the upper complement of troughs were not affected since they were taken the next evening by which time the trough discharge had returned to normal.

E. Stream Tests

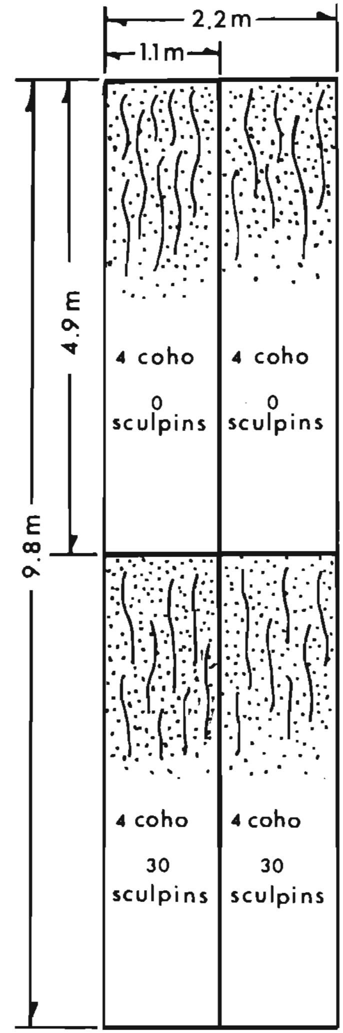
Four riffle-pool enclosures located 100m downstream of the trough system in Dicks Creek were constructed to compare the experimental trough results with a similar test in the natural stream (Fig. 5). Because of restricted space in the stream channel, the enclosures sat two abreast and two in tandem. Figure 6 gives the construction details. After completion of the enclosures, all resident fish were removed by electroshocking.

FIGURE 6

Schematics of Dicks Creek
comparison enclosures.

FIGURE 5

Photograph of stream comparison
enclosures at 175m in Dicks Creek.


2.2m
1.1m
0.6 cm wire mesh
4.9 m
9.8 m
4 coho
0
sculpins
4 coho
0
sculpins
0.6 cm wire mesh
4 coho
30
sculpins
4 coho
30
sculpins
0.6 cm wire mesh

In order to show the maximum effect of sculpins on coho growth, two extremes of treatment were chosen and replicated. The upper two compartments contained four coho fry each and no sculpins and the lower compartment contained four coho and thirty sculpins each (refer to Fig. 6). No effort was made to restrict coho to pools or sculpins to the riffle areas. To eliminate the effects of tandem enclosures the low density treatments were placed upstream of the high density treaments. Preliminary electroshocking in Dicks Creek indicated the relative abundance of coho fry and *Cottus aleuticus* to be similar to the low density treatment so that food availability should have been similar in both upper and lowe enclosures. All other parameters were assumed to have an equal effect on all compartments.

All fish were weighed and measured prior to being placed in the compartments. Forty-five days later all fish were removed by electroshocking and lengths and weights taken. This experiment was conducted at the same time as the trough experiment.

F. Calculation of Growth of Coho

Growth increments in each treatment were evaluated by measuring length and weight changes of individual coho fry. Of the four coho in each pool only the dominant and sub-dominant fry were incorporated in the subsequent analysis since in some treatments one or both subordinate coho died and had to be replaced during the experiment. Growth in weight ($\Delta w_{tot.}$/53 days) and length ($\Delta l_{tot.}$/53 days) were regressed against individual trough discharge, numbers of drifting benthos (total available food) and sculpin densities using the equation:

$$Y = a + bX \qquad (1)$$

III. Life History and Ecology Sampling Techniques

A. Downstream-Upstream Movement

The monitoring of the spring downstream spawning movement and subsequent fall upstream movement of both species of sculpin began in March 1971 with permanent downstream trapping facilities located at 170m. In 1972 a more efficient trapping fence was installed at 100m (Figs. 7, 8, 10). Trap operations are summarized in Table 2.

Each spring before the downstream traps were installed a single cone fyke net was installed at 170m. Catch records provided an indication of when the annual downstream spawning migration of cottids began. All upstream traps were covered with 0.31cm wire mesh to insure capture of the smallest sculpins. Estimates of trap efficiency during fishable discharges are given in Table 2. All traps were checked twice daily; at 0800 hrs. and again at 1900 hrs. Fish removed from the traps were counted, measured and replaced in their respective direction of movement.

B. Population Estimates

Six representative areas of the lowest 2500 meters of the stream were chosen in order to measure a variety of parameters including sculpin densities (Fig. 9). Each study area was positioned in the stream relative to a zero meter reference mark at the head of tidewater (defined as the upper limit of mixohaline waters at summer mean high tide).

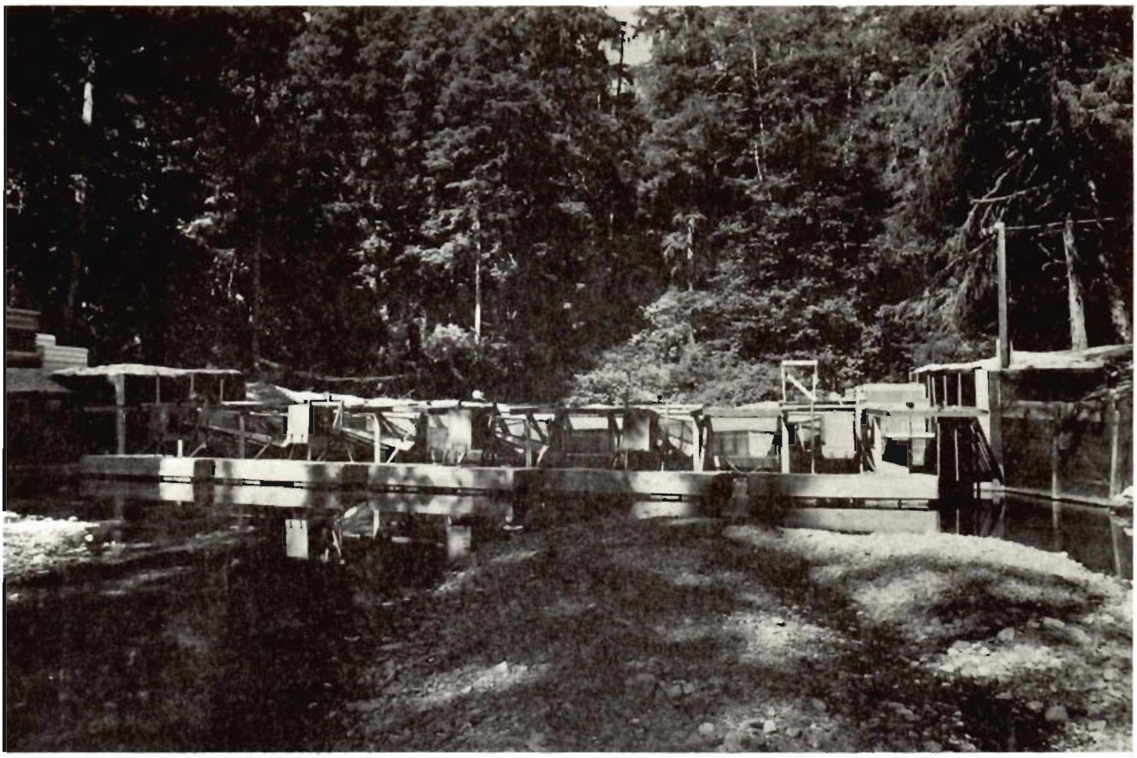
Measurements of relative abundances of both sculpin species (whenever possible) were made in the study sections several times each summer (Table 3).

FIGURE 7

Photograph of downstream trapping facilities in Carnation Creek (1972 - 1973).

FIGURE 8

Photograph of upstream trapping facilities in Carnation Creek (1972 - 1973).



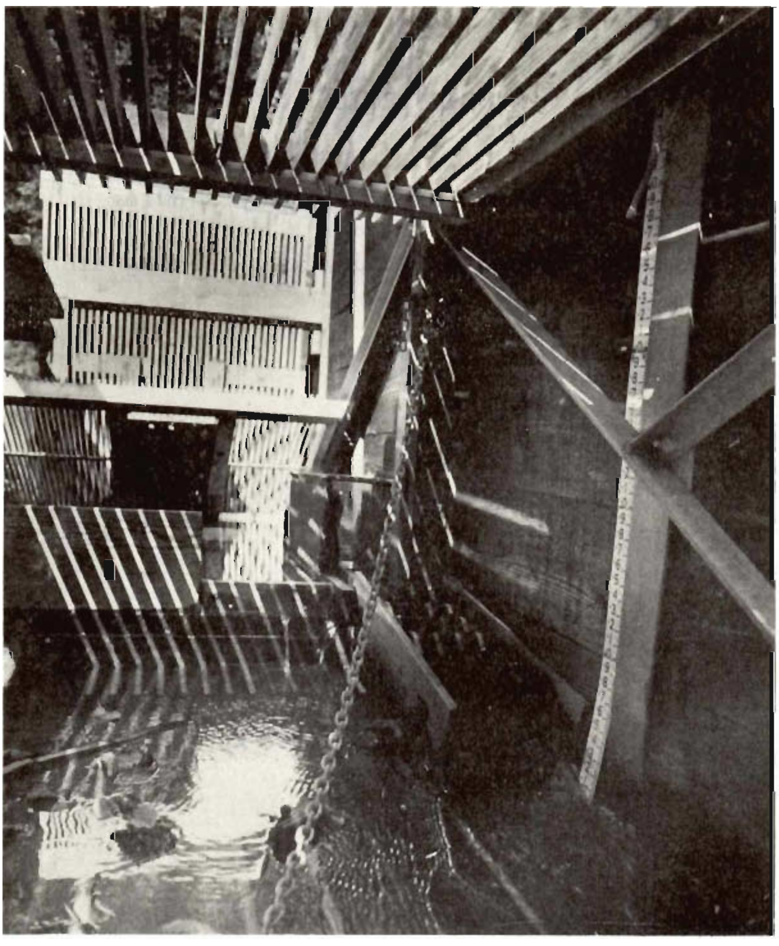
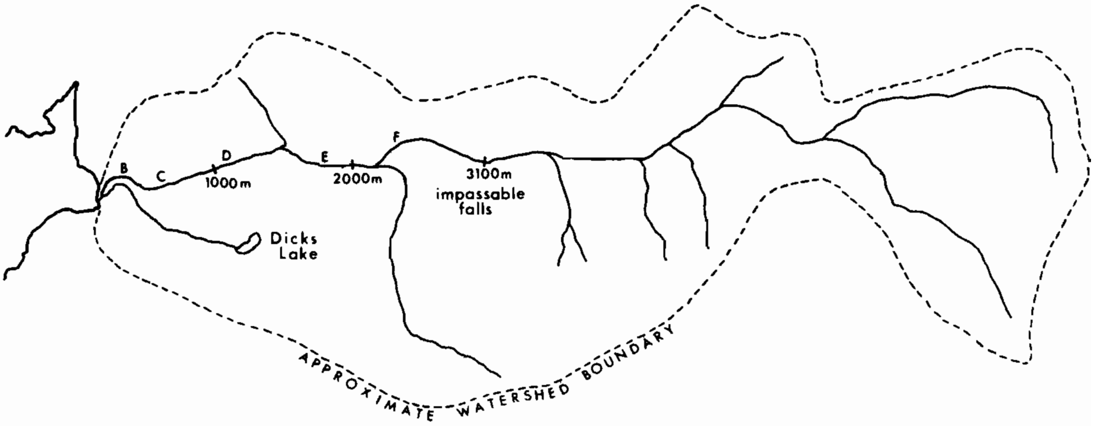


FIGURE 9

Map of Carnation Creek indicating study sections, meterage, impassable falls.

FIGURE 10

Map of Carnation Creek estuary showing meterage trapping facilities, seining areas.


B
C
D
1000m
E
2000m
F
3100m
impassable
falls
Dicks
Lake
APPROXIMATE WATERSHED BOUNDARY

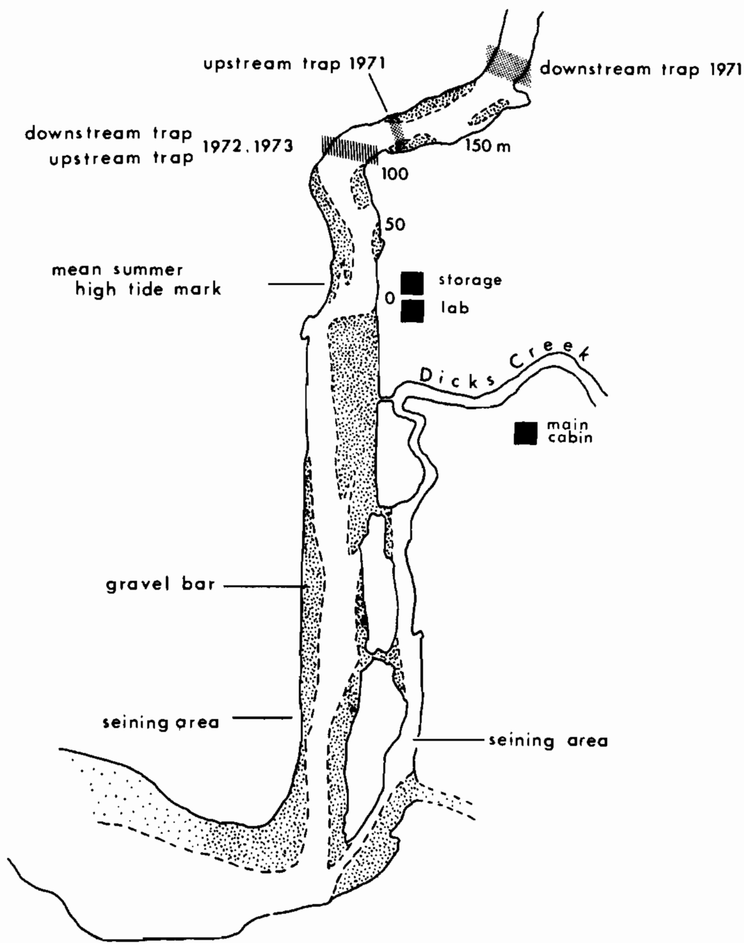

upstream trap 1971
downstream trap 1971
downstream trap
upstream trap
1972, 1973
150 m
100
50
0
storage
lab
mean summer
high tide mark
Dicks Creek
main
cabin
gravel bar
seining area
seining area

TABLE 2. SUMMARY OF TRAP OPERATIONS

TRAP	YEAR	TYPE	PERIOD OF OPERATION	MAXIMUM FISHABLE DISCHARGE m^3/SEC.	% DAYS OPERATED	ESTIMATED % EFFICIENCY
DOWNSTREAM	1971	3 inclined plane wire mesh chutes opening into wooden holding pens	March 1 - Oct. 17	2.12	90	80
	1972 1973	5 inclined plane wire mesh chutes opening into wooden holding pens	April 12 - Oct. 17 Feb. 1 - July 18	4.25 4.25	99.5	100 100
UPSTREAM	1971	Single cone 25x25x62.5 cm steel frame covered with .051 cm galvanized wire mesh. Two .31 cm wire mesh wings extended from the trap to either bank.	May 4 - Oct. 17	.212	60	90
	1972 1973	Single cone 30x75.5x 75 cm steel frame cage covered with .051 cm wire mesh located at head of fish ladder at downstream trap	April 12 - Dec. 5	.425	85-90	25-50

TABLE 3. SUMMARY OF STUDY AREA PARAMETERS

STUDY SECTION		B		C		D		E		F	
RELATIVE POSITION (m)		240 - 410		630 - 755		1160 - 1260		1870 - 2000		2300 - 2415	
		LENGTH m	AREA m^2	LENGTH m	AREA m^2	LENGTH m	AREA m^2	LENGTH m	AREA m^2	LENGTH m	AREA m^2
YEAR	DATE										
1971	August 15, 11	170	861.2	-	-	-	-	130	374.8	-	-
	Sept. 15, 16	170	861.2	125	607.5	100	579.7	130	371.8	115	367.4
1972	July 31 - Aug. 2	59.5	338.7	82.9	347.6	67.7	321.8	64.6	325.4	73.2	245.1
	Sept. 11-13	98.5	377.4	107.3	420.6	65.5	312.9	113.5	358.9	91.5	335
1973	July 25-28	68.6	453.9	107.9	520.9	32.9	240.8	58.8	379.4	70.7	336.3
	Aug. 29-31	63.4	333.8	82.3	310.1	34.1	218.9	52.1	246.3	51.2	190.1
	Sept. 10-14	67.1	286.9	82.3	298.6	43.9	289.3	52.1	114.4	51.8	180.0

All fish captured were anesthetized in 2-phenoxyethanol (concentration 1.5:4500), measured to the nearest millimeter, finclipped (1971 only) and returned to the stream. Population estimates made in August and September of 1971 used the standard Peterson mark and recapture technique:

$$\tilde{N} = MC/R \qquad \text{Ricker, 1968 (2)}$$

where $\tilde{N}$ is an estimate of the population; M equals the number of marked individuals placed in the population; C equals the total number of specimens in the recapture sample; and R is the number of marked recaptures. Standard errors were calculated using the formula:

$$S.E.\tilde{N}. = \frac{(N-M)}{MC}\,\frac{(N-C)}{(N-1)} \qquad \text{Ricker, 1968 (3)}$$

Estimates made in August 1971 were confined to study sections "B" and "E". Specimens in a 40m segment of section "B" were collected using a 2m wide fine mesh seine mounted on two aluminum poles. Seining was carried out in the late evening when it was assumed that active feeding would insure a representative sampling of the population. The specimens were marked with a caudal fin clip, revived in fresh water, and replaced in the stream. Another sample was kept to check for delayed mortality. Reseining for marked individuals in this 40m segment was carried out four hours later.

Recapture using a Smith-Root 400 volt pulsed D.C. Shocker was used to compare fishing gear selectivity. This technique was used the day following the evening seining recapture method, repeating section "B" then section "E". In section "B" the same marked specimens were used for recapture by seining and by shocking.

The similar size distribution of *C. aleuticus* marked and recapture samples strongly suggests that marked sculpins were subject to equal catchability within the population sampled in the 40m segment (Fig. 11). Although both recapture techniques gave comparable results, probably night seining gave more reliable estimates. Seining was employed four hours after the marked specimens were initially released whereas electroshocking did not take place until the following day when electroshocking above the 40m release area revealed a significant emigration of marked *C. aleuticus* specimens. With a decreased number of marked specimens available for recapture in the 40m segment, the Peterson techniques would produce inflated estimates.

In September 1971 population estimates were made in all sections by electroshocking. In section "B" however, estimates were limited to the 40m segment mentioned above and results were extrapolated for the total section.

Population estimates carried out in 1972 and 1973 employed a removal method (Seber and Le Cren, 1967). Each study area was divided into segments. Each segment, enclosed at the upstream and downstream ends by nets stretched across the stream, was shocked twice with a 15 to 45 minute interval between. The time per unit effort of each run was constant. Fish retrieved each time were counted and measured. Fish captured on the first run were not returned to the stream segment until the second run was completed. The results of individual segments were combined to give population estimates of the total section using the equation:

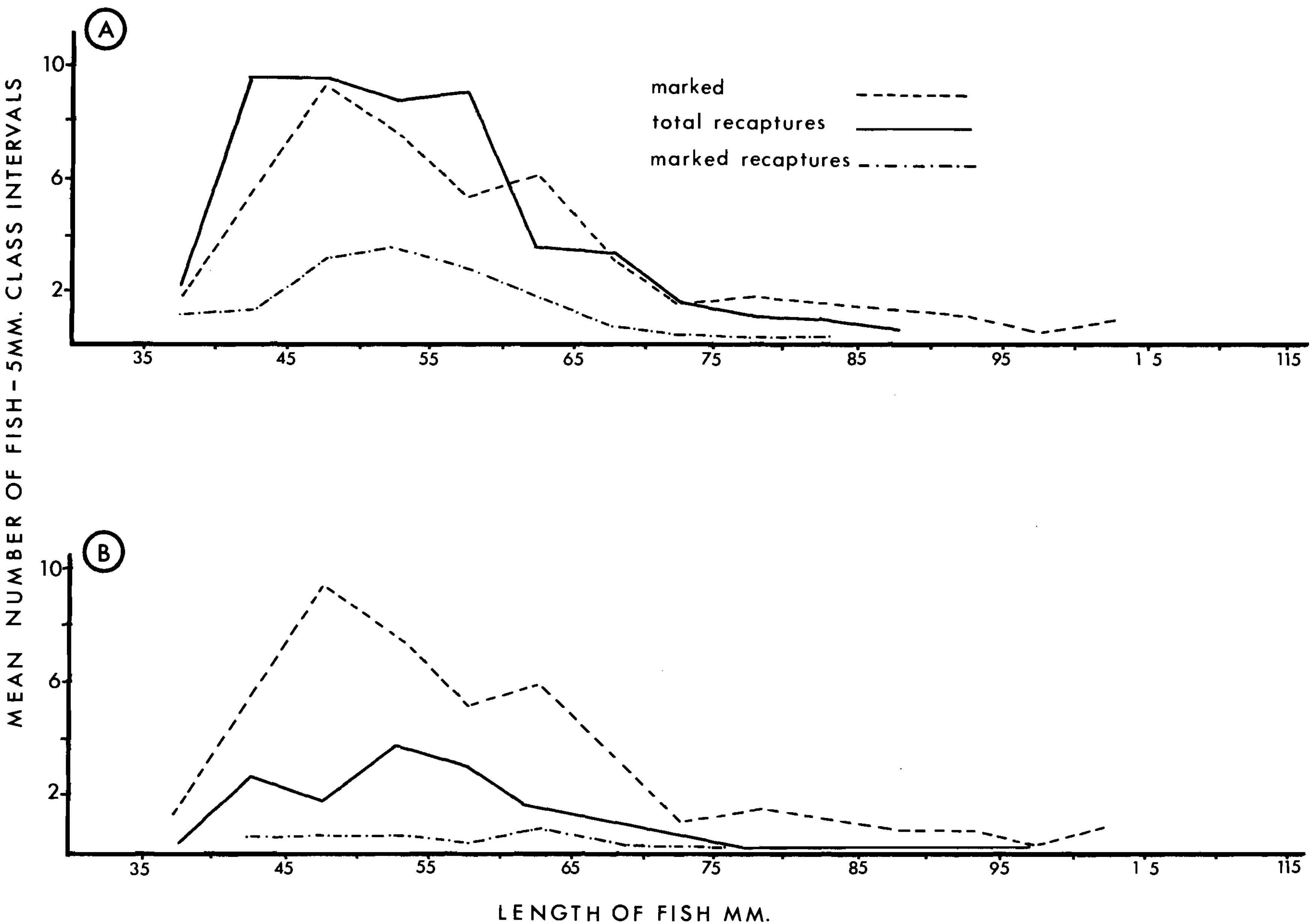
$$N = \frac{C_1^2}{C_1 - C_2} \qquad (4)$$

FIGURE 11

Length composition of mark and recapture *C. aleuticus* individuals from population estimates study section B, August 15, 1971.

A. Night seining

B. Electroshocking



A
B
marked
total recaptures
marked recaptures
MEAN NUMBER OF FISH - 5MM. CLASS INTERVALS
10
6
2
35
45
55
65
75
85
95
1 5
115
LENGTH OF FISH MM.

Variance estimates were made using the formula:

$$\text{VAR } [\tilde{N}] = \frac{C_1{}^2 C_2{}^2 (C_1 + C_2)}{(C_1 - C_2)^4} \qquad (5)$$

C. Microhabitat Survey

In order to better understand the microhabitat requirements of the sculpins a detailed survey in the lowest 2000m of the stream was carried out on August 6, 1971. Subjectively selected riffle and pool areas of the stream between 480 - 560m and 1450 - 1470m were carefully electroshocked. Appendix 1 gives the environmental and habitat parameters also measured in each area. Substrate size was categorized using the classification of Taylor (1966).

(a)	Silt	
(b)	Sand	
(c)	Fine Gravel	Sand < Fine Gravel < 3.0cm
(d)	Coarse Gravel	3.0cm < Coarse Gravel < 8.0cm
(e)	Boulders	8.0cm < Boulders < 35cm

D. Age, Growth, and Reproduction

Age and growth of both species of sculpins were determined by otolith examination of representative samples of fish taken from Carnation Creek estuary in June and August 1971. The smallest cottids caught in the estuary in June were accepted as Age I. Ringstad and Narver (MS 1973) have presented photographs of otoliths representative of each age group of both species.

Length-weight relationships of both species were obtained in August 1973 at which time the fish were assumed to be most fit. Fish were captured by stream seining during the day, anesthetized, dried on paper towel, measured to the nearest millimeter, and weighed to the nearest 0.001gm. Cottids were then returned to the stream.

Information on the size and distribution of *Cottus asper* egg nests in the estuary of Carnation Creek was collected in the spring of 1973. Nests were located by probing rocks with a metal rod and watching for adult males to dart away. Nests were usually located on the underside of large rocks. Egg nests were preserved in 10 per cent formalin and egg counts were made volumetrically.

E. Diel and Seasonal Feeding

Feeding studies in 1971 and 1972 were confined to a riffle pool complex at the 200m mark, and in 1973, at the 1600m mark. Four to six *Cottus aleuticus* were taken every four to six hours over a 24 hour sampling period by pole seining, anesthetized in 2-phenoxyethanol, then placed in 10 per cent formalin. Stomachs were removed from each fish by severing the alimentary tract at the oesophagus and the pyloric sphincter. Wet weights of contents were measured to 0.0001gm on a Sartorius pan balance, then stored in individual vials for subsequent identification. Wet weights of contents were related to fish size (Narver, 1972). Contents were identified to order for most organisms and to family in the case of Diptera for all of the 1971 samples. Only spot checks were made to identify stomach contents of the 1972 and 1973 samples.

RESULTS

I. Experimental Study

Fish in the troughs were observed at regular intervals throughout the experiment (August 1 - September 23, 1973). In the pools coho fry immediately grouped and headed into the current. Within twenty minutes social hierarchies began to be established and within two hours most of the fish had taken up permanent territories. A dominant fish defended the upper one-third of the pool while a sub-dominant occupied space in the middle of the pool. The remaining two fish were subordinates and remained at the lower end of the trough near the substrate or under cover of rocks. This pattern of social behaviour was exhibited in all eight troughs and was maintained throughout the experiment. In a few instances subordinate individuals died and were replaced.

Sculpins released into each trough immediately sought cover under rocks. Throughout the experiment sculpins were seen only at night when they were assumed to be actively foraging for food.

A. Analysis of Basic Trough Data

Water temperatures taken daily between 0800 - 1200 hours during the experiment ranged from 12 - 14.5^{o}C (Appendix 2). There were no temperature differences among troughs. A two-way analysis of variance showed small though significant differences ($p<.05$) among means of individual trough discharges (1.52; 1.45; 1.51; 1.59 l/s). Appendix 3 presents the mean combined discharge of individual troughs for four day intervals.

Measurements of drifting benthos during the pre-experimental period suggested that by June 23, the production of benthos in the various troughs had stabilized (Table 4).

TABLE 4. DRIFT DENSITY MONITORED IN THE UPPER COMPLEMENT OF TROUGHS PRIOR TO EXPERIMENT.

	Number of Organisms/Litre (Based on 24 Hr. Samples)				
Trough Number	1	2	3	4	$\bar{X}$
June 15, 1973	.190	.158	.151	.208	.177
June 23, 1973	.294	.213	.260	.264	.258
July 6, 1973	.247	.226	.182	.174	.207
July 8, 1973	-	-	.202	.188	.195
July 11, 1973	.294	.203	.206	.170	.218
$\bar{X}$	.256	.200	.200	.201	

Despite an overall stability there were some small differences in benthos production among individual troughs. Regression analysis of drifting benthos showed the numbers of organisms to be positively correlated with trough discharge (Fig. 12, A, B, C, and Table 5). Samples were taken five times (n = 18) from the upper complement of troughs prior to the experiment. Appendix 4 gives the taxonomic breakdown to order and to families in some cases, for the drifting benthos for each sample.

TABLE 5. CORRELATION OF DRIFT RATE WITH DISCHARGE VOLUME DURING PRE-EXPERIMENTAL PERIOD (JUNE 15 - JULY 11, 1973).

	r	B	A	Sy.x	t.05[16]	tb.
Total No. Organism/24 Hrs.	.823	156.37	56.30	93.48		5.802***
Ephemeroptera Nymphs/24 Hrs.	.780	44.96	17.18	31.21	2.120	4.997***
Chironomid Larvae/24 Hrs.	.652	60.35	88.64	60.95		3.438**

r = correlation coefficient, B = slope of regression,
A = slope intercept, Sy.x = standard error of estimate
*** significant at p<.01,
** p<.05

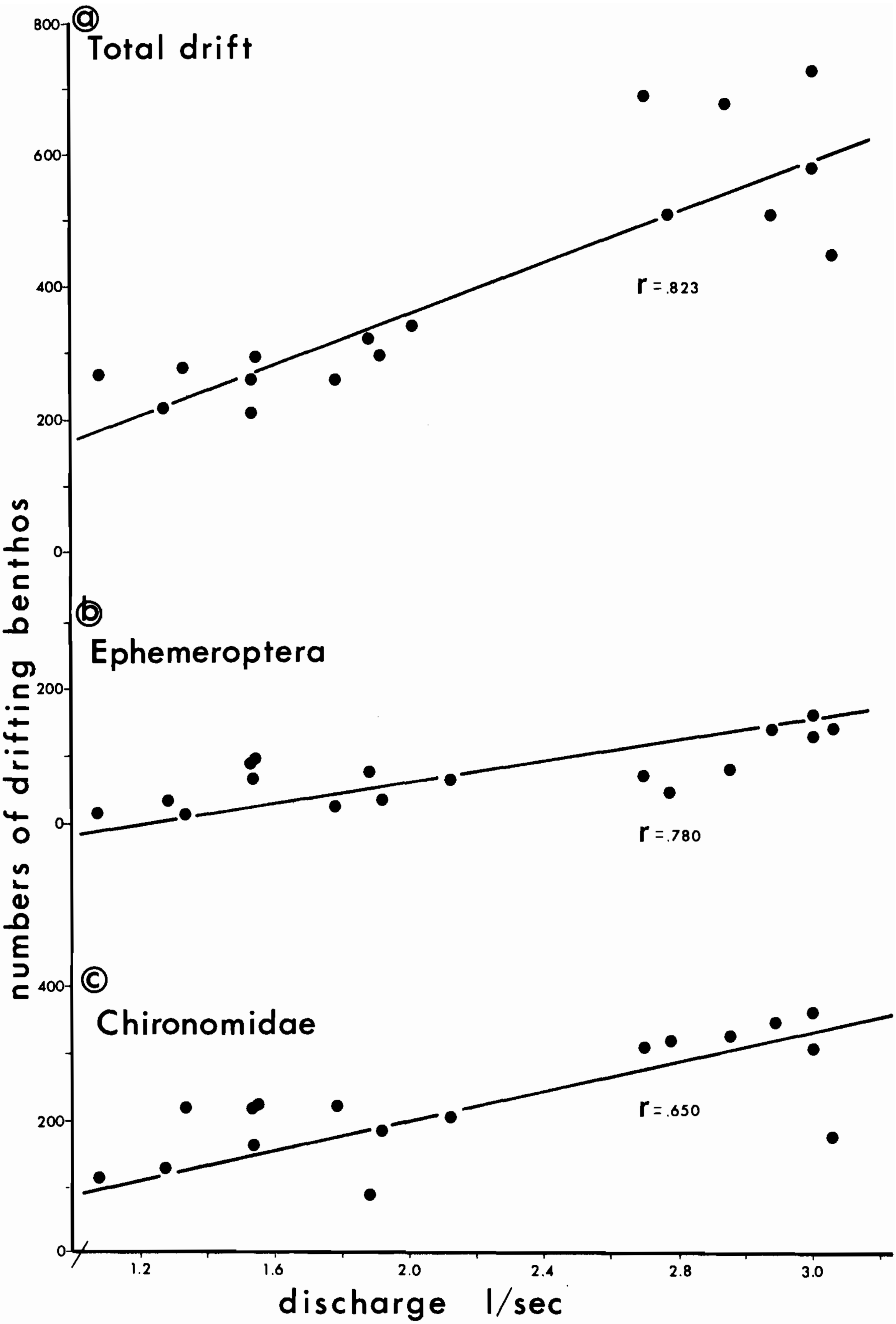
FIGURE 12

Regression of drifting benthos versus discharge in the upper complement of troughs prior to experiment.

A) total drifting benthos.

B) Ephemeroptera nymphs only.

C) Chironomid larvae only.



a
Total drift
r = .823
b
Ephemeroptera
r = .780
c
Chironomidae
r = .650
numbers of drifting benthos
800
600
400
200
0
200
0
400
200
0
1.2
1.6
2.0
2.4
2.8
3.0
discharge l/sec

B. Effects of Sculpin Density on Drifting Benthos in Troughs

During the experiment a significant difference in drift density (# organisms/L) among treatments (1, 2) and (3, 4) became evident with time (Fig. 13). For the last two sampling periods regression of drift rate (# organism/24 hrs.) versus discharge indicated a non-significant correlation (r = .475, tb = 1.323ns). However, regression of mean drift density versus sculpin density for the last two sampling periods showed a significant ($p<.1$) negative correlation (r = -.929, tb = -4.098). At the two higher sculpin densities (treatments 3 and 4) the benthos was apparently cropped down thus reducing the drift density.

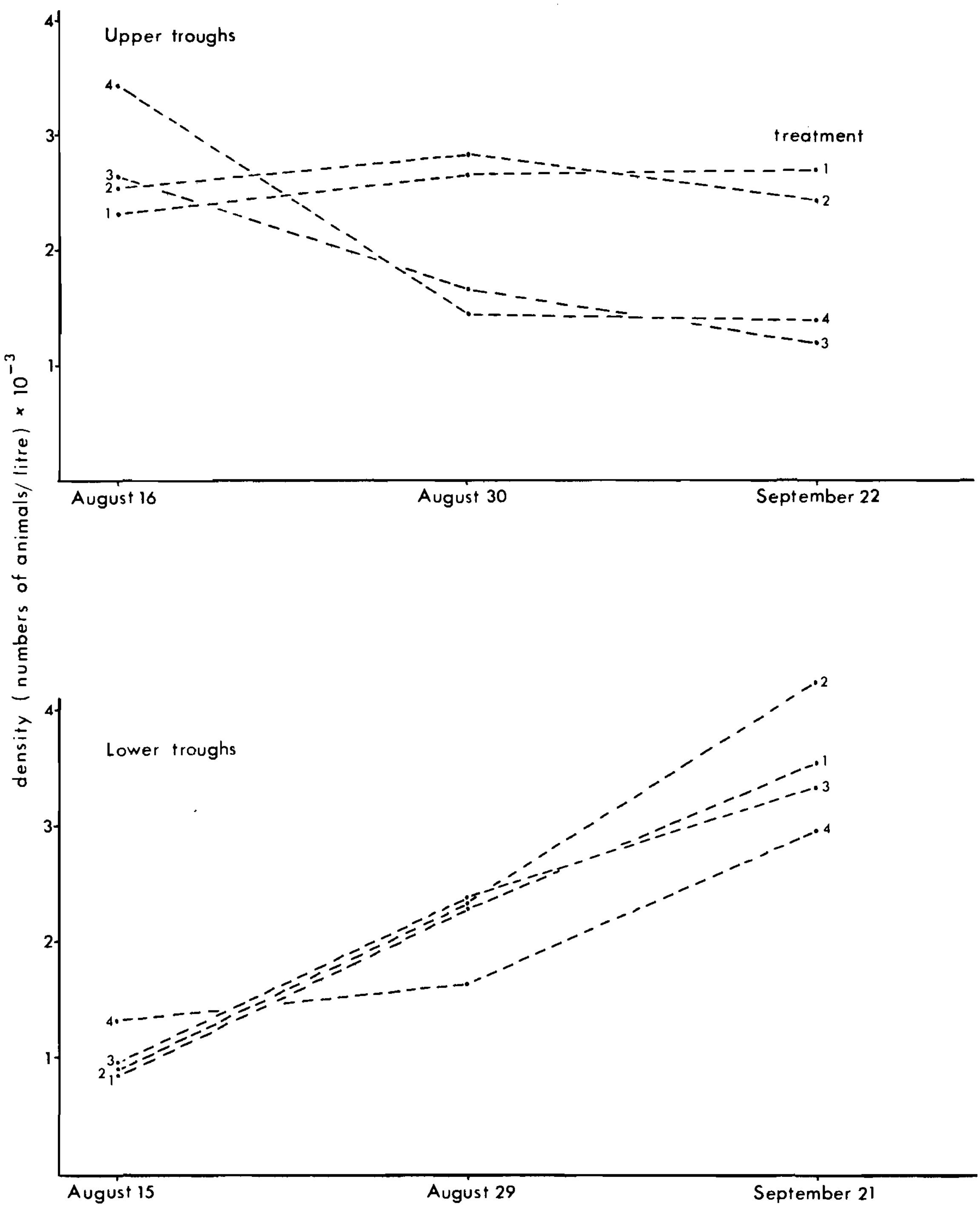
In the lower troughs the density of drifting benthos increased throughout the experimental period (Fig. 14). Within this overall temporal pattern two features are noteworthy. First, regression of drift rate versus discharge for the last two sampling periods indicates a significant ($p<.05$) positive correlation (r = .716, tb = 2.514). Second, treatment 4 (highest sculpin density) showed the least change in density with time, a result which parallels the high density - cropping effect in the upper troughs. That treatment 3 (trough 7) did not show a similar pattern was expected. Electroshocking at the end of the experiment revealed that only three of the original eight sculpins were still living. Correlation between mean density of drifting benthos and sculpin density for the last two sampling periods was not significant (r = -.743, tb = -1.568ns). The extreme differences in aquatic insect production and drift between the upper and lower complement of troughs cannot be explained at this time.

FIGURE 13

Drifting benthos density with time in upper complement of troughs during experiment.

FIGURE 14

Drifting benthos density with time in lower complement of troughs during experiment.



Upper troughs
treatment
August 16
August 30
September 22
Lower troughs
August 15
August 29
September 21
density (numbers of animals/ litre) × 10^{-3}

C. Growth of Coho Fry

(i) Experimental Troughs

With the exception of trough 7, all fish not recovered from the troughs at the end of the experiment were assumed to have been present but not retrievable by electroshocking (Appendix 6). Sculpin growth was not calculated.

Appendix 7 shows coho length, weight, and condition factor defined by the equation:

$$K = \frac{100w\ (gm)}{l^3\ \ (cm)} \qquad \text{Ricker, 1968} \qquad (6)$$

for individual fish for each trough. Growth rates for the dominant and sub-dominant fish in each trough are shown in Table 6. Since some of the subordinate fish died and had to be replaced, they were not included into the growth estimates.

TABLE 6. COMBINED GROWTH INCREMENTS OF DOMINANT AND SUB-DOMINANT COHO FRY.

	Upper Complement of Troughs			Lower Complement of Troughs		
Sculpins/m^2	Trough	*Δw_{gm}	*Δl_{mm}	Trough	Δw_{gm}	Δl_{mm}
0	4	.88	6.5	5	.09	3.5
1.97	2	.35	5.0	8	-.03	3.5
5.26	1	.61	4.0	7	.24	4.0
8.55	3	-.86	1.0	6	-.14	3.0

Footnote:

* Measurement units of growth in weight ($\Delta w_{tot.}$) and growth in length ($\Delta l_{tot.}$) are gm/53 days and mm/53 days respectively.

Regression analysis indicated high negative correlations between sculpin densities and length and weight in both the upper and lower complement of troughs, although only $\Delta l_{tot.}$ produced a significant T_b value (Fig. 15, Table 7).

TABLE 7. SUMMARY OF CORRELATION COEFFICIENTS AND REGRESSION T_b VALUES.

	Upper Complement of Troughs				Lower Complement of Troughs			
	$\Delta w_{tot.}$		$\Delta l_{tot.}$		$\Delta w_{tot.}$		$\Delta l_{tot.}$	
	r	T_b	r	T_b	r	T_b	r	T_b
Sculpin Density	-.845	-2.24	-.979	-6.82	-.702	-1.39	-.719	-1.46
Discharge	.341	.513	.303	.450	.203	.293	.427	.468
Drifting Benthos	.500	.818	.773	1.730	-.473	-.760	-.328	-.491

(ii) Stream Comparison Tests

Individual weight and length changes for the replicates of each treatment were pooled (Table 8).

Preliminary testing of pooled treatment replicates (8 fish) indicated no significant differences in variance of length or weight changes ($.2<p<.1$) between treatments. A t-test showed a significant difference in means between treatments for both length and weight changes ($.1<p<.05$).

FIGURE 15

Regression of growth in length of coho fry versus sculpin density in the upper complement of troughs.

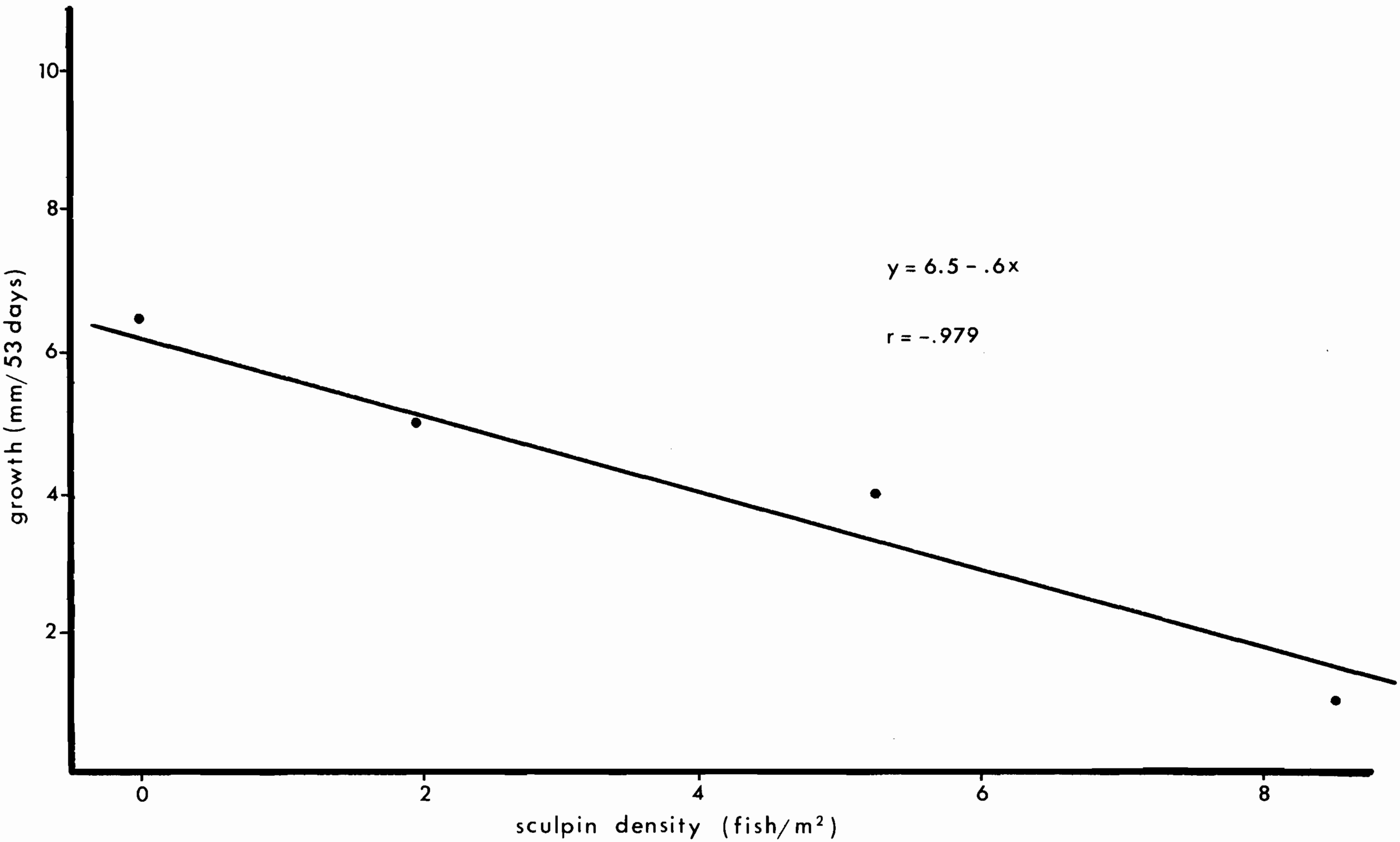

y = 6.5 - .6x
r = -.979
growth (mm/ 53 days)
sculpin density (fish/m²)
10
8
6
4
2
0
2
4
6
8

TABLE 8. LENGTH AND WEIGHT CHANGES OF COHO FRY IN STREAM COMPARISON TEST.

Treatment Sculpins/m^2		Tot. Wt. Change (gm)	Mean Wt. Change (Pooled Replicates)	F	[3]tb	Tot. L. Change (mm)	Mean L. Change (Pooled Replicates)	[4]F	tb
[1]0	(A)	1.309				14.2			
			.357				3.84		
[2]0	(B)	1.544		2.90	1.94	16.5		2.95	1.81
5.56	(A)	.808				8.7			
			.052				.9625		
5.56	(B)	-.389				-1.0			

Footnotes

[1](A) = left side, [2](B) = right side, [3]t-test, [4]f-statistic

II. Life History and Ecology

A. Temporal and Spatial Distribution

The two species of sculpins make up a significant portion of the fish biomass in Carnation Creek. The prickly sculpin, *Cottus asper* is most abundant in the estuary and in the lower reaches of the stream up to 1500m with a few large individuals found up to 2000m. The Aleutian sculpin, *C. aleuticus* is distributed throughout the stream up to 3100m.

The microhabitat survey results indicated that in the lower sections of Carnation Creek during low summer flow, *C. aleuticus* individuals (45 - 60mm) were located in the head and tail areas of shallow riffles (Refer to Appendix 1). Larger individuals (>60m) were found in deeper water where cover such as logs, boulders, and overhanging brush was available. Occasionally *C. aleuticus* and *C. asper* (>60mm) were found together in pools though *C. aleuticus* was always located in areas of higher current velocity. *C. asper*, on the other hand, was found mostly under cutbanks, logs, and debris in low water velocities or near the tail end of deep pools.

In the upper section of the stream *C. aleuticus* (>70mm) was more abundant and usually confined to the head and tail sections of riffles. The few *C. asper* present were found deep under cutbanks and exposed root wads. Only *C. aleuticus* was found in open pools containing boulders and debris substrate. Current velocities in these areas were negligible.

Electroshocking in areas of Carnation Creek above 2000m indicated *C. aleuticus* occupied space under root wads, logs, and undercut banks in the absence of *C. asper*. They were also found in riffle areas. Both species of sculpins tended to occupy similar habitats, however, in the presence of *C. asper*, *C. aleuticus* was usually restricted to the periphery of the habitat.

Adults of both species migrate downstream in the spring to spawn, mostly in the lower reaches of the stream and estuary. A proportion of *C. aleuticus* spawns upstream. The spawning migration in 1971 as indicated by the capture of 3,233 *C. asper* individuals and 2,560 *C. aleuticus* showed peak movement in the third week of March and a second peak in the third week of April (Figs. 16, 17; Table 9). Unfortunately until May 20, 1971 cottids moving upstream could be washed into the downstream traps so that estimates of downstream movement prior to this date probably exceed the actual numbers. Although downstream catches in 1972 (658 *C. asper* and 331 *C. aleuticus*) and 1973 (765 *C. asper* and 266 *C. aleuticus*) are smaller, there were definite peaks of downstream activity. In 1972 most downstream movement took place between April 20 - May 7. In 1973 downstream movement of *C. asper* was observed throughout April and May, and for *C. aleuticus*, all of April.

Downstream movement was most intense at night. Gonad examination at regular intervals (total of 150 specimens) showed the sex ratio of migrants to be 1:1 for both species. Downstream trap data for the total study period (1971 - 1973) are probably underestimates because of infrequent discontinuous trapping during periods of high discharge (Table 2).

Age-length studies of downstream migrants showed both species to be missing a high proportion of the first age group (Appendix 8; i-iv). Extensive seining in all areas of Carnation Creek showed that most of this age group is located in the lower reaches of the estuary in June.

FIGURE 16

Downstream-upstream movements of *C. asper* in Carnation Creek, 1971 - 1973.

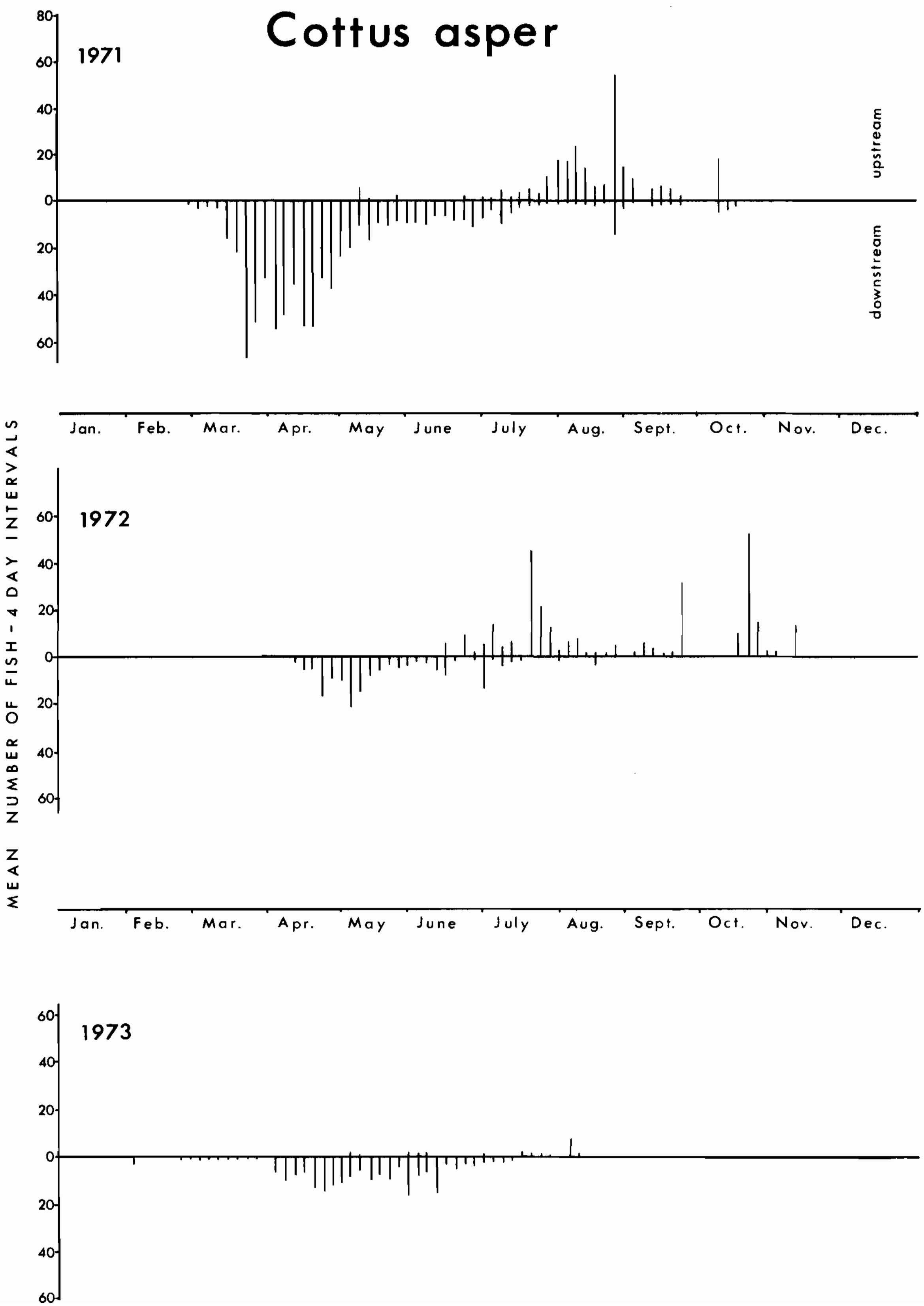

Cottus asper
1971
1972
1973
upstream
downstream
MEAN NUMBER OF FISH - 4 DAY INTERVALS
80
60
40
20
0
20
40
60
Jan.
Feb.
Mar.
Apr.
May
June
July
Aug.
Sept.
Oct.
Nov.
Dec.

FIGURE 17

Downstream-upstream movements of *C. aleuticus* in Carnation Creek, 1971 - 1973.

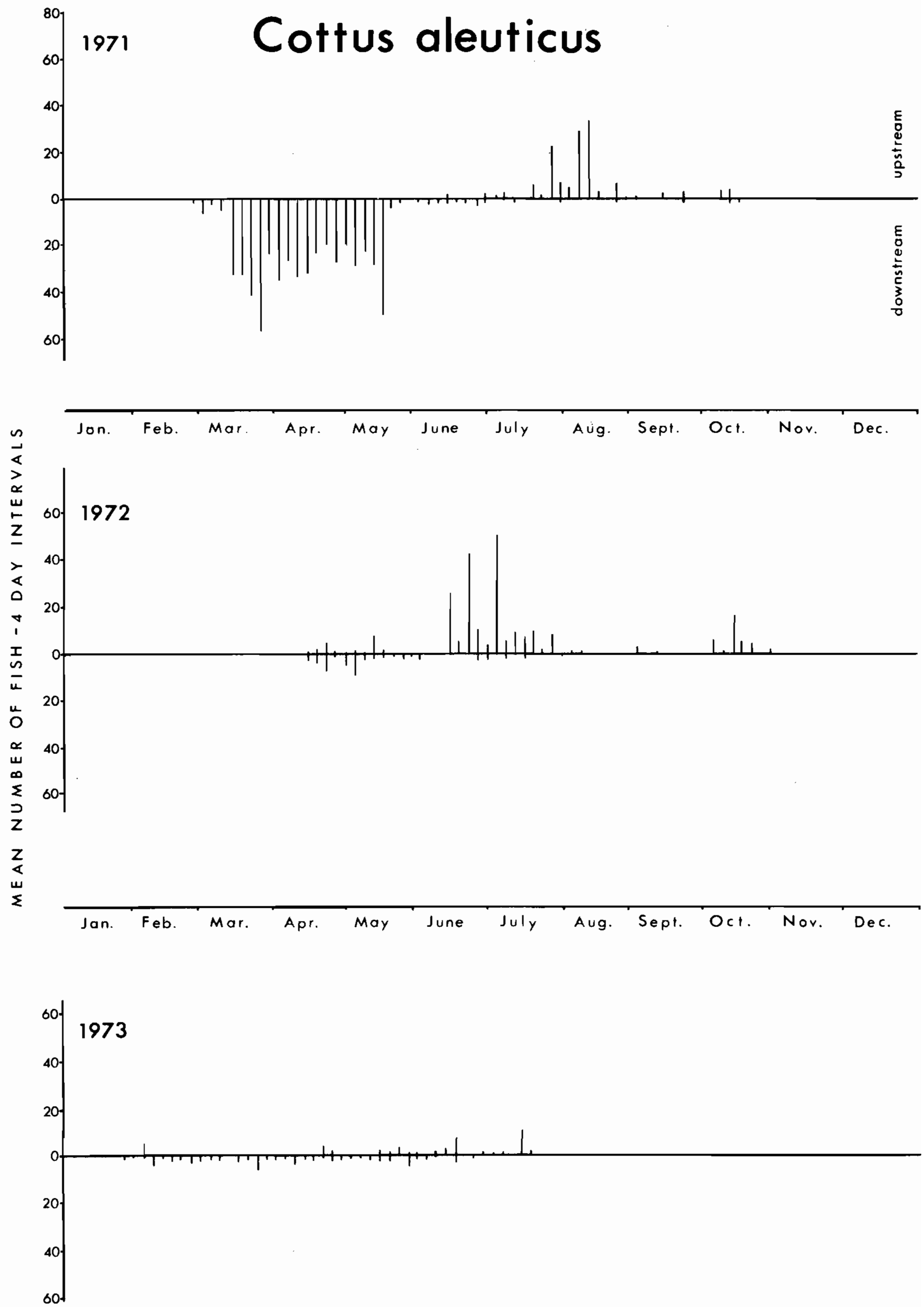

Cottus aleuticus
1971
1972
1973
MEAN NUMBER OF FISH - 4 DAY INTERVALS
upstream
downstream
80
60
40
20
0
Jan.
Feb.
Mar.
Apr.
May
June
July
Aug.
Sept.
Oct.
Nov.
Dec.

TABLE 9. MEANS OF SEVEN-DAY INTERVALS OF DOWNSTREAM TRAP RECORDS FOR *C. asper* AND *C. aleuticus* IN CARNATION CREEK.

		Cottus asper						*Cottus aleuticus*					
	DATE	1971		1972		1973		1971		1972		1973	
		DOWN	UP	DOWN	UP	DOWN	UP	DOWN	UP	DOWN	UP	DOWN	UP
Feb.	1-7					8						6	
	8-14					1						5	28
	15-21					0						24	2
	22-28					2						19	0
March	1-7	12				4		36				23	
	8-14	41				8		97				8	
	15-21	233				8		318				7	
	22-28	481				3		390				12	
Mar.-Apr.	29-4	315				37		211				26	
	5-11	284				59		212				21	
	12-18	326		43	2	93	1	233		26		20	
	19-25	307		89	0	89	0	156		56		12	
Apr.-May	26-2	206		57	3	64	0	160		25		14	
	3-9	126	15	150	5	39	5	207	4	69		6	24
	10-16	115	24	72	1	70	0	211	0	18		8	1
	17-23	73	7	21	0	36	0	166	3	18		3	0
	24-30	69	0	31	0	89	15	11	1	12		19	16
May-June	31-6	58	1	13	0	51	5	11	0	12	0	9	17
	7-13	53	0	19	0	59	0	10	0	15	0	17	4
	14-20	49	1	27	23	12	4	4	3	14	129	1	3
	21-27	70	5	0	54	18	0	21	0	0	208	3	7
June-July	28-4	50	8	68	72	9	14	5	2	38	75	1	35
	5-11	52	1	19	45	6	0	14	11	2	160	2	0
	12-18	27	20	24	31	0	6	6	5	20	63	0	4
	19-25	11	29	0	245	—	2	10	29	0	46	—	2
July-Aug.	26-1	21	77	9	88	765	34	8	110	3	37	226	51
	2-8	20	122	0	42		0	2	42	0	3		0
	9-15	17	145	0	31		—	8	235	0	1		—
	16-22	10	44	12	20		86	4	15	3	0		194
	23-29	81	233	0	18			6	22	0	0		
Aug.-Sept.	30-15	17	72	0	15			1	2	—	0		
	6-12	8	21	0	35			3	0	331	11		
	13-19	19	46	0	14			4	3		3		
	20-26	13	20	4	129			5	8		0		
Sept.-Oct.	27-3	3	3	0	0			1	1		0		
	4-10	32	70	0	0			3	11		0		
	11-17	34	57	0	23			26	13		20		
	18-24	—	—	—	263			—	—		56		
	25-31	3233	1021	650	36			2560	520		55		
Nov.	1-7				4						6		
	8-14				50						8		
	15-21				0						—		
	22-28				0						881		
	29-5				1								
	6-12				—								
	13-19				1250								
	20-26												

Figure 18 shows the length composition of *C. asper* in the estuary between June 1971 - January 1974. Figure 19 shows the length composition of *C. aleuticus* sampled immediately below the trapping facilities in 1973. Year class growth in Figure 17 is shown by modal progression (shaded bars).

Cottid eggs hatch into pelagic larvae. Drift samplers set up at 900m in Carnation Creek in the summer of 1971 to capture drifting benthos also trapped pelagic cottid larvae. Accordingly a series of drift samplers was set up in riffles to monitor larval downstream movement. These showed a gradual decrease in relative abundance from 0 - 2400m (Appendix 9). This movement, ending the last week of July, was restricted to the darkest hours of the night. It was composed mostly of *C. aleuticus* larvae but with some *C. asper*, both spawned and hatched in upstream areas. It is suggested that metamorphosis from pelagic larvae to benthic adult form takes place almost entirely in the lower estuary. Extensive plankton hauls made in the estuary revealed cottid larvae to be most abundant during the darkest hours of the night when the tides were high (Appendix 10). No cottid larvae were obtained either from plankton hauls taken during daylight or hauls taken in Numukamis Bay at the mouth of Carnation Creek. Drift samples placed in the estuary to sample outgoing tides during the evenings also failed to capture any larvae.

Metamorphosed underyearling cottids began appearing in the upper estuary in late July, 1971. (Refer to Fig. 18). By October of 1972 and 1973, fry of both species were abundant in the estuary where they exhibited distinct habitat differences. *C. aleuticus* fry were always

FIGURE 18

Length composition of *C. asper* in Carnation Creek estuary June 1971 - January 1974.

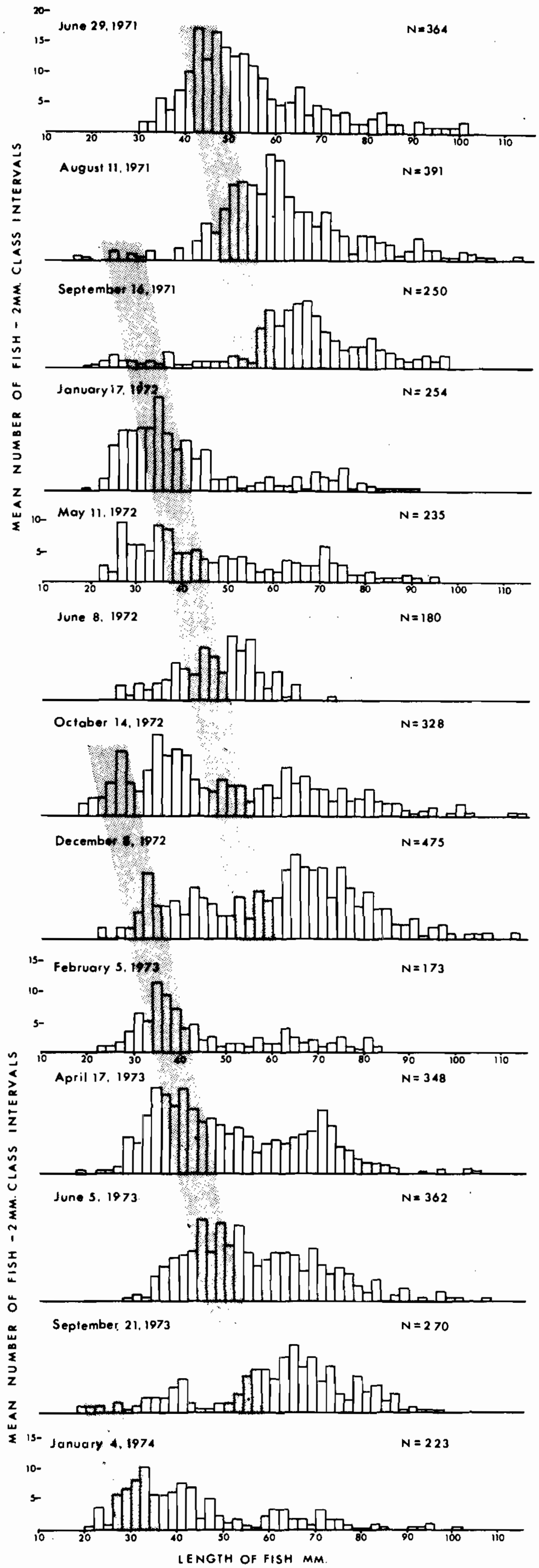
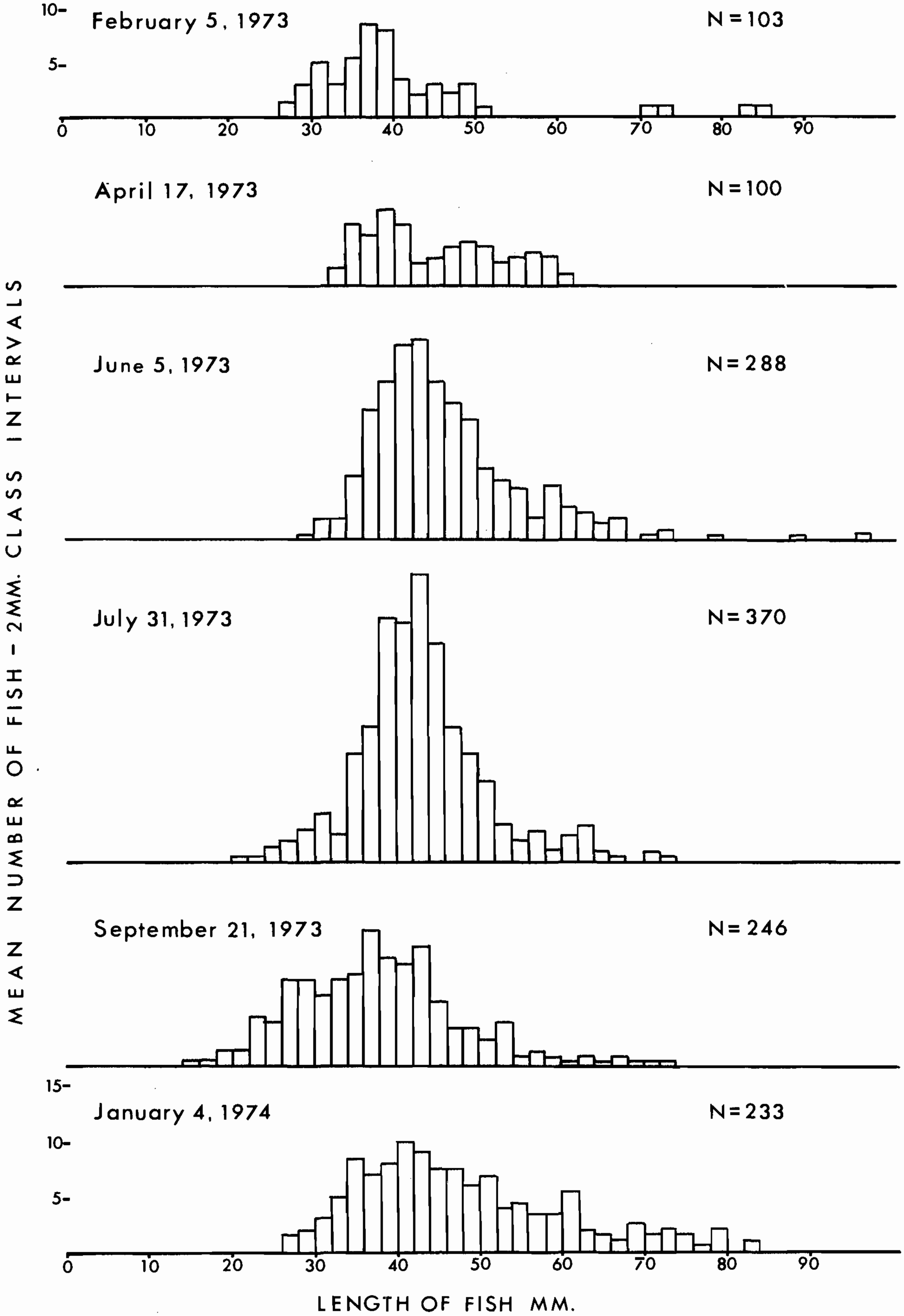

June 29, 1971
N=364
August 11, 1971
N=391
September 16, 1971
N=250
January 17, 1972
N=254
May 11, 1972
N=235
June 8, 1972
N=180
October 14, 1972
N=328
December 8, 1972
N=475
February 5, 1973
N=173
April 17, 1973
N=348
June 5, 1973
N=362
September 21, 1973
N=270
January 4, 1974
N=223
MEAN NUMBER OF FISH – 2MM. CLASS INTERVALS
LENGTH OF FISH MM.

FIGURE 19

Length composition of *C. aleuticus* in Carnation Creek sampled immediately below the downstream trapping facilities at 100m, 1973.



February 5, 1973
N = 103
10-
5-
0
10
20
30
40
50
60
70
80
90
April 17, 1973
N = 100
June 5, 1973
N = 288
July 31, 1973
N = 370
September 21, 1973
N = 246
January 4, 1974
N = 233
15-
10-
5-
MEAN NUMBER OF FISH - 2MM. CLASS INTERVALS
LENGTH OF FISH MM.

found in the riffle areas buried under rocks and in course gravel while *C. asper* fry were confined to slack water areas and back eddies.

Figures 18, 19, and trap data strongly suggest that underyearlings of both species overwinter in the estuary and migrate upstream the following summer and fall as yearlings. Adult cottids also migrate upstream in the summer and fall.

In 1971 upstream movement of *C. asper* adults and yearlings began in late July (Appendix 8:i). Seining indicated most yearlings (40 - 58mm) had moved out of the estuary by September 22, and adults by January of the following year. In 1972 upstream movement of *C. asper* yearlings began in July (Appendix 8:ii). By October most of the yearlings had disappeared from the estuary while some larger individuals remained at least until December. The upstream movement of *C. asper* was not well documented in 1973 but seining suggested most yearlings had disappeared from the estuary by September, and adults by January 1974. Extensive seining immediately below the trapping facilities in the late fall and winters of 1971 - 1973 revealed few *C. asper* individuals. It was thus speculated they had moved upstream.

Upstream movement of *C. aleuticus* in 1971 began the second week in July with a few yearlings and adults (Appendix 8:iii). Movement in August and September was primarily by yearlings. In 1972 movement of yearlings began the third week of June and continued through July while larger individuals (>45mm) comprised the migrants later in the fall (Appendix 8:iv). Upstream trap records for 1973 are sparse. Estuary seining revealed a substantial accumulation of *C. aleuticus* immediately below the trapping facilities. By January 1974 a number of individuals had disappeared (Fig. 19). This accumulation of sculpins was not evident from seining in 1971 and 1972.

B. Population Estimates

Population estimates for the three-year study period indicated a general decrease in the abundance of *Cottus aleuticus* from 0 - 1800m, then an increase from 1800 - 2400m (Table 10; Appendices 11, 12). Because of their cryptic habit during the day, estimates of *C. asper* abundance are sparse and probably not reliable.

In 1971 the density of both species of sculpins increased from August to September in the lower section of the stream. This increase (*C. aleuticus* 2.15 - 3.24 fish/m^2, *C. asper* .44 - 1.55 fish/m^2) coincided closely with the upstream movement of yearling and adult cottids from the estuary.

Estimates made in the lower sections of Carnation Creek in July and September 1972 showed no increase in fish densities. Although trap records indicated that a few yearling and adult sculpins of both species had moved upstream in July 1972. Estuary seining in October and December 1972 revealed a substantial number of at least *C. asper* still in the estuary.

Estimates made in the lower section of the stream in 1973 indicated a definite increase in *C. aleuticus* density (.52 - 2.05 fish/m^2) from July to September. The density of *C. asper* increased slightly (.03 - .08 f/m^2) in August, then decreased (.08 - .04 f/m^2) in September. These results were closely correlated with the upstream movement of cottids from the estuary.

TABLE 10. SUMMARY OF POPULATION ESTIMATES IN CARNATION CREEK (1971 - 1973)

		1971		1972		1973		
		Aug.15-16	Sept.15-16	July 31-Aug.2	Sept.11-13	July 25-23	Aug.29-31	Sept.10-14
Section	Species	f/m^2	f/m^2	f/m^2	f/m^2	f/m^2	f/m^2	f/m^2
B	*C. asper*	.44	1.55	.03	-	.03	.08	.04
	C. aleuticus	2.15	3.24	.60	.59	.52	.84	2.05
C	*C. asper*	-	-	-	-	-	-	-
	C. aleuticus	-	.42	.20	.12	.13	.10	.16
D	*C. aleuticus*	-	.43	.30	.08	.10	.07	.08
E	*C. aleuticus*	-	-	.10	.05	.12	.12	.15
F	*C. aleuticus*	.70	1.10	.30	.19	.24	.15	.14

C. Age, Growth, and Reproduction

i. Age, Growth

There was a considerable overlap in size of consecutive age groups (Fig. 20 A, B). Ages were determined by otolith examination. Age groups 1 - 4 comprise the majority of the population numbers of both species. As expected the relative growth rate (per cent of absolute length increase to initial length) decreased with increasing age in both species (Table 11).

That the 65 day growth increment does not decrease regularly with age suggests that otolith interpretation may have introduced some error.

TABLE 11. SUMMARY OF THE GROWTH OF THE FIRST FOUR AGE GROUPS OF BOTH SPECIES OF SCULPIN (JUNE - AUGUST 1971) (65 DAYS)

	Cottus aleuticus N=40				*Cottus asper* N=40			
	Age 1	Age 2	Age 3	Age 4	Age 1	Age 2	Age 3	Age 4
Mean Length (mm) of Age Class (June)	32.5	47.0	59.5	71.5	37.5	55.0	72.5	87.5
Mean Length (mm) of Age Class (August)	41.5	57.0	70.0	79.5	45.0	65.5	89.5	98.5
Relative Growth	27.7	21.3	17.6	11.2	20.0	19.1	23.4	12.6

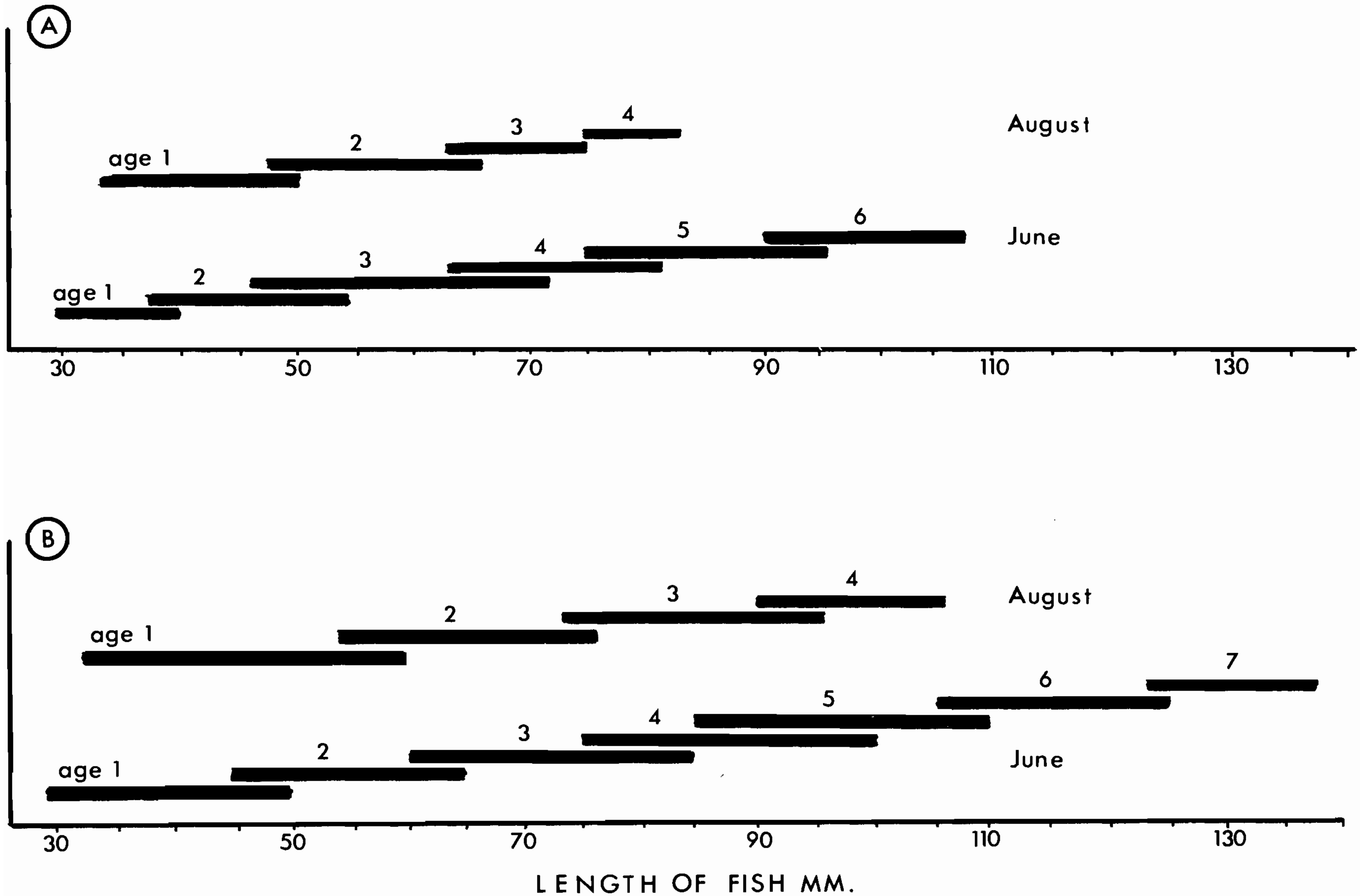
FIGURE 20

Age groups of:

A) *C. aleuticus*

B) *C. asper*

in June and August 1971,
as determined by otolith
examination.


A
August
age 1
2
3
4
June
age 1
2
3
4
5
6
30
50
70
90
110
130
B
August
age 1
2
3
4
June
age 1
2
3
4
5
6
7
30
50
70
90
110
130
LENGTH OF FISH MM.

The length-weight relationship of both species indicated growth to be isometric (Figs. 21, 22; Table 12).

TABLE 12. SUMMARY OF LENGTH-WEIGHT REGRESSION PARAMETERS, (AUGUST 1973).

	B	A	r	Sy.x
Cottus asper	3.177	-5.314	.998	.0429
Cottus aleuticus	3.244	-5.430	.997	.0389

B = slope coefficient, A = slope intercept

r = correlation coefficient, Sy.x = standard error of estimate

ii. Reproduction

From March to June spawning occurs under logs, cutbanks, and rocks in the estuary and the lower reaches of the stream. Although actual spawning behaviour was not observed, females probably attach adhesive egg clumps to the roof of the nest. The male guards the nest until all eggs have hatched (personal observation).

Results of the egg nest counts are summarized in Table 13. All nests were assumed to be those of *C. asper*. Most nests found were attached to the underside of flat-bottom rocks in water depths of approximately 0.3m at low tide, water velocities of about 0.3m/sec and water temperatures ranging between 10 - 15.5^{o}C.

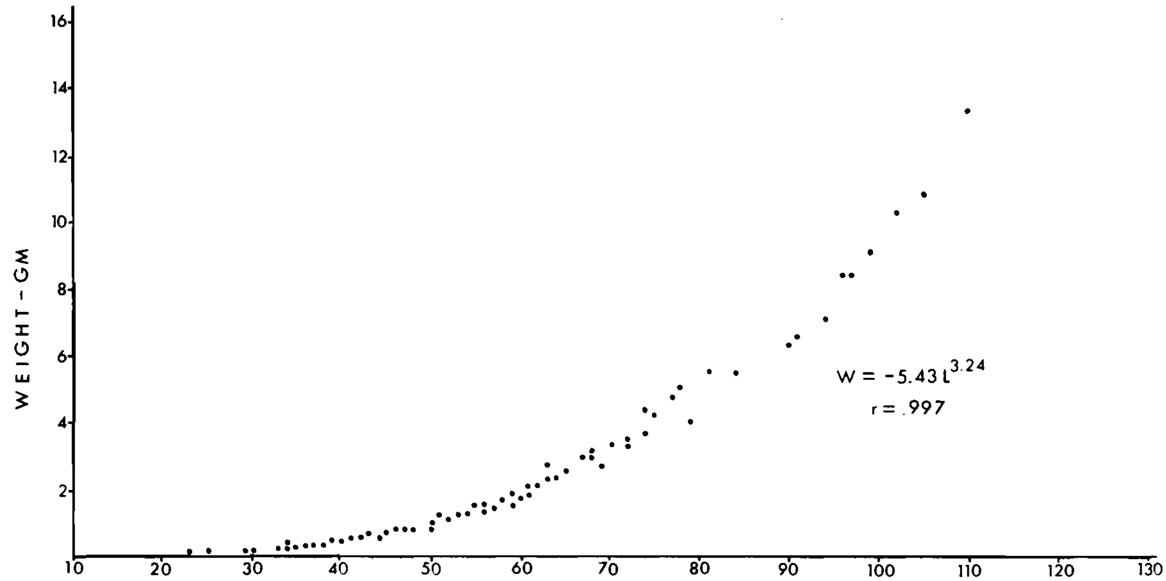
Egg masses were usually composed of two or more distinct clumps, each at a different stage of development. Several nests contained non-eyed eggs in one clump and hatching eggs in another. Probably more than one female spawns in a single nest.

FIGURE 21

Length-weight relationship of *C. aleuticus* in Carnation Creek in August, 1973

FIGURE 22

Length-weight relationship of *C. asper* in Carnation Creek in August, 1973.


WEIGHT - GM
16
14
12
10
8
6
4
2
10 20 30 40 50 60 70 80 90 100 110 120 130
W = -5.43 L^3.24
r = .997

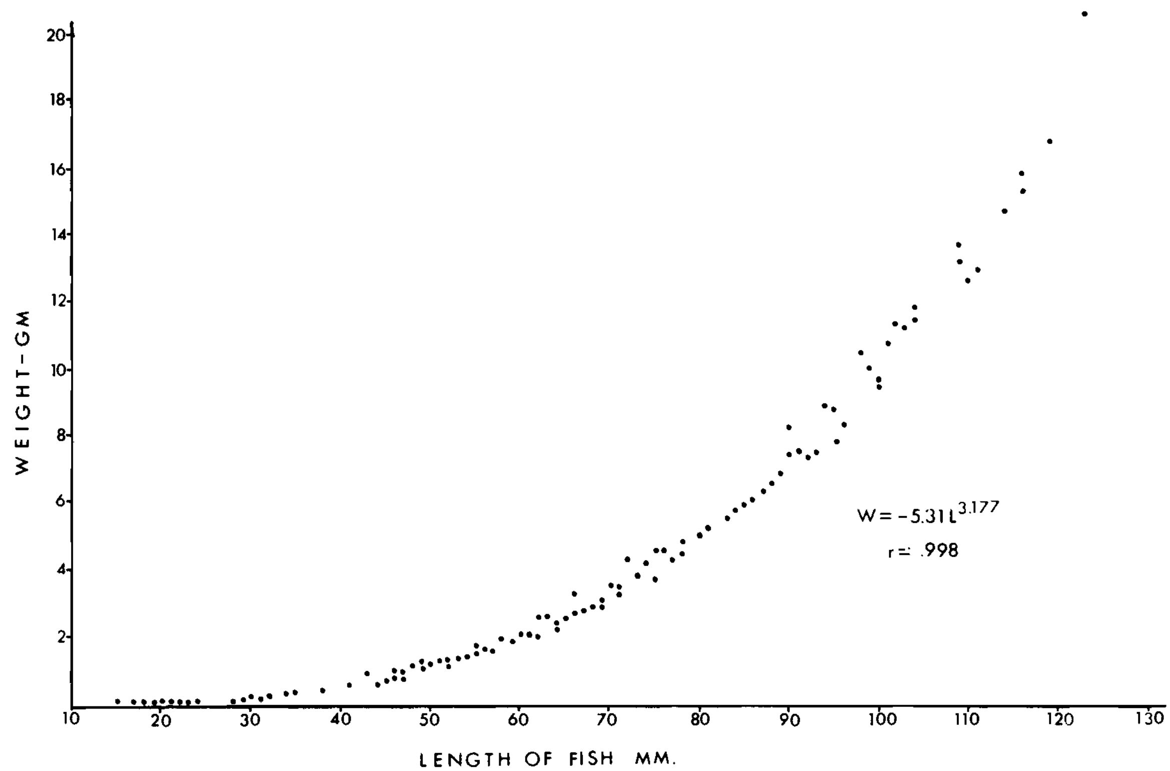

WEIGHT-GM
20
18
16
14
12
10
8
6
4
2
10 20 30 40 50 60 70 80 90 100 110 120 130
W = -5.31 L^3.177
r = .998
LENGTH OF FISH MM.

TABLE 13. DESCRIPTION OF *C. asper* EGG NESTS FROM CARNATION CREEK ESTUARY MAY - JUNE, 1973

No.	Date Collected	Location	# Clumps /Nest	% Eyed Eggs Late	% Eyed Eggs Early	% Eyed Eggs Non-Eyed	Mean Diameter of Eggs Eyed	Mean Diameter of Eggs Non-Eyed	Total No. Eggs/Nest
1	14/5/73	Lower Dicks Creek	4	-	-	100	-	1.45	10330
2	14/5/73	Lower Dicks Creek	2	55	-	45	1.55	1.60	2915
3	28/5/73	+50m c.c.	1	-	30	70	1.65	1.60	3320
4	1/6/73	+50m c.c.	?	100	-	-	1.75	-	5090
5	1/6/73	-5m c.c.	?	100	-	-	-	-	13630
6	1/6/73	-5m c.c.	1	-	10	90	1.5	-	4800
7	1/6/73	-6m c.c.	2	90	-	10	-	-	17050
8	1/6/73	-6m c.c.	2	50	30	20	1.81	1.52	16200
9	1/6/73	-7m c.c.	2	-	50	50	-	1.92	13160
10	1/6/73	-8m c.c.	3	50	30	20	-	-	24570
11	1/6/73	-15m c.c.	2	-	-	100	-	1.55	2660
12	1/6/73	-15m c.c.	2	80	-	20	1.85	1.76	12430
13	1/6/73	-20m c.c.	1	-	-	100	-	1.76	2144
14	1/6/73	-80m c.c.	1	-	-	100	-	-	1537
15	1/6/73	-90m c.c.	1	-	-	100	-	1.50	960
16	1/6/73	-100m c.c.	1	-	60	40	1.60	-	2805

Egg counts ranged from 960 - 24,500. The smallest nest collected contained small bright yellow non-eyed eggs (mean diameter 1.45mm). In some instances such nests were probably collected before spawning had been completed. The diameter of eggs ranged from 1.24 - 1.91mm. There was little correlation between egg diameter and stage of maturity although the size trend could have been masked by the differing effects of the formalin in which the eggs were stored.

D. Diel and Seasonal Feeding

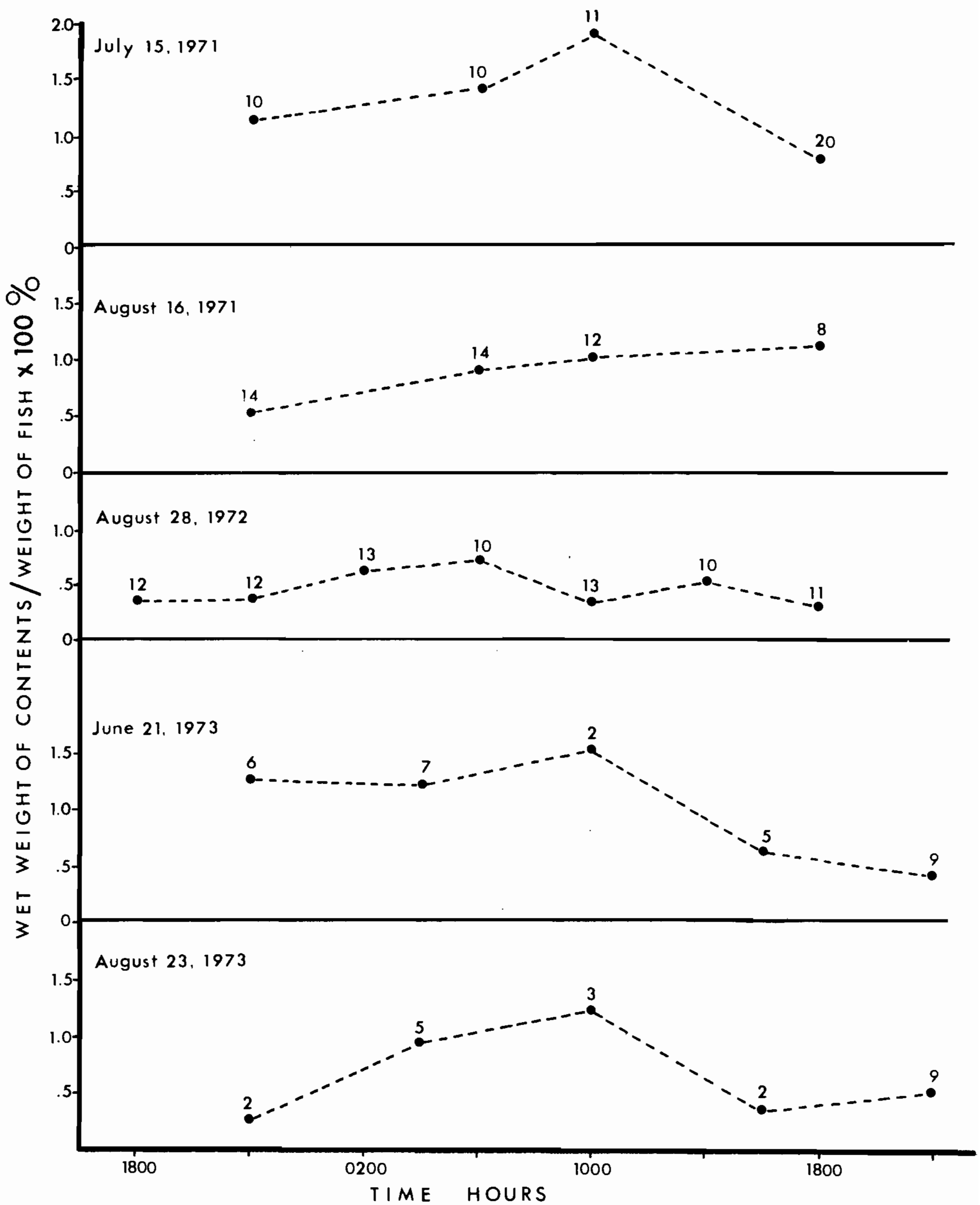
Cottus aleuticus feed heavily on benthic insect larvae and nymphs, with maximal feeding activity throughout the darkest hours of the night (Fig. 23, Appendix 13). Since at each sampling time the stomach contents of individual fish represented the accumulation of food items ingested in the previous 4 - 6 hours, results may not be representative.

During July, 1971, Plecoptera and Ephemeroptera nymphs were found to be most abundant in sculpin stomachs in the late evening and early morning (Appendix 14). During the afternoon and early evening Trichoptera larvae were the major food items ingested. Chironomid larvae were an important food item during the late evening and early morning but decreased in abundance during daylight hours. Simuliid larvae occurred only occasionally, a few stomachs contained large numbers of individuals of the families Halicaridae, Ixodidae, and Orobatidae. Except for one cottid larvae no fish or fish remains were found in any of the stomachs suggesting the size range of *C. aleuticus* (40-75mm) were not an important predator of salmonid fry or young of its own species at this time of the year.

FIGURE 23

Diel feeding pattern of *C. aleuticus*

in Carnation Creek, 1971 - 1973.


July 15, 1971
August 16, 1971
August 28, 1972
June 21, 1973
August 23, 1973
WET WEIGHT OF CONTENTS/WEIGHT OF FISH x 100 %
TIME HOURS
1800
0200
1000
1800
2.0
1.5
1.0
.5
0

Feeding patterns did not significantly change from July to August although Ephemeroptera nymphs were more abundant in stomachs followed in order by Plecoptera nymphs and Trichoptera larvae (Appendix 14).

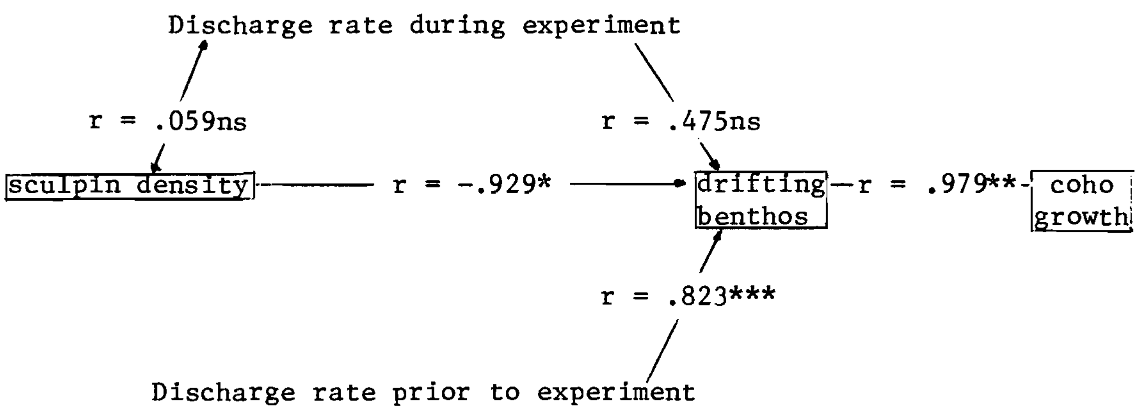
A brief survey of the stomach samples in June and August 1973 indicated seasonal differences in food (data not presented). In June Plecoptera nymphs dominated the food items in *C. aleuticus* stomachs in the darkest hours of the night followed by chironomid larvae and Ephemeroptera nymphs. Throughout the morning and early afternoon mayfly nymphs were most abundant in stomachs followed by Trichoptera and chironomid larvae. Mayflies were also abundant in the early evening. Several *C. aleuticus* contained individuals of the families Orobatidae, Halicaridae, and Ixodidae of the order Acarina. Several sculpins sampled at night contained numerous Amphipods (*Gammarus*). One sculpin (94mm) sampled in the evening contained two coho fry (<30mm).

In August 1973, mayfly nymphs were most abundant in *C. aleuticus* stomachs throughout the total 24 hour study period. During the late evening and early morning Plecoptera nymphs and Trichoptera larvae were more abundant than throughout the daylight hours whereas chironomid larvae were most abundant throughout the afternoon and early evening.

The occasional winged adult insect taken throughout the total study period suggest possible sporadic feeding at or near the stream surface. Sand grains present in the stomachs of most fish sampled were probably the accumulation of caddisfly larvae cases or debris picked up while foraging for food.

DISCUSSION

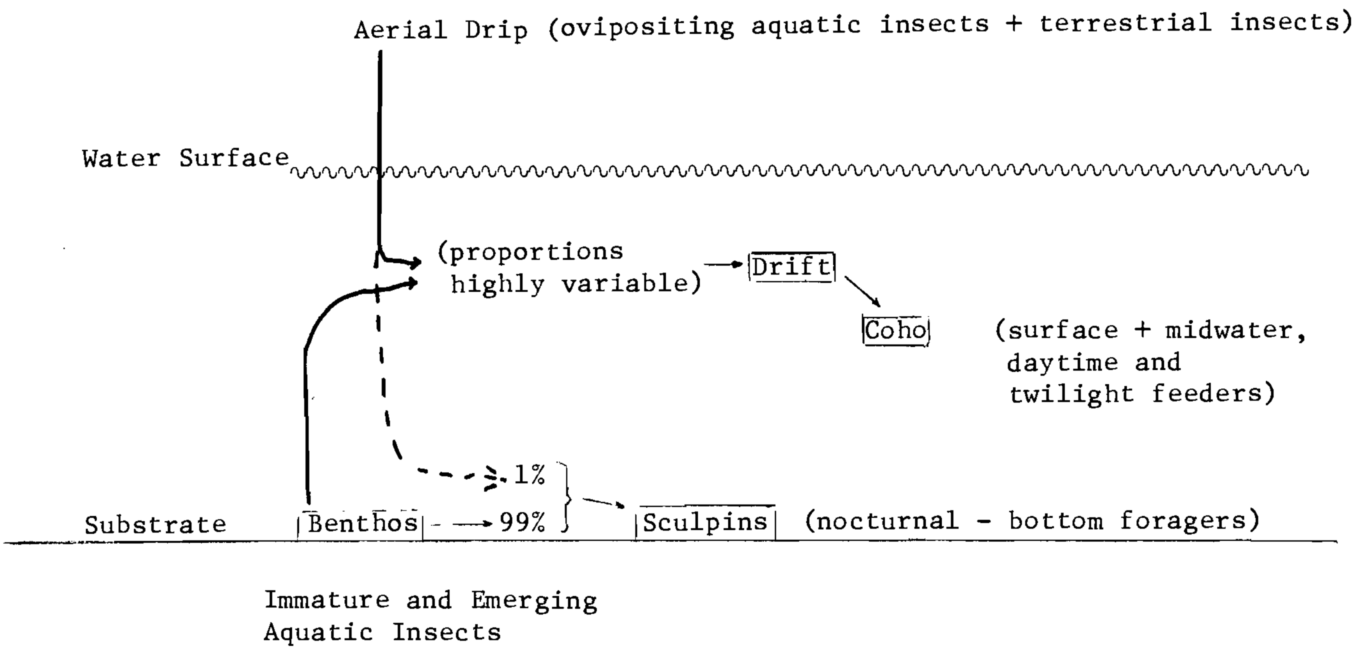
This study shows that at natural densities sculpins probably do not crop the benthos sufficiently to limit coho fry growth. This was true even though terrestrial insects, often an important component of coho diets, were excluded from the experimental troughs. The results showed further that at very high densities, *C. aleuticus* significantly reduced the amount of drifting benthos. This was in turn reflected in a decreased growth rate of coho fry. The following model summarizes the findings.



The diagram shows that before fish were added to the experimental troughs the rate of drifting benthos directly reflected flow rate. With coho fry and sculpins present the drift rate becomes inversely related to sculpin density and coho growth decreases with decreasing drift rate. All of the above correlations are statistically significant.

What is the significance of these findings in the context of a natural stream situation? There are many factors which make the application of the experimental results to the natural stream tenuous.

The following model summarizes the competitive interaction for food between sculpins and coho fry.



Two points are noteworthy. In the experimental troughs coho depended solely on food originating from the benthos, the same production that sculpins depend on. In the natural stream coho have an additional food source, non-aquatic insects which fall into the water. Growth of coho in the troughs, even in the absence of terrestrial drip, was comparable to coho growth in the natural stream situation. In the treatment with 0 sculpin density the growth of coho fry was 5.0mm, while the growth of fry in Carnation Creek during the experimental period was approximately 4.5mm.

In natural stream situations the relative contributions of terrestrial and benthic organisms to the diet of coho fry are highly variable, subject to changing environmental conditions such as degree of stream cover, and species composition, stream flow, proximity of coho rearing habitat to potential food supply, time of year, etc. The importance of aquatic insects as a food source for juvenile salmon has been well documented (Chapman 1966, Demorey 1961, Hoar 1942, Maitland 1965, Mounce and Mundie 1972, Mundie 1969, 1971, Narver 1972, Ricker 1937).

In Oregon, Demorey (1961) showed that coho fry (*O. kisutch*) fed almost exclusively on mid-water or surface drifting organisms and that in two out of three streams, aquatic insect larvae represented by the family Tendipedidae (= Chironomidae Diptera) were the most important food items in terms of dry weight. Demorey noted that the predominance of either terrestrial or aquatic organisms was directly related to the abundance of stream cover and surface flow between pools during low summer flow. Fish fed primarily on aquatic organisms when there was surface flow between pools but were restricted to terrestrial drip when isolated in pools. Coho fed more heavily on aquatic insects in areas of the stream where overhead cover, which supplied much of the terrestrial input, was sparse or absent. Demorey also suggests the possibility of increased availability in winter, of the mayfly *Paraleptophlebia* due to decreased light intensities.

Narver (1972) states that coho and trout juveniles in two streams on the east coast of Vancouver Island relied heavily on adult and immature aquatic insects in timbered sections, but consumed more terrestrial insects in logged areas of the stream. Although Demorey's (1961) results contradict those of Narver (1972), it is conceivable that the differences were due to different species composition of the stream canopies. Narver states that during the late summer and early fall Diptera larvae were most important in timbered sections. Coho fry relied more heavily on terrestrial food items than did trout (*Salmo gairdneri*).

In situations such as the experimental troughs where terrestrial food is scarce or absent, coho must rely entirely on drift organisms originating from the benthos. Since benthic drift in Carnation Creek was mainly nocturnal in timing (Scrivener, personal communication), this implies that coho fry feed actively at very low light intensities in the experimental troughs, i.e. at dusk and dawn.

Brett and Groot (1963) indicated that coho fry can effectively search out and feed on *Daphnia* under reduced light conditions. Inhibition of feeding occurred at 0.01 ft.-c, a feeding rate of one-half the maximum was still possible at 10^{-4}ft.-c, with an extinction level of close to 10^{-5}ft.-c. Brett and Groot note that bright moonlight was approximately 300X the extinction level. The overlap between the light intensity which initiates activity and drift of benthos and the minimum light intensity in which coho can feed strongly suggests that coho can utilize nocturnal drift.

In the experimental trough system, elimination of terrestrial food probably artificially sharpened the competitive interaction between coho and sculpins. With terrestrial food available in the natural stream very high sculpin densities would be needed before coho growth would be adversely affected. Sculpin densities in Carnation Creek range from .01 - 3.3 fish/m^2. Sculpin density in the experimental troughs (high density treatment) ranged up to 2.5 times higher and in the stream comparision test, approximately two times the maximum density found in Carnation Creek. Several natural factors probably limit high sculpin densities. During low summer flows, at which time available habitat would be minimal and interspecific competition for food probably maximal, a high proportion of sculpins reside in the estuary. Overwintering sculpin mortality due to high stream discharges disturbing the substrate might also be a possible limiting factor.

Stream carrying capacity for salmonids is a function of available food and space (Chapman 1966), and highly variable (Burns, 1971). In Carnation Creek, during low summer flow coho juvenile densities in pools range from .49 - 2.8 fish/m^2 (mean range .76 - .83). An unusual density in June 1972 of 4.6 fish/m^2 was recorded. Coho fry density in the experimental troughs was close to five times the mean stream density, but coho density in the stream comparison test approximated the stream density (.74 f/m^2).

In summary the results permit rejection of the null hypothesis that the presence of *Cottus aleuticus* does not affect the growth of coho fry. However, the sculpin effect is obtained only at densities much higher than those occurring naturally in Carnation Creek. In streams more productive than Carnation Creek food competition would occur only at extremely high densities.

Autecology of *Cottus asper* and *Cottus aleuticus*

Juveniles of both species are found mostly in the estuarine areas of Carnation Creek during the summer. *C. asper* spawns mainly in the estuary but many *C. aleuticus* young are hatched in upstream areas and apparently carried passively downstream to the estuary (Taylor, 1966). Both species spend a period as pelagic larvae in the estuary before metamorphosing to the benthic adult form. Krejsa (1967) records a 30 - 35 day interval between egg hatching and metamorphosis of *C. asper* larvae in the Little Campbell River. As the summer progresses the two species select different habitats. Estuary seining in Carnation Creek at low tide revealed *C. asper* fry to be most abundant in the back eddies and slack pools while *C. aleuticus* fry were present mostly in the riffles of the upper estuarine main stream channel area. Seining confirmed the virtual absence of underyearling cottids from the non-tidal portions of Carnation Creek. By September most *C. aleuticus* had moved out of the mixohaline waters into the lower section of the stream still within tidal influence. This pattern of distribution differs from that reported by Taylor (1966) and Krejsa (1967). Taylor states that both species moved into the lower section (tidal but non-mixohaline) of the Little Campbell River. Krejsa documented the presence of *C. asper* fry only in the Little Campbell River estuary and that *C. asper* juveniles move upstream to their respective habitats in the late summer. Krejsa's sampling sites indicated *C. asper* moved out of the estuary but not necessarily out of the lower reaches of the stream under tidal influences. These differences may be due to major differences in the estuarine areas of Carnation Creek and the Little Campbell River and/or to differing biological influences. The Little Campbell River estuary is a low gradient system running out on very extensive mud flat areas. This estuary maintains a high salinity mixohaline area as indicated by the abundance of typically marine species, staghorn sculpin (*Leptocottus armatus*) starry flounder (*Platichthys stellatus*) and barnacles (*Balanus sp.*). At low tide the Little Campbell estuary has a minimum of available *C. asper* habitat. Since adult sculpins migrate upstream to their respective habitat, the movement of juveniles from the estuary to the lower reaches of the river under tidal influences, inter and intraspecific competition and adjustments to salinity changes would be minimized.

Carnation Creek, on the other hand, has a higher gradient, well flushed estuary in which marine fish species are not abundant, and a considerable amount of *C. asper* habitat is available. It would seem that in such favourable circumstances *C. asper* fry remain in the estuary.

The upstream movement of *C. aleuticus* in the fall in Carnation Creek precedes the annual spawning run of chum salmon. McLarney (1967) noted a definite upstream movement of *C. aleuticus* (all age groups but only sculpins >65mm were tagged) preceding the annual spawning migration of pink salmon (*Oncorhynchus gorbuscha*) in Alaska. The spawning activity of chum salmon could explain the upstream displacement of *C. aleuticus* in Carnation Creek.

Upstream migration of all age groups except underyearlings takes place in the fall months. Yearling upstream movement precedes that of adults.

Above tidal waters *C. asper* and *C. aleuticus* continue to show some spatial separation. *C. asper* is most abundant in the lower reaches of the stream (0 - 1500m) where they occupy space under cutbanks, debris and rubble. *C. aleuticus* is distributed throughout the stream up to 3100m.

In the area of species overlap *C. aleuticus* (<45mm) occurs mainly in exposed riffle areas and larger individuals (>45mm) in areas with cover but peripheral to *C. asper*. Upstream in the absence of *C. asper*, *C. aleuticus* occurs in all available habitat.

In Carnation Creek the age groups 1 - 4 comprise the majority of the number of both species of sculpins. Table 14 presents the mean lengths of age groups and annual relative growth rate of both species from Oregon (Bond, 1963); British Columbia (results of present study); and *C. aleuticus* only from Alaska (McLarney 1967).

TABLE 14. MEAN LENGTHS OF AGE GROUPS AND ANNUAL RELATIVE GROWTH RATE OF *C. asper* AND *C. aleuticus* FROM THE LITERATURE.

		Age Group mm (Annual Relative Growth %)							
		1		2		3		4	Time of Collection
Oregon	*C. asper*	45.7	(18.16)	54.0	(30.7)	70.6	(20.6)	85.2	?
	C. aleuticus	46.4	(21.12)	56.2	(23.7)	69.5	(10.8)	77.0	Aug.
B.C.	*C. asper*	45.0	(44.4)	65.0	(36.0)	89.0	(10.7)	98.5	Aug.
	C. aleuticus	41.5	(37.3)	57.0	(22.8)	70.0	(13.5)	79.5	Sept.
Alaska	*C. aleutucus*	44.0	(18.18)	52.0	(15.38)	60.0	(16.0)	69.6	Sept.

That the annual growth rate decreases regularly with increasing ages suggests some accuracy in the results of the present study, although in comparison to other aging studies appears significantly higher. There is no obvious correlation between growth and geographic distribution and the differences cannot be explained at this time. In Carnation Creek sculpins attain approximately 50 per cent of their annual growth during the months of July and August.

Lacking an air bladder cottids are restricted from long periods of swimming or surface feeding. Thus inhabiting the stream bottom sculpins occupy an ecological niche which minimizes the competition with coho juveniles for space.

Food preferences, however do overlap. Stomach analyses from the present study indicate that *C. aleuticus* feeds almost exclusively on benthic insect larvae of the orders Ephemeroptera, Plecoptera, Trichoptera, and the family Chironomidae of the order Diptera. Feeding increases throughout the night and is probably maximal at or just before dawn. This feeding pattern strongly suggests that sculpin foraging is a function of benthos activity. Baily (1952) indicates that bottom dwelling insects comprise up to 99 per cent of the total number of food items ingested by *Cottus bairdi* in southwestern Montana: (Chironomid larvae 92.6%; Plecoptera nymphs 0.5%; Ephemeroptera nymphs 1.1%). For *Cottos gobio* L. in Sweden Andreasson (1971) shows the food items in order of importance to be chironomid larvae, Trichoptera larvae, *Gammarus pulex* and Ephemeroptera nymphs. A few terrestrial insects and fish remains are also noted. Zarbock (1932) states that competition between *C. bairdi* Semiscaber, brown trout (*Salmo trutta*) and eastern brook trout (*Salvelinus fontinalis*) for the food (Plecoptera, Ephemeroptera, and Trichoptera) may be increased during the winter when the feeding habits of trout are restricted to bottom foraging.

That *C. asper* make a definite downstream migration in the spring to spawn has been suggested by Bond (1963), Hunter (1959), Patten (1971), Shapovalov and Taft (1954) and documented by Krejsa (1967). A spawning migration of *C. aleuticus* has been suggested by McLarney (1967) and

Taylor (1966). A definite downstream movement of *C. asper* between March and May and subsequent upstream movement in the fall in Carnation Creek was documented. Although some pre-spawning and post-spawning movement of *C. aleuticus* in Carnation Creek was also observed, probably the majority of *C. aleuticus* spawns upstream.

SUMMARY

1. Under experimental conditions higher than natural sculpin densities lead to reduced coho growth. Presumably sculpins crop the benthos sufficiently to significantly reduce stream drift, the major source of coho food. Under natural stream conditions it seems improbable that sculpins would reach population levels high enough to limit coho growth. Thus even though there is a food species overlap between sculpins and coho, competition for food is probably minimal.
2. Underyearling cottids of both species apparently have distinct habitat preferences. While confined to the estuary, during low tide *C. aleuticus* fry are located primarily in the riffle areas of the main stream under tidal influence. *C. asper* juveniles by contrast are found in the quiet pool areas and back washes of the estuary. In the fall *C. aleuticus* fry move further upstream above mixohaline water, but still under tidal influence.
3. A definite post-reproductive upstream migration of the adults of both species takes place in the late summer.
4. Young of the year of both species remain in the estuary over winter and migrate upstream the following autumn as yearlings. Upstream movement of yearlings precedes that of the adults. Probably yearlings occupy the same habitat as adults upstream.
5. During the non-breeding season *C. asper* is distributed primarily in the lower 1500m of the stream with a few large individuals found sporadically up to 2000m. Typically *C. asper* is found in deep pools and low-velocity areas where suitable cover is available. *C. aleuticus* is distributed throughout the entire stream up to 3100m where a

physical barrier precludes further upstream movement. Where the distribution overlaps *C. aleuticus* seems to be restricted to riffle areas and the periphery of available cover. Upstream where *C. asper* is absent, *C. aleuticus* occupies both pool and riffle areas.

6. Reproductively mature *C. asper* and *C. aleuticus* migrate downstream mainly in the months of March and April. Most *C. asper* spawn in the lower reaches of the estuary. *C. aleuticus* spawns mainly in freshwater. Upstream spawning of *C. aleuticus* results in pelagic larvae which are passively carried downstream to the estuary at night. Both larval froms are pelagic for several weeks before metamorphosing to benthic adult form. *C. aleuticus* larvae settle to the bottom in the estuary to metamorphose to the benthic fry form.

7. Age and growth studies reveal that all age groups of *C. aleuticus* are smaller than *C. asper*. Both species live for at least seven years. Annual growth rate of *C. asper* decreases from 44.4% to 10.7% while *C. aleuticus* decreases from 37.3% to 13.5% in the first four years. Both species attain approximately 50% of their annual growth during July and August. The majority of the population of each species is comprised of the first four age classes.

8. *C. aleuticus* is on the average 4 times more abundant than *C. asper*. Sculpin numbers increase in the lower section of Carnation Creek from July to September, which correlates with the upstream movement of adults and yearlings out of the estuary.

9. Both species are bottom foragers feeding mainly on aquatic insect larvae. Feeding activity is maximal at or just prior to dawn. Food

preferences seem to change with changing species composition of benthos throughout the summer.

Retrospective Comments on Experimental Design

The object of the trough experiment was to duplicate natural stream conditions so that competition for food (originating from benthic production) between sculpins and coho could be evaluated. In the present study a major assumption was that production in the troughs was comparable quantitatively and qualitatively to production in the natural stream. A major limitation of artificial troughs is the difficulty of evaluating quantitatively how closely the troughs duplicate benthos production in the natural stream. There were, in addition, several design problems with the present trough system. Problems concerning upstream effects arise when troughs are placed in tandem. Also, the trough size prohibited a sample larger than 4 coho fry. Social hierarchy and territorial dominance displayed by coho created greater variation in growth within than among treatments.

Should a similar design be used again, the troughs should be much larger (>1.5m x 8m) to allow for larger standing crops of benthos and greater pool holding areas for coho fry. Sample size of coho per trough should be >10.

It might be desirable to model the trough design and measure all trough parameters and competitive interaction in terms of energy.

If the object of the study is to make a quick evaluation of competitive interaction among fish species for food, the experiment should be carried out in a small stream with good flow control. Placement of treatment enclosures directly in the stream channel should be far enough apart (>50m) to nullify tandem effects.

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APPENDICES

APPENDIX 1. ENVIRONMENTAL AND HABITAT PARAMETERS OF HABITAT SURVEY, AUGUST, 1971.

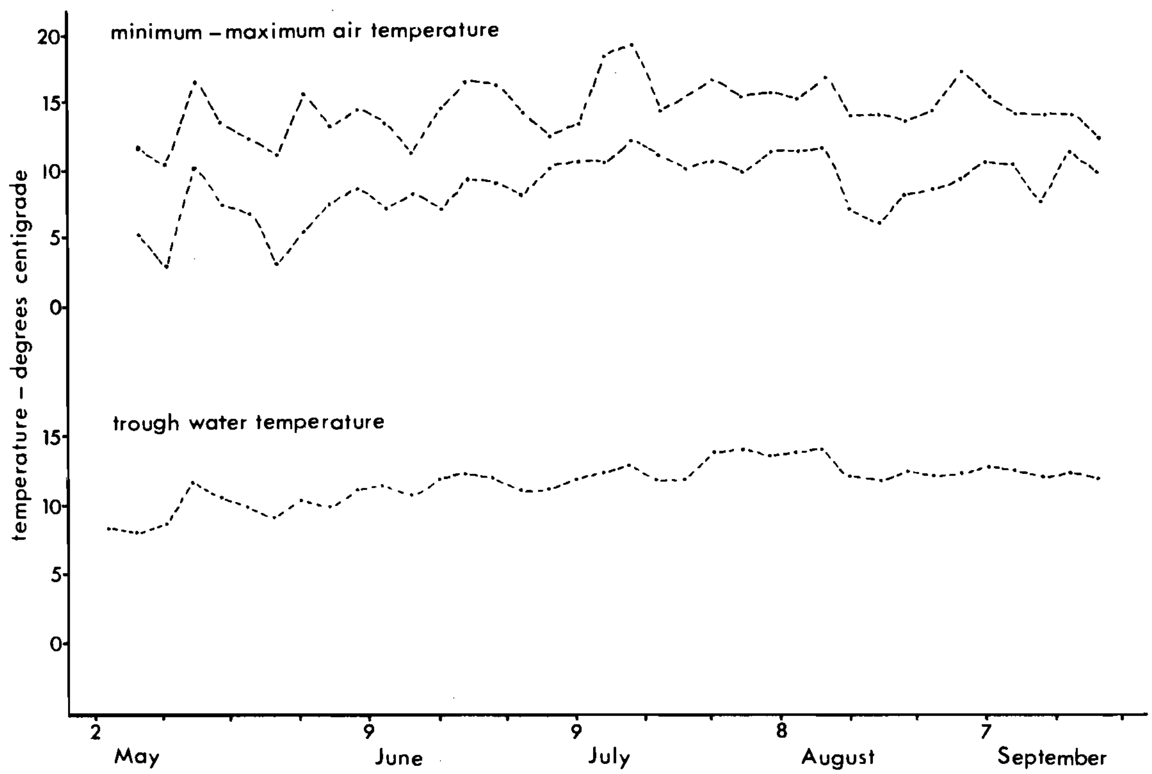
Reference Point Meters	Habitat General	Habitat Specific	Substrate	Average H_2O Depth cm	Av. H_2O Velocity f/s	Av. H_2O Velocity m/s	Fish	$\bar{L}$ (mm)	Remarks
480	Riffle	Head	Fine	6.5	1.63	.489	3 *C. aleuticus*	51	Riffle 3m x 6m
		Middle	Mixed	5.0	2.30	.69			
		Upper Tail	Gravel	2.5	1.93	.579	3 *C. aleuticus*	50	
		Extreme Tail		10.0	.966	.290			
500	Riffle	Head	Mixed	7.5	1.56	.468	4 *C. aleuticus*	49.8	Wider than Riffle No.1 "Pockety"
		Middle	Gravel	7.5	1.40	.420	3 *C. aleuticus*	45.3	
		Tail		7.5	1.13	.339	4 *C. aleuticus*	50.0	
510	Pool	Cutbank	Silt	40	Negligible		*C. asper*	88.8	Pool shaded Most of stream passed through pool
		Overhanging Brush	Sand		-		-		
		Submerged Logs	Fine		-		2 *C. aleuticus*	49.5	
		Pool Periphery	Coarse	25	-				
525	Pool	Log at One End	Mixed Fine	40	Negligible		4 *C. asper*	99.2	No immediate overhanging cover
			and				2 *C. aleuticus*	61.5	
		Gravel Banks	Coarse Gravel	30	-				
550	Pool	Head of Plunge Pool	Mixture of		2.95		5 *C. aleuticus*	105.0	All cottids drawn from upper boulders
			Boulders	90					
		Tail of Plunge Pool	Coarse → Fine		2.20		5 *C. asper*	79.2	
560	Glide	Overhanging Brush	Silt Sand	45	1.0	.333	3 *C. aleuticus*	730	
		Submerged Logs	Fine Coarse						
1460	Pool	Root Wad Complex	Fine	60	Negligible		2 *C. asper*	104.4	
		Open	Coarse	45	Slight		3 *C. aleuticus*	87.0	
1470	Riffle	Head Riffle	Coarse	10	1.76	.528	2 *C. aleuticus*	73.0	No immediate overhanging cover
		Tail of Riffle		15			2 *C. aleuticus*	88.0	

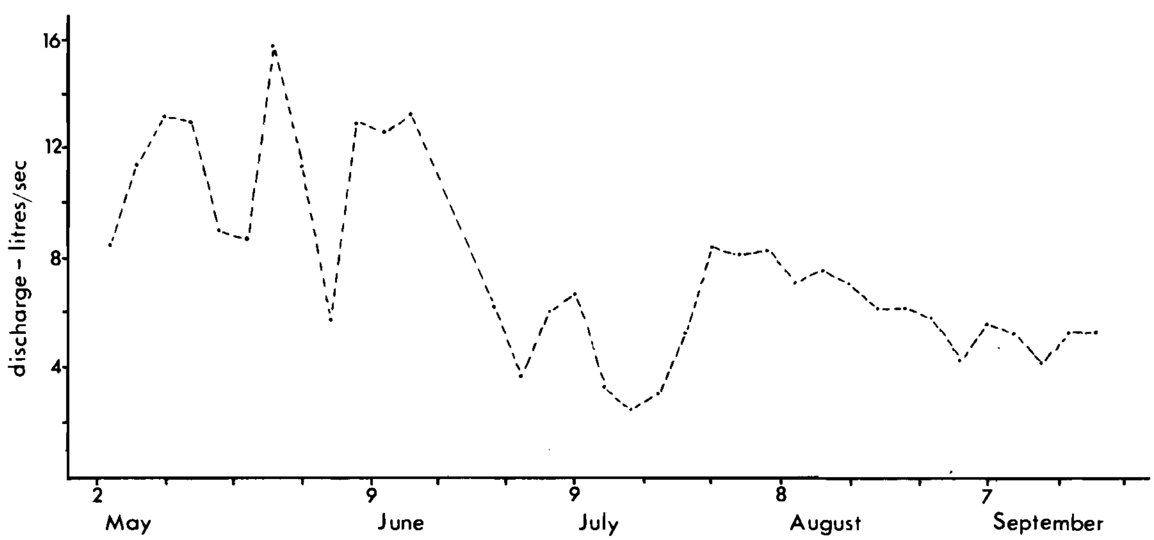
APPENDIX 2

Minimum-maximum air temperature
and trough water temperature.

APPENDIX 3

Trough discharge as the combined mean
trough discharges for four-day intervals.


minimum – maximum air temperature
trough water temperature
temperature – degrees centigrade
20
15
10
5
0
15
10
5
0
2
May
9
June
9
July
8
August
7
September


discharge – litres/sec
16
12
8
4
2
May
9
June
9
July
8
August
7
September

APPENDIX 4. TAXONOMIC BREAKDOWN OF DRIFTING BENTHOS OF PRE-EXPERIMENTAL CALIBRATION STUDY

	Trough	Plecoptera Nymphs	Ephemeroptera Nymphs	Trichoptera Larvae	Trichoptera Total Cases	Aquatic Diptera Simuliidae Larvae	Aquatic Diptera Chironomidae Larvae	Aquatic Diptera Chironomidae Pupae	Misc.	*Total Edible Organisms
15/6/73	1	28	136	12	0	32	348	28	196	506
	2	32	132	12	8	44	172	45	148	445
	3	28	184	1	2	30	246	60	159	551
	4	23	124	5	2	49	302	69	165	574
23/6/73	1	12	68	8	0	256	308	28	164	688
	2	16	45	8	0	92	312	24	96	509
	3	12	156	12	4	143	360	28	120	720
	4	16	124	16	0	140	320	32	88	672
6/7/73	1	14	14	0	0	46	218	28	143	284
	2	0	96	0	8	16	180	8	44	300
	3	0	37	9	0	18	219	18	34	300
	4	12	28	0	0	8	212	16	16	268
8/7/73	3	16	128	8	4	36	84	52	56	328
	4	16	64	4	0	28	200	32	56	344
11/7/73	1	0	18	0	0	23	213	18	65	273
	2	12	92	8	4	20	124	4	68	268
	3	5	36	0	4	18	160	0	36	223
	4	4	68	8	4	0	112	20	48	224

* Not including miscellaneous.

APPENDIX 5. TAXONOMIC BREAKDOWN OF DRIFTING BENTHOS SAMPLES TAKEN DURING EXPERIMENT.

	Trough	Plecoptera Nymphs	Ephemeroptera Nymphs	Trichoptera Larvae	Trichoptera Total Cases	Aquatic Diptera Simuliidae Larvae	Aquatic Diptera Chironomidae Larvae	Aquatic Diptera Chironomidae Pupae	Misc.	*Total Edible Organisms
16/8/73	1	4	144	8	4	24	192	32	130	404
	2	8	168	8	0	0	152	20	130	364
	3	4	184	16	4	28	276	36	68	544
	4	8	120	16	8	12	196	8	88	868
15/8/73	5	0	52	0	0	72	12	12	24	136
	6	8	60	4	0	4	104	12	28	192
	7	0	80	4	0	0	72	0	32	156
	8	0	76	0	0	4	64	0	4	144
30/8/73	1	4	132	0	0	0	76	8	28	220
	2	4	160	0	4	0	168	28	24	364
	3	0	100	0	0	0	76	4	28	180
	4	16	196	8	8	4	96	36	32	356
27/8/73	5	0	180	0	0	4	128	8	56	320
	6	8	156	0	0	0	44	8	24	216
	7	4	120	4	0	4	120	20	32	300
	8	8	172	0	0	8	112	24	28	324
22/9/73	1	16	92	0	0	16	16	4	40	144
	2	8	228	4	4	4	20	12	40	276
	3	8	104	4	4	16	20	8	24	160
	4	20	236	4	4	36	32	4	44	336
21/9/73	5	4	408	0	0	16	108	8	76	544
	6	8	416	4	0	20	52	4	56	504
	7	4	404	0	0	32	52	4	52	496
	8	8	456	8	8	20	116	4	80	620

* Not including miscellaneous.

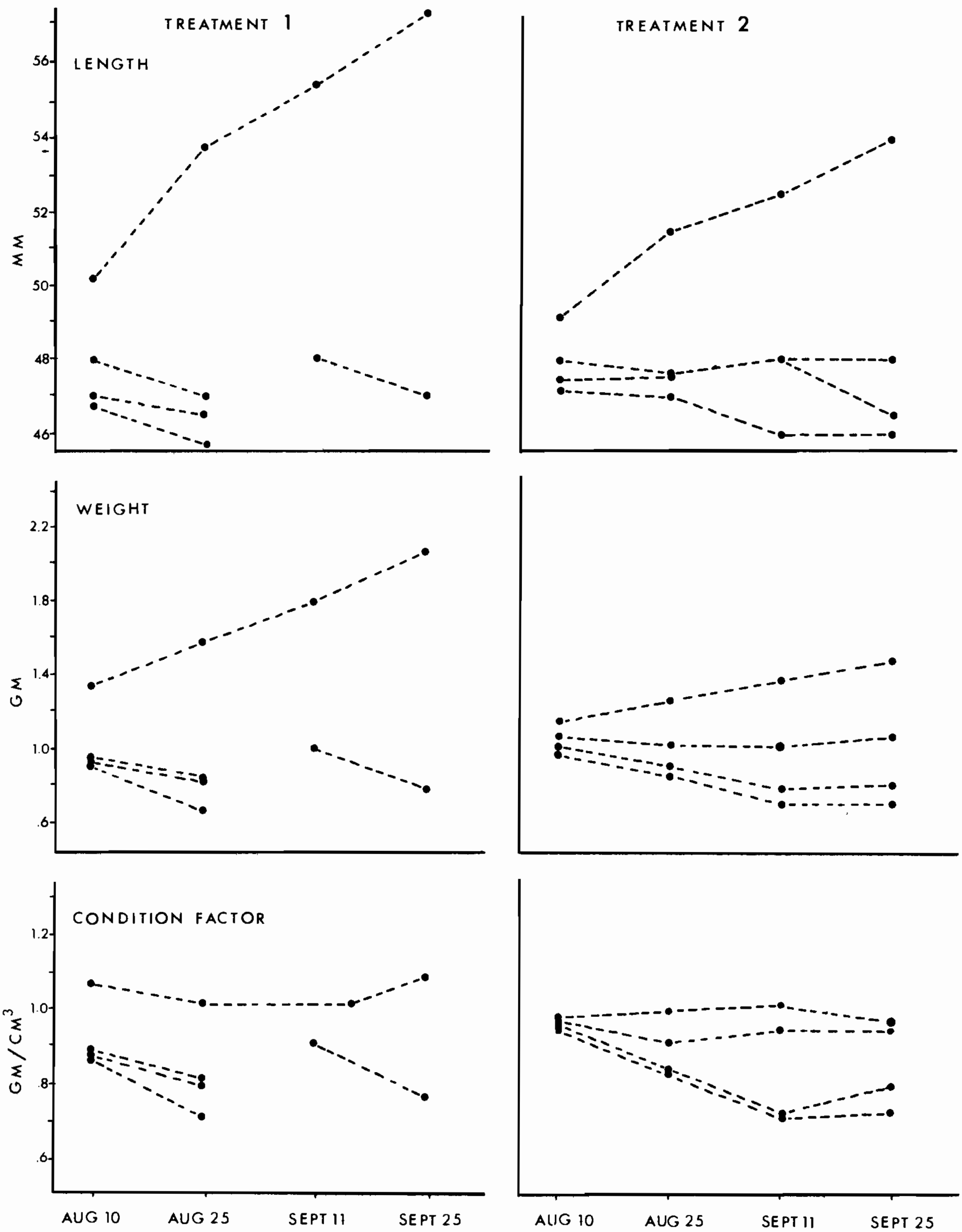
APPENDIX 6. NUMBER OF SCULPINS EXPECTED AND RETRIEVED FROM THE EXPERIMENTAL TROUGHS.

		Sculpins In		Sculpins Retrieved	
Trough	Treatment	Pool	Riffle	Pool	Riffle
1	3	4	8	2	6
2	2	4	3	3	2
3	4	4	13	4	13
4	1	4	0	4	0
5	1	4	0	2	0
6	4	4	13	2	8
7	3	4	8	2	4
8	2	4	3	4	3

APPENDIX 7

Length, weight, and condition factor of individual coho fry in the experimental troughs.

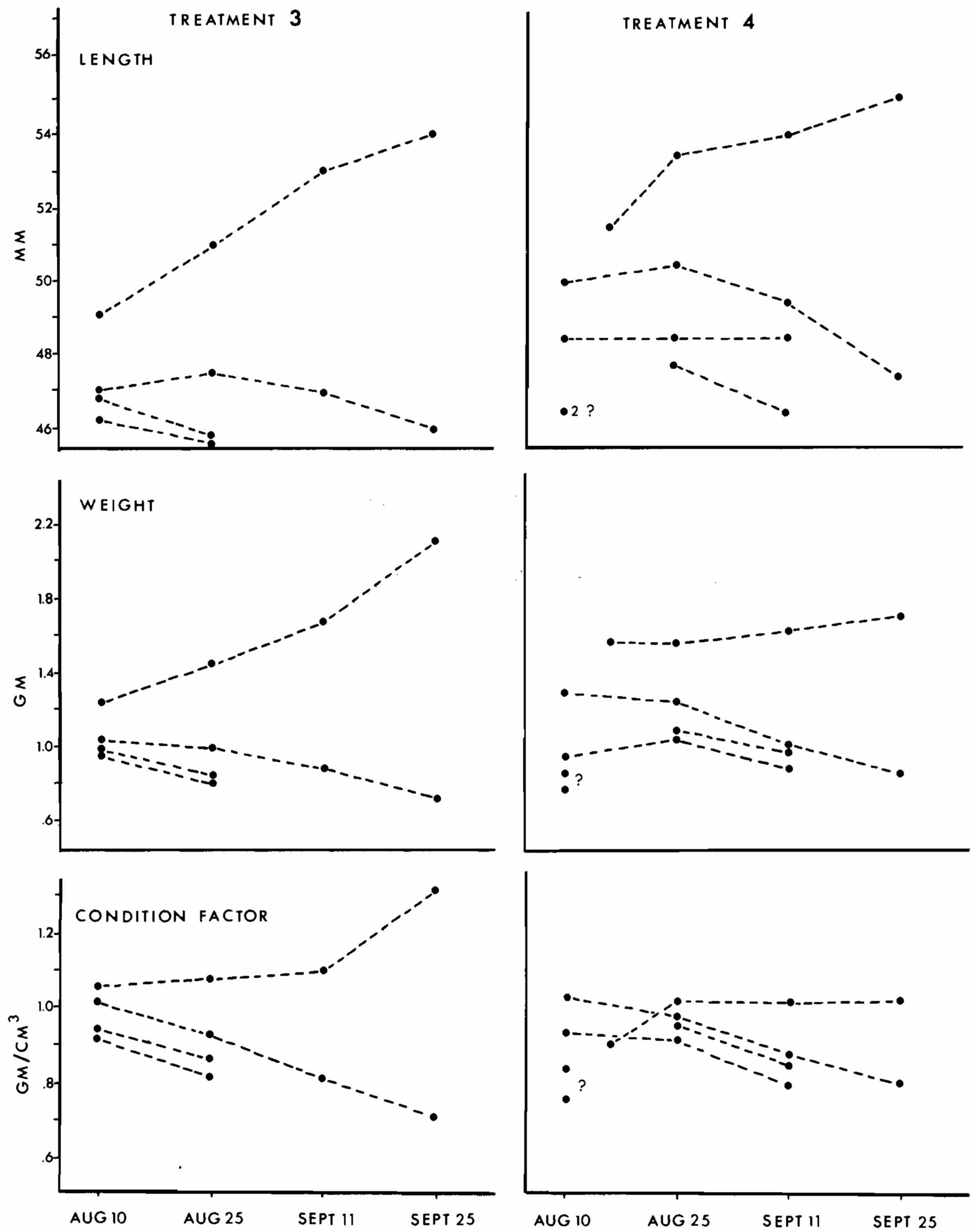
Upper troughs (Treatments 1 and 2).



TREATMENT 1
TREATMENT 2
LENGTH
MM
56
54
52
50
48
46
WEIGHT
GM
2.2
1.8
1.4
1.0
.6
CONDITION FACTOR
GM/CM3
1.2
1.0
.8
.6
AUG 10
AUG 25
SEPT 11
SEPT 25

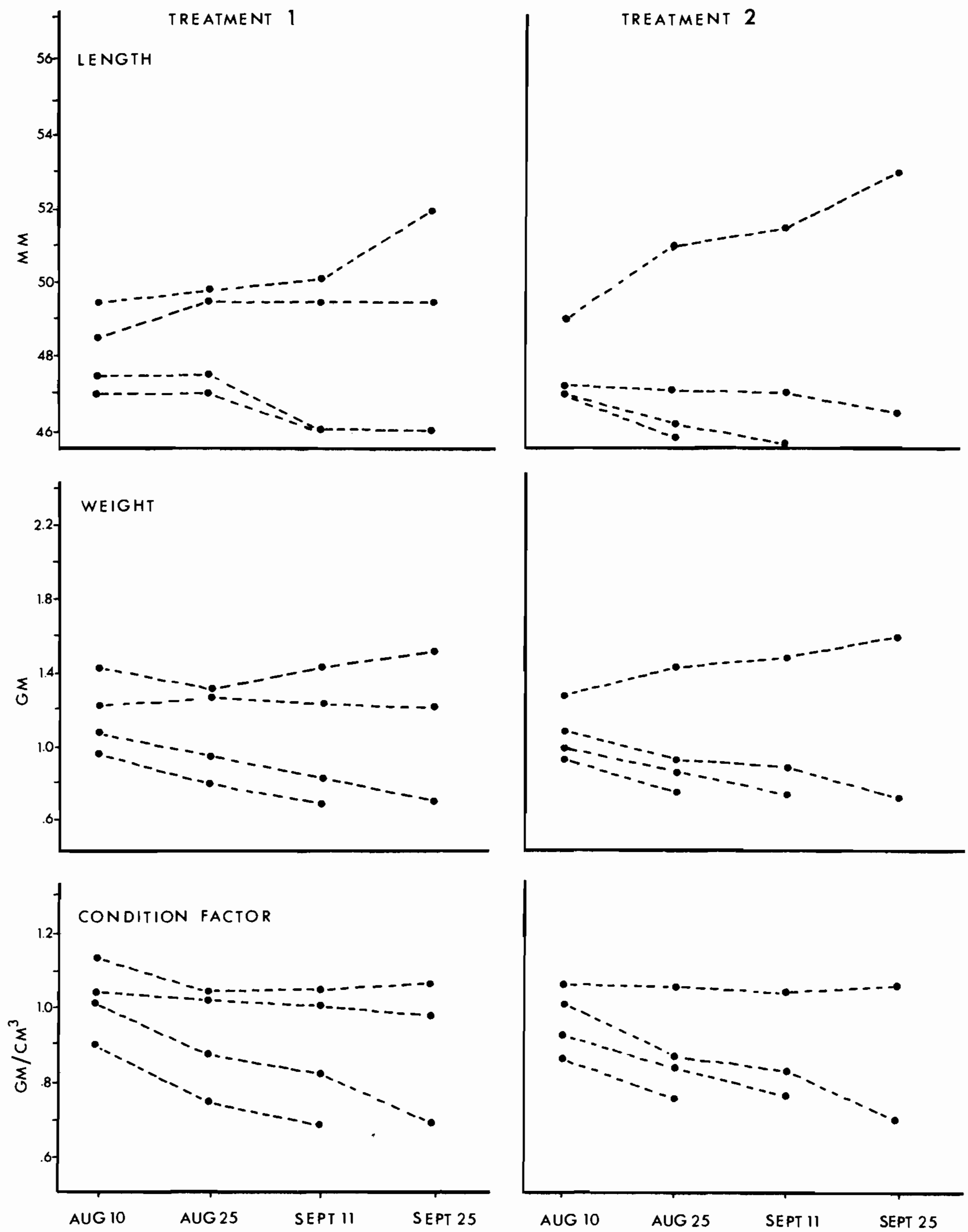
APPENDIX 7 (Cont'd)

Upper troughs (Treatments 3 and 4).


TREATMENT 3
TREATMENT 4
LENGTH
MM
56
54
52
50
48
46
2 ?
WEIGHT
GM
2.2
1.8
1.4
1.0
.6
?
CONDITION FACTOR
GM/CM3
1.2
1.0
.8
.6
?
AUG 10
AUG 25
SEPT 11
SEPT 25
AUG 10
AUG 25
SEPT 11
SEPT 25

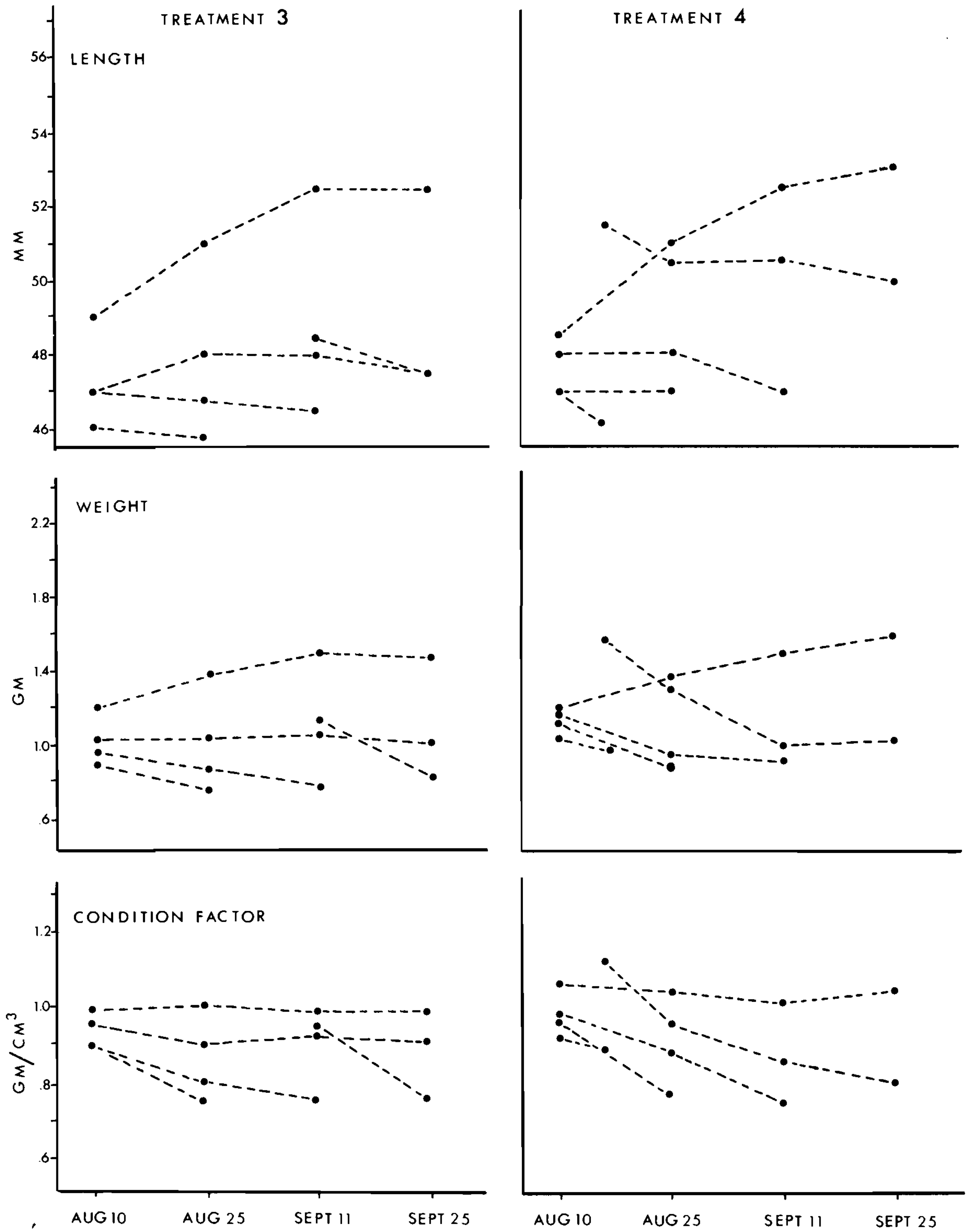
APPENDIX 7 (Cont'd)

Lower troughs (Treatments 1 and 2).


TREATMENT 1
TREATMENT 2
LENGTH
MM
56
54
52
50
48
46
WEIGHT
GM
2.2
1.8
1.4
1.0
.6
CONDITION FACTOR
GM/CM3
1.2
1.0
.8
.6
AUG 10
AUG 25
SEPT 11
SEPT 25

APPENDIX 7 (Cont'd)

Lower troughs (Treatments 3 and 4).



TREATMENT 3
TREATMENT 4
LENGTH
MM
56
54
52
50
48
46
WEIGHT
GM
2.2
1.8
1.4
1.0
.6
CONDITION FACTOR
GM/CM3
1.2
1.0
.8
.6
AUG 10
AUG 25
SEPT 11
SEPT 25
AUG 10
AUG 25
SEPT 11
SEPT 25

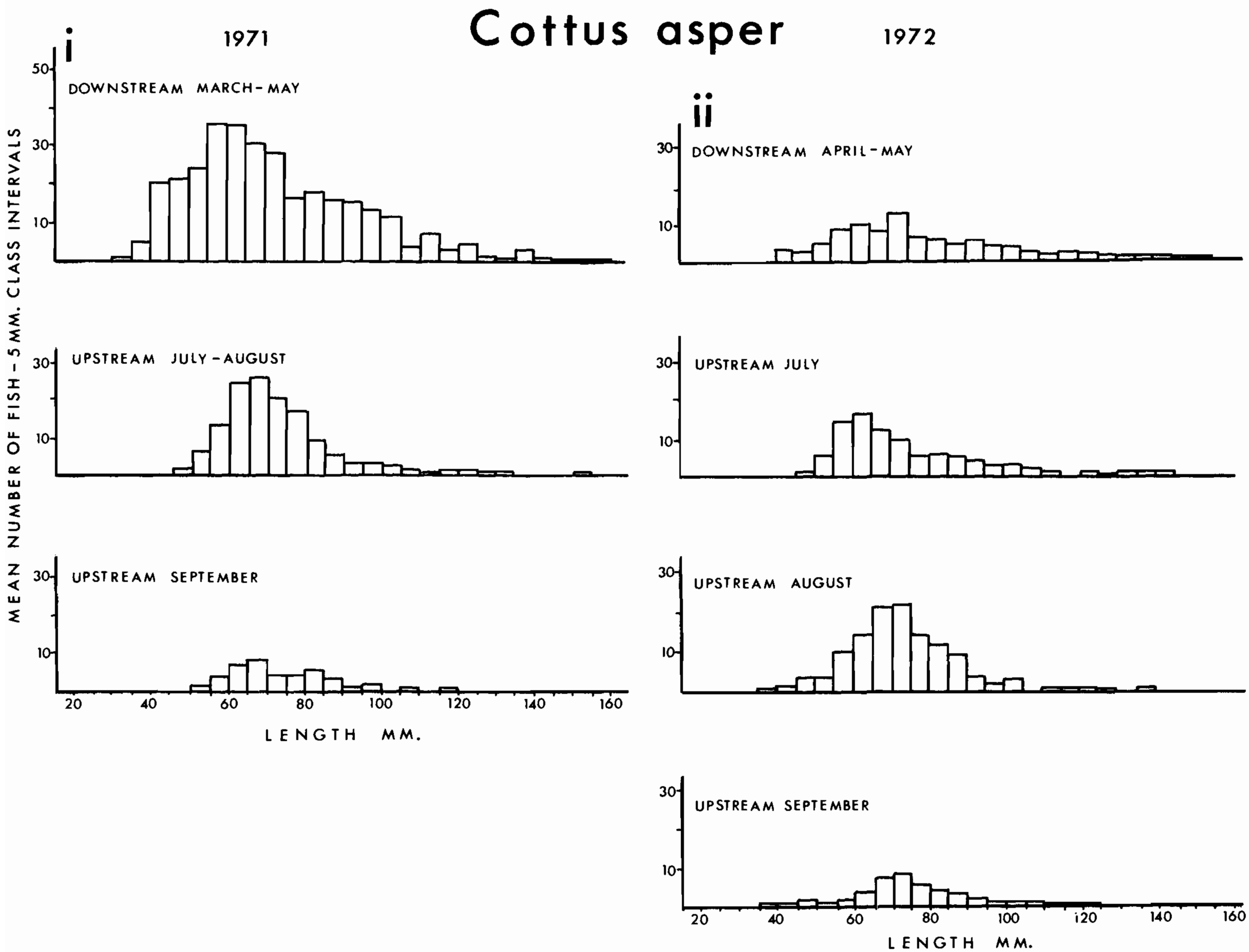
APPENDIX 8

Length composition of

downstream-upstream migrants

i) *C. asper*, 1971

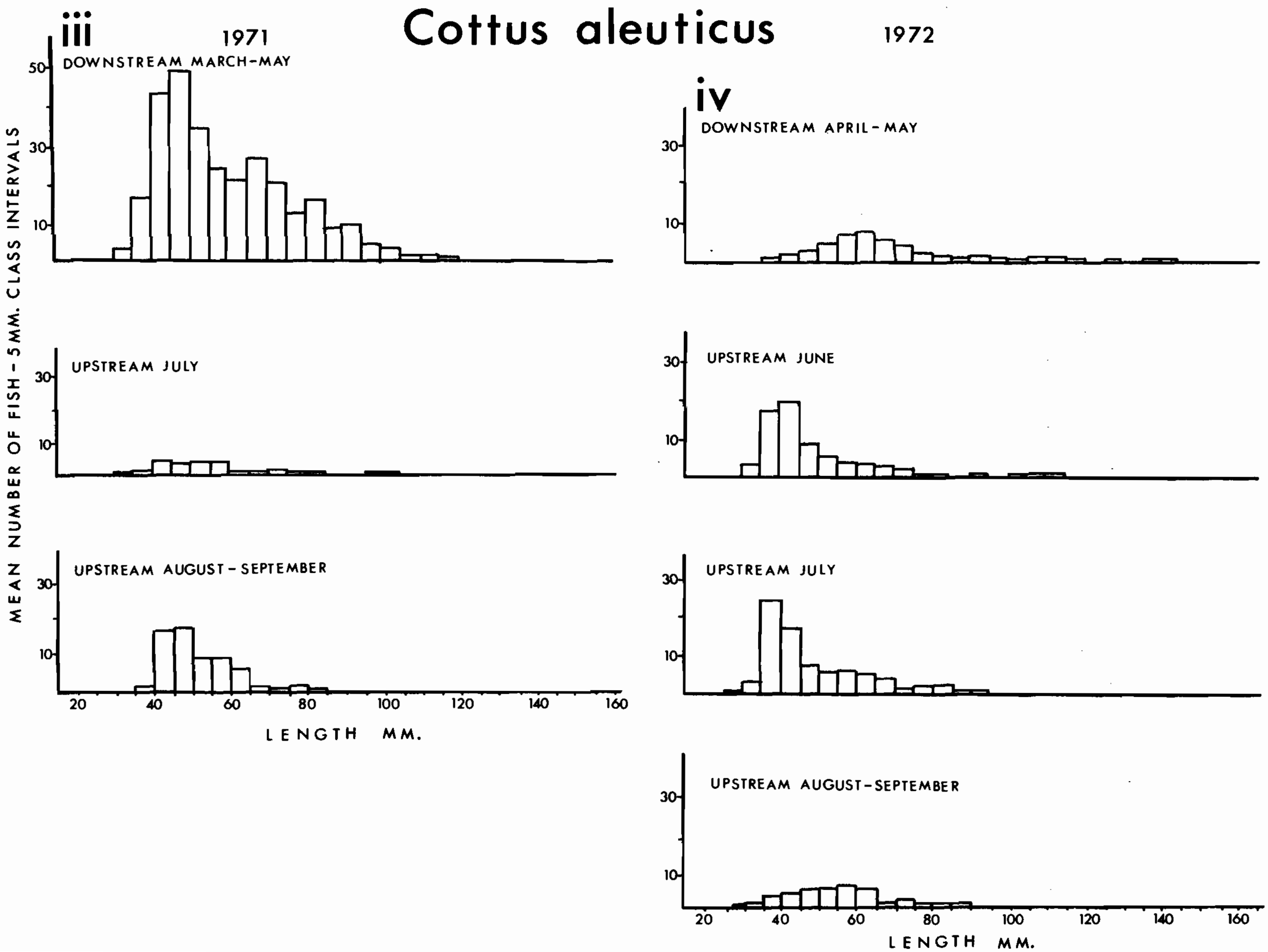
ii) *C. asper*, 1972


Cottus asper
i
1971
1972
ii
DOWNSTREAM MARCH-MAY
DOWNSTREAM APRIL-MAY
UPSTREAM JULY-AUGUST
UPSTREAM JULY
UPSTREAM SEPTEMBER
UPSTREAM AUGUST
UPSTREAM SEPTEMBER
MEAN NUMBER OF FISH - 5 MM. CLASS INTERVALS
LENGTH MM.
LENGTH MM.
50
30
10
20
40
60
80
100
120
140
160

APPENDIX 8 (Cont'd)

iii) *C. aleuticus*, 1971

iv) *C. aleuticus*, 1972



iii
1971
Cottus aleuticus
1972
DOWNSTREAM MARCH-MAY
UPSTREAM JULY
UPSTREAM AUGUST-SEPTEMBER
MEAN NUMBER OF FISH - 5 MM. CLASS INTERVALS
LENGTH MM.
iv
DOWNSTREAM APRIL-MAY
UPSTREAM JUNE
UPSTREAM JULY
UPSTREAM AUGUST-SEPTEMBER
LENGTH MM.
10
30
50
20
40
60
80
100
120
140
160

APPENDIX 9. DOWNSTREAM MOVEMENT OF COTTID LARVAE IN CARNATION CREEK, 1971.

Date	Distance from 0-m	No. of Larvae Night Sample	No. of Larvae Day Sample
June 12, 1971	0	52	2
	200	145	0
June 13	400	49	0
	600	106	Remains of I
	800	54	Remains of I
June 14	1000	56	0
	1200	37	0
	1400	11	0
June 15	1600	7	0
June 16		8	0
June 15	1800	12	0
June 16		10	0
June 17	2000	2	0
June 18		3	0
June 17	2200	2	0
June 18		3	0
June 17	2400	1	0
June 18		2	0
July 3, 1971	0	52	0
July 29	230	1	0
July 30	230	1	0

APPENDIX 10. PLANKTON HAULS FOR COTTID LARVAE IN CARNATION CREEK ESTUARY, 1971.

Date	Time (Hr.)	Sampling Method	No. of Cottids	Remarks
May 20	1345-1830	Drift Sampler	0	Port Alberni Low Tide 1435 hr., 3.3 ft.
May 24	1200-1530	"	0	P.M. high 1245 hr., 9.4 ft., P.M. low 1800 hr., 4.3 ft.
May 25	0030	Plankton Haul	22	P.M. high 2355 hr. on 24/5/71, 11.8 ft.
	1400	"	0	P.M. high 1335 hr., 9.4 ft.
	1600-2100	Drift Sampler	0	P.M. low 1935 hr., 4.8 ft.
May 26	0030	Plankton Haul	248	A.M. high 0045 hr. 11.6 ft.
	1515	"	0	P.M. high 1425 hr., 9.3 ft.
May 30	2230	"	12	P.M. low 2330 hr., 5.3 ft.
		Tides Changed from Port Alberni to Tofino		
June 1	2000	Plankton Haul	0	P.M. high 1945 hr., 9.5 ft.
June 3	2110	"	3	P.M. high 2040 hr., 9.9 ft.
June 4	1045	"	0	A.M. high 1040 hr., 10.0 ft.
June 8	0020	"	150	P.M. high 2310 hr., 7/6/71, 11.0 ft.,
June 13	0400	"	40	A.M. high 0250 hr., 10.6 ft.
June 26	1500	"	0	P.M. high
June 29	0400	"	3	A.M. high

APPENDIX 11. POPULATION ESTIMATES PARAMETERS 1971

Date	Section	Species	Section Length m	Area m^2	Marks Out	Marks Recovered	Pôp.	S.E.$\tilde{N}$	Extrapolation for Total Study Area	Fish/m^2
15-16/8/71	B	*C. asper*	170	861.2	22	4	127*	52	380	.44
	Night Seine	*C. aleuticus*			218	86	619*	36	1855	2.15
		C. asper			22	1	220*	204	657	.76
	Shocking	*C. aleuticus*			218	22	882*	155	2637	3.96
	E	*C. asper*	130	374.8	3	0	-	-	-	-
		C. aleuticus			44	6	264	91	-	.70
15-16/9/7L	B	*C. asper*	170	861.2	28	2	448*	295	1339	1.55
		C. aleuticus			177	12	935*	121	2795	3.24
	C	*C. asper*	125	607.5	8	0	-	-		
		C. aleuticus			25	3	258	133		.42
	D	*C. asper*	100	579.7	4	1	-	-		
		C. aleuticus			29	3	251	129		.43
	E	*C. asper*	130	371.8	0	0	-	-		-
		C. aleuticus			27	0	-	-		-
	F	*C. asper*	115	367.4	0	0	-	-		-
		C. aleuticus			53	3	406	212		1.10

* For 40m Segment of Section B

APPENDIX 12. POPULATION ESTIMATE PARAMETERS 1972-1973.

Date	Section	Species	Length Section m	Area m^2	Catch I	Catch II	P̂op	Confidence Limits Lower	Confidence Limits Upper	γ̂	Var.	F/m^2	$\bar{w}t$(gm)	$\bar{L}$(mm)
July 31-Aug. 1972	B	*C. asp.*	59.5	338.7	6	3	12	0	24	.50	36.0	.03	13.5	100.3
		C. aleut.			90	52	213	136	290	.42	1491.6	.6	1.8	56.8
	C	*C. asp.*	82.9	347.6	1	0							20.5	127.0
		C. aleut.			29	15	60	31	89	.48	216.7	.2	4.5	73.6
	D	*C. asp.*	67.7	321.8	2	0							15.0	106.5
		C. aleut.			29	21	105	-29	240	.27	4529	.3	59	78.7
	E	*C. asp.*	64.6	325.4										
		C. aleut.			13	18	34	-43	72	.38	363.4	.1	5.6	77.7
	F	*C. asp.*	73.2	245.1										
		C. aleut.			53	20	85	68	102	.62	69.2	.3	6.4	80.4
	All Sections	*C. asp.*	347.9	1578.6	9	3	13	8	19	.67	6.7	.01	16.0	111.3
		C. aleut.			214	116	467	373	561	.46	2204.7	.3	4.5	73.4
Sept. 11-13 1972	B	*C. asp.*	98.5	377.4	4	5								
		C. aleut.			117	56	224	178	271	.52	536.4	.59	2.2	59.2
	C	*C. asp.*	107.3	420.6	5	0								
		C. aleut.			14	10	.49	-37	135	.28	1837.5	.12	4.1	71.1
	D	*C. asp.*	65.5	312.9										
		C. aleut.			7	5	24	-36	85	.28	918.7	.08	5.5	77.5
	E	*C. asp.*	113.5	358.9										
		C. aleut.			14	4	20	15	24	.71	5.6	.05	6.4	81.1
	F	*C. asp.*	91.5	335										
		C. aleut.			21	14	63	-8	134	.33	1260	.19	9.0	81.9
		C. asp. (B+C)					20	-1	43	.44	110.7	.01	9.1	89.8
	All Sections	*C. aleut.*	1804.8	476.5	173	89	356	285	426	.48	1247	.2	3.1	65.4
Sept. 25-28 1973	B	*C. asp.*	68.6	453.9	11	2	13	11	15	.81	1.0	.029		
		C. aleut.			126	59	237	192	282	.53	507.4	.522		
	C	*C. asp.*	107.9	520.9										
		C. aleut.			40	16	67	50	83	.60	69.1	.129		
	D	*C. asp.*	32.9	240.8										
		C. aleut.			14	6	24	13	36	.57	34.5	.099		
	E	*C. asp.*	58.8	3794										
		C. aleut.			19	11	45	9	81	.42	319.9	.119		
	F	*C. asp.*	70.7	336.3										
		C. aleut.			54	17	79	68	90	.69	31.9	.235		
	All Sections Combined	*C. asp.*	338.9	1931.3	11	2	13	11	15	.82	1.0			
		C. aleut.			253	109	445	394	495	.57	640.3			
Aug. 24-31 1973	B	*C. asp.*	63.4	333.8	10	6	25	-0.5	55	.4	225.0	.075		
		C. aleut.			149	70	281	232	330	.53	611.7	.842		
	C	*C. asp.*	82.3	310.1										
		C. aleut.			22	6	30	24.8	35.7	.73	7.4	.097		
	D	*C. asp.*	34.1	218.9	0	1								
		C. aleut.			7	4	16	-4	37	.42	106.5	.073		
	E	*C. asp.*	52.1	246.3										
		C. aleut.			17	7	29	17	41	.59	34.0	.118		
	F	*C. asp.*	51.2	190.1										
		C. aleut.			16	7	28	15	42	.56	44.0	.147		
	All Sections Combined	*C. asp.*	283.1	1299.2	10	7	33	-31	97	.30	1028.4			
		C. aleut.			211	94	381	330	431	.55	640.3			
Sept. 10-14 1973	B	*C. asp.*	67.1	286.9	7	2	10	6	13	.71	2.8	.035		
		C. aleut.			100	83	588	-189	1865	.17	150942.5	2.049		
	C	*C. asp.*	82.3	298.6	6	2	9	5	13	.67	4.5	.030		
		C. aleut.			12	9	48	-62	158	.25	3024.5	.161		
	D	*C. asp.*	43.9	289.3										
		C. aleut.			11	6	24	2	46	.45	118.5	.083		
	E	*C. asp.*	52.1	114.4										
		C. aleut.			11	4	17	10	24	.64	12.1	.149		
	F	*C. asp.*	51.8	180.1										
		C. aleut.			13	6								
	G	*C. asp.*	37.5	193.1										
		C. aleut.			21	3	24	23	26	.86	9.0	.124		
	All Sections Combined	*C. asp.*	334.7	1362.4	13	14	19	13	24	.69	7.0			
		C. aleut.			168	111	495	303	687	.34	9191.1			

APPENDIX 13. SUMMARY OF RATIO OF WEIGHT OF CONTENTS TO WEIGHT OF FISH X100 FOR *C. aleuticus*, 1971 - 1973.

Hour	1971		1972	1973	
	July 14/5 (N)	August 15, 16 (N)	August 27, 28 (N)	June 20, 21 (N)	August 22, 23 (N)
1800			.364 (12)		
2000					
2200	1.17 (10)	.525 (14)	.391 (12)	1.30 (6)	.286 (2)
2400					
0200			.618 (13)		
0400	1.41 (10)	.916 (14)		1.29 (7)	.942 (5)
0600			.730 (10)		
0800					
1000	1.91 (11)	1.02 (12)	.384 (13)	1.56 (2)	1.27 (3)
1200					
1400			.559 (10)		
1600	0.80 (20)	1.15 (8)		.640 (5)	.384 (2)
1800			.323 (11)		
2000					
2200				.440 (9)	.550 (9)

APPENDIX 14. TAXONOMIC BREAKDOWN OF STOMACH CONTENTS *C. aleuticus* JULY 14, 15, 1971.

Time (Hr.)	2230		0500		1030		1700	
Sample Size N	10		10		11		20	
Mean Length of Fish (mm)	56		59		47		49	
	Freq. of Occurrence %	Mean # Org./Fish	Freq. of Occurrence %	Mean # Org./Fish	Freq. of Occurrence %	Mean # Org./Fish	Freq. of Occurrence %	Mean # Org./Fish
Plecoptera	70	1.1	80	2.8	36	3.3	40	.5
Ephemeroptera	50	.5	70	2.2	27	.3	5	.05
Trichoptera	40	.6	50	.7	91	2.0	50	.9
Diptera								
a) Simuliidae	0	0	20	.2	0		10	.1
b) Chironomidae	90	4.1	80	1.0	64	.9	35	.7
Acarina	20	2.8	10	1.0	27	.7	35	1
Others								
a) Cottid larvae	10	.1						
b) Sand	20	1.5	30	1.0	36	.7	15	.5

APPENDIX 15. TAXONOMIC BREAKDOWN OF STOMACH CONTENTS *C. aleuticus* AUGUST 14, 15, 1971.

Time (Hr.)	2200		0530		1000		1700	
Sample Size N	14		14		12		8	
Mean Length of Fish (mm)	68		58		50		50	
	Freq. of Occurrence %	Mean # Org./Fish	Freq. of Occurrence %	Mean # Org./Fish	Freq. of Occurrence %	Mean # Org./Fish	Freq. of Occurrence %	Mean # Org./Fish
Plecoptera	14	.2	29	.6	25	.3	13	.1
Ephemeroptera	36	.7	84	1.5	50	.8	25	.3
Trichoptera	14	.8	42	.5	25	.5	38	.4
Diptera								
a) Simuliidae	0		0		0		0	
b) Chironmidae	22	.6	7	.4	25	.3	25	.9
Acarine	7	.2	22	.6	0		25	.7
Others								
a) Sand	14	.8	29	.9	25	1.3	38	.5
b) Nematoda	0		7	.07	17	.2	0	
c) Gastropoda	7	.07	0		8	.09	0	
d) Trich. Adult	14	.1	0		0		0	