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No. 1267

Some Aspects of the Ecology of Two Species of Sculpin *(Cottus)* in a West Coast Vancouver Island Stream

by

Norman R. Ringstad[1] and David W. Narver

([1]Revision of a thesis submitted by Ringstad in partial fulfilment of the requirements for the degree of Bachelor of Science (honours) in the Department of Biology, University of Victoria)

Pacific Biological Station, Nanaimo, B.C.

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Page 13, Table 5: Summer - August replaces October.

Page 15, 7th line below Table: 155 replaces 115. and 244 replaces 240.

Page 16, last sentence of 2nd paragraph: Delete.

Page 25, Ricker, 1968: IBP replaces IPB.

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ABSTRACT

This study was part of an investigation of the impact of logging on the production of salmonid fishes in Carnation Creek, a small coastal stream on the west coast of Vancouver Island. The Aleutian sculpin, *Cottus aleuticus*, and the prickly sculpin, *C. asper*, both occur commonly in streams of coastal British Columbia. In Carnation Creek sculpins comprise from 33 to 66% of the total late summer fish biomass with the greatest abundance in the lowest part of the stream.

Both species undertake downstream migrations in the early spring prior to spawning in April to early June. *C. asper* spawns mainly in the upper estuary where the adhesive egg cluster is placed on the underside of logs and rocks. *C. aleuticus* apparently spawns in the stream above tide water. Upon hatching the larvae of both species are pelagic and all drift to the estuary where they settle and metamorphose to the juvenile form. Adults of both species begin to migrate upstream after the spawning season, but young of the year remain in the estuary for more than one year, moving upstream the following fall as yearlings. In late summer *C. aleuticus* occur under rocks in moving water from the high tide level to a barrier falls about 3,100 m upstream. At the same time *C. asper* occur in quiet water under cover such as roots and cutbanks in the lowest 1,000 m of the stream. The ratio of *C. aleuticus* to *C. asper* was 4:1 in a study section 300 m from the mouth in late summer. In the upstream area where *C. asper* is absent, *C. aleuticus* occurs in both pool and riffle areas.

C. aleuticus are shorter per age group than *C. asper*. The life span of each species is up to seven years. Both species feed mainly on benthic insect larvae. Feeding activity is maximum at dawn.

INTRODUCTION

Of the seven species of North American freshwater sculpins, Cottus asper and Cottus aleuticus, are common in coastal streams of British Columbia. Their commonness suggests their probable importance in stream ecology.

Cottus aleuticus Gilbert, the aleutian sculpin, ranges from the Aleutian Islands to the Carmel River, California, while C. asper Richardson, the prickly sculpin, ranges from Chilcoot Lake, Alaska and the Upper Peace system, south to the Ventura River drainage in California (Carl, Clemens, and Lindsey, 1967). Cottus aleuticus and C. asper are the only two species of sculpins inhabiting streams on the Queen Charlotte Islands and Vancouver Island (Fig. 1).

I. Taxonomy

Cottus aleuticus was originally described in 1880 as Uranidea microstoma, from specimens collected from the Kodiak Islands by Lockington. Since the specific name microstoma was already occupied in the genus, Gilbert in 1895 placed the specimen in the genus Cottus and changed the species to aleuticus. Cottus asper was first described by Richardson in 1836 from specimens collected from the Columbia River drainage system by Gardner (McPhail and Lindsey, 1970). Krejsa (1966) has completely reviewed the nomenclatural history of C. asper.

II. State of ecological knowledge

Although it has been suggested that the ecological importance of sculpins lies in their potential as predators on salmon and trout eggs and fry, some workers have shown that sculpins had no significant detrimental effects on salmon and trout populations. Rainbow trout (Greely, 1932), brook trout (Dineen, 1951), and coho salmon (Shapovalov and Taft, 1954) are reported to be heavy predators on their own eggs and fry as compared to those consumed by sculpins. Pritchard (1936) in a study carried out at Masset Inlet, Queen Charlotte Islands, reported that although cottid species were possibly heavy predators of the pink salmon fry, they were the least detrimental of all the predatory fish studied (Dolly Varden char, cutthroat, Cottus sp. and coho).

Shapovalov and Taft (1954) at Waddell Creek, California found that juvenile coho salmon and steelhead were heavily preyed upon by older age classes of their own species, but C. asper and C. aleuticus had pronounced effects on the survival rates of the salmonids. They suggested that C. asper was the most damaging of the two sculpins and that most damage occurred immediately after fry emergence.

Phillips and Claire (1966), working in Oregon with Cottus perplexus, suggested the possibility of this species having the potential to burrow in stream gravel to depths of normal egg deposition. Krohn (1968), working with the same species, showed that intragravel movement and predation on salmon eggs and fry by C. perplexus was unlikely. Minimum predator size was 69 mm.

Krohn suggested predation intensity to be a function of salmon fry density but not an important factor influencing coho production and smolt yield.

McLarney (1967, 1968), from a study of the predation effects of *C. aleuticus* on the eggs of pink salmon reported that an estimated 960,000 pink salmon eggs were consumed (7.6% of total egg deposition) in Sashin Creek, Baranoff Islands, in 1965. It was shown that this number of eggs could have been supplied over the total spawning period by unburied waste eggs. McLarney suggested that although *C. aleuticus* was a potential predator on eggs, they did not significantly affect the production of pink salmon in 1965.

Patten (1962) studying the predation on coho salmon by *C. perplexus* and *C. rhotheus*, reported that the incidence of salmon predators among predatory-size cottids (73 mm and larger) from samples of *C. rhotheus* was 9.2%; C. perplexus, 3.1% and combined 7.9%. Since overall size and mouth capacity were comparable, Patten suggested that specific feeding habits and habitat preference of each species of sculpin as well as the density of coho fry in relation to suitable cover were important factors in governing the frequency of fry predation. Hikita and Nagasawa (1960; as cited by Patten, 1962) showed the density dependent nature of predation on chum salmon fry by the cottid, *C. nozawae*, in test flumes. The rate of predation on 200 chum salmon fry by five sculpins gradually decreased to 0 by the time the prey were reduced to 70. At this point the sculpins died of starvation.

Patten (1971a), in a study carried out on the effects of predation on hatchery-released fall chinook fry by four species of sculpins, *C. rhotheus*, *C. perplexus*, *C. asper*, and *C. aleuticus*, in Washington, estimated losses of fry to sculpins to be 3.9%, 1.3%, and 3.6% of three successive hatchery releases. Patten confirmed his earlier suggestion that the intensity of predation on hatchery-released chinook fry is related to diet and size of fry at release. It was found that *C. asper*, the heaviest predator, has a relatively larger mouth size than *C. aleuticus*.

Direct competition between salmonids and cottids is minimized by their contrasting respective surface and benthic feeding patterns according to Zarbock (1951), Dineen (1951) and Baily (1952). Dineen suggests that competition for benthos may be increased during the winter months when salmonids are seeking refuge near or in the stream substrate. Ricker (1960), Heard (1965), and Sinclair (1968) suggest that some species of cottids and cottid larvae are important as a food source for other fish and also some birds.

As referred to above, some work has been done on the ecological importance of sculpins in Alaska and the Pacific northwestern states, but most of this research has been concerned primarily with sculpins as potential predators on eggs and fry of salmon and trout. By contrast, in British Columbia little work has been done on any aspect of the ecological impact of sculpins on stream ecology. The life history of *C. asper* including spawning migration patterns and behaviour has been documented by Krejsa (1967). Taylor (1966) has reported on the spatial distribution and habitat preferences of *C. asper* and *C. aleuticus*. Both of these studies were done on a low gradient stream in the lower Fraser River valley, British Columbia.

Knowledge of the life history of C. aleuticus remains particularly meagre.

In coastal streams C. asper is located primarily in pools and slow moving water, usually in the lower reaches of the stream. This form is tolerant of salt water and may be found under estuarine conditions (Bond, 1963). There is considerable geographic variation within C. asper. Two distinct populations occur. There is a coastal catadromous form which undertakes an annual downstream migration to the estuary to spawn and an inland form which undergoes only local migration, with spawning restricted to fresh water. The coastal population also has a more pronounced prickling pattern of the scales than that of the inland form. It is suggested that the inland form is a derivative of the coastal population (Krejsa, 1967). C. aleuticus typically inhabits riffle areas of high velocity in coastal streams. This species is found in conjunction with C. asper. According to McPhail and Lindsey (1970), C. aleuticus undergoes only local migrations in the spring, and spawning is restricted to fresh water. This species and C. asper are the only two freshwater species of sculpin to have an intermediate pelagic larval stage following hatching of the eggs.

III. Research objective

The objective of this report is to describe some of the general ecology of C. asper and C. aleuticus in a coastal stream on the west coast of Vancouver Island as determined from field studies conducted in 1971. Particular emphasis is placed on spawning migration and behaviour, temporal and spatial distribution, relative abundances, age and growth, and diel and seasonal changes in feeding patterns. This will serve as a basis for further work on their role as ecological components in stream systems.

IV. The study site

The Carnation Creek watershed is located in Barkley Sound on the west coast of Vancouver Island (Fig. 2). Amabalis fir-hemlock-Sitka spruce-red cedar is the vegetative association of the watershed. Located approximately 8 km from the mouth of Alberni Canal, Carnation Creek is 6.5 km long, drains an area of 29 km^2 and empties into Namukamis Bay.

Carnation Creek has a high pool to riffle ratio. The lower reaches of the stream form a 200 m long intertidal area which is part of a small, gravelly estuary.

The stream is typical of most small west coast of Vancouver Island streams. The highly variable discharge reached a maximum of 550 ft^3 per sec (c.f.s.) during prolonged heavy rainfall in the spring of 1971. For several weeks during the late summer of 1971 the flow in the riffles of the lowest portion of the stream became subsurface. At this time the minimum discharge was 1.5 c.f.s. One upper section of the stream (2500-3000 m) virtually dried up leaving only isolated pools. The mean summer (August) flow was 6.5 c.f.s. The stream temperature ranged from 1.5-12 C with a summer range of 10-12 C. Primary production is very low, and the stream contains little dissolved solids (22-50 ppm). The benthic animals are primarily nymphs of the orders Ephemeroptera and Plecoptera, larva of the order Trichoptera, dipteran larvae, and a few species of the order Acarinae.

The relative abundance of the three species of salmonid fishes present in the stream, in decreasing order, is coho salmon, rainbow trout (steelhead), and cutthroat trout. Rainbow and cutthroat trout are more abundant in the upper sections of the stream, above 1,500 m. Coho juveniles are distributed throughout the stream up to 3,100 m at which point there is a physical barrier to upstream movement (Fig. 3).

Population estimates indicate a total stream population in late summer, 1971, in the order of 10,500 coho fry, 1,000 coho yearlings, and 4,400 rainbow of all age groups. Cutthroat were too few for a population estimate. Approximately 123,000 coho fry and 2,400 coho smolts passed through the downstream trap located at the head of tidewater between May and September of 1971.

Chum salmon spawn in the lower reaches of Carnation Creek with about 80% spawning below the downstream trap (Fig. 3). The number of chum salmon fry migrating through the downstream trap was estimated at 356,000.

METHODS AND MATERIALS

I. Study sections

Five representative study sections were chosen along the stream (Fig. 3, Table I). The reference point of 0 m was located at the limit of the estuary as defined by the upper limit of mixohaline water at mean summer high tide.

Table 1. Lengths of study sections and relative positions in Carnation Creek.

Section	Distances covered in metres from 0 ref.	Length of section in metres	Wetted area in metres^2*
B	240-410	170	861.2
C	630-755	125	607.5
D	1160-1260	100	579.7
E	1870-2000	130	371.8
F	2300-2415	115	367.4
Total		664	2787.6

*Area at mean summer flow.

II. Sampling techniques

A. Movements

Migration data and specimens for age and growth were collected by the use of downstream and upstream trapping facilities. The downstream trap was located at 170 m and the upstream trap was situated 40 m below the downstream trap at 130 m (Fig. 3).

The downstream trap was a permanent structure which sampled the entire stream at low to medium flows. It consisted of three wire mesh inclined plane traps, each emptying into wooden holding pens. At low flow only one or two traps were operated.

The upstream trap was a temporary structure which sampled the full stream width only during low flow which was almost continuous in July and August but intermittent in September and October. This structure consisted of a 40.8 × 40.8 × 122.2 cm steel frame cage covered with .10 cm galvanized wire mesh with a trap door in the upstream end and a single tunnel opening in the downstream end. An apron and two .051 cm galvanized wire mesh wings extended from the trap to either bank. In the late summer the trap was covered with .051 cm wire mesh to exclude the possibility of young of the year sculpins escaping through the trap. Both upstream and downstream traps were checked twice a day: at 0800 hr and 1900 hr. During periods of high discharge the traps were checked more often. All fish captured were measured.

B. Distribution and population estimates

Downstream migration of cottid larvae was investigated using drift samplers stationed at 200 m intervals from 0-2400 m. These samplers were checked twice daily and remained in position for 24 hr periods. Sampling in the estuary for cottid larvae was carried out using a 250μ mesh plankton net towed at high tide with a boat and outboard motor.

The relative abundance of sculpins was estimated August 8-10, and September 13-15. Population estimates were calculated using the standard Petersen mark and recapture formula $\tilde{N} = MC/R$, where $\tilde{N}$ is an estimate of the population; M is the number of marked individuals placed in the population; C is the total number of specimens in the recapture sample; and R is the number of marked recaptures. Standard error of the estimates were calculated using the formula:

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

Population estimates made in August were confined to study sections "B" and "E" (Fig. 3). Specimens in section "B" were collected in the evening after dark using a 2 m pole seine mounted on two aluminum poles. It was assumed that a more representative selection of the population could be obtained at this time when the fish were expected to be active. Specimens were anesthetized in a 1.4:4500 solution of 2-phenoxyethanol, measured to the nearest millimetre, the top of the caudal fin clipped, and placed in buckets of fresh stream water for recovery from the anesthetic. A sample was kept for 24 hours to check for delayed mortality. The marked specimens were placed back in the stream in the area from which they were captured. Reseining for marked specimens was carried out four hours later. Those indivduals captured were placed back in the stream after having been counted and measured to the nearest millimetre and checked for marks. Assuming uniform density, extrapolation of this count gave an estimate of the total study section. Estimates for the entire stream were not calculated because of the migratory behaviour of both species of sculpins at this time of the year.

Another method for recapture was used to compare two techniques for possible fishing selectivity. A Smith-Root 400 volt pulsed D.C. shocker was used the day following the evening seining in August. In section "B" the same marked specimens were used for recapture by seining and by shocking, while in section "E" specimens for both marking and recapture were obtained by shocking. Population estimates in September were made in all five study sections by electrofishing.

C. Age and growth

The age structure of both populations was determined using length frequency distributions substantiated by otolith examination. The frequency distributions were compiled using the lengths at 5 mm intervals of all downstream migrants. Samples collected using different sampling techniques, different areas and times of year were kept separately for examining gear selectivity and differences in temporal and spatial distribution of different age groups.

Otoliths were taken in the spring and in August for determination of individual age groups. The specimens from the spring collection included downstream trap samples taken from the period of March to May 1971. Since the stream temperature did not rise above 6 C during this period, it was assumed that growth would have been minimal. Yearlings were collected in the estuary in the first part of June. The specimens comprising the August otolith sample were collected over a two-day period. In each set of otoliths representative specimens of the complete size range of each species were obtained.

Otoliths were cleared and stored in 50% glycerin - 50% isopropanol. They were read against a black background. A base line Age I was subjectively chosen by collecting the smallest specimen possible in June and assuming this to be a yearling.

A growth study was conducted by evening seining in two areas in the estuary in which a high density of Cottus asper was present (Fig. 4). Seining was conducted on June 29, August 11 and September 16, 1971, and on January 17, 1972.

D. Diel and seasonal feeding

A study of diel feeding patterns was carried out on July 14 and August 15, 1971, using a section of stream at 200 m. This area, consisting of a riffle and a shallow pool, was sampled four times in a 24 hr period (July 14, 2230 hr; 0500 hr; 1303 hr; and 1700 hr; August 15, 2200 hr; 0530 hr; 1000 hr; and 1700 hr). The time change between the two sampling dates was to compensate for changes in day length.

Sampling was by standard pole seine with only six specimens collected at each sampling time in order not to bias the next sample. Specimens were heavily anesthetized prior to being placed in 10% formalin.

Stomach analyses entailed measuring the wet weights of stomach contents and stomach walls, counting number of organisms by order per fish, and calculating the mean number of organisms and frequency of occurrence per sample. A Mettler H20 T-pan balance was used for weighing. Insect fragments and digested material were classed as unidentifiable. Insects were counted as whole if they could be recognized to order from head and body parts. Of course, frequency of occurrence of food material may be biased because indigestible chitinous material remains identifiable in the stomach longer than softer food material.

RESULTS

The two species of sculpins present in the stream, *Cottus aleuticus* and *C. asper*, make up an important portion (33-66%) of the fish biomass in the stream. The prickly sculpin, *C. asper*, are most abundant in the estuary and in the lower reaches of the stream up to 1000 m. A few large specimens are found up to 2000 m (Fig. 5). The Aleutian sculpin, *C. aleuticus*, occurs throughout the stream up to a physical barrier at 3000 m.

I. Movements

From March 31 to October 17, 1971 permanent downstream trapping facilities operated almost continuously. A definite downstream movement of both species of sculpins took place in the early spring with a peak in the third week of March (Fig. 6, Table II). Several smaller peaks occurred in April and May. Downstream movement was most intense at night. Gonad examination of specimens taken from the trap at regular intervals showed the sex ratio to be 1:1 for both species. Unfortunately, until May 20 it was possible for upstream migrating fish to be washed back into the downstream traps, so the total downstream counts prior to that date are probably in error.

An upstream movement of both species of cottids began in the last week of July (Table 2). Figure 7 shows upstream movement of all age groups. The low number recorded during the latter part of September was due to high discharge, hence discontinuous trapping.

Table 2. Downstream and upstream movement of *C. asper* and *C. aleuticus* in Carnation Creek in 1971.

Date	*Cottus asper* Downstream	*Cottus asper* Upstream	*Cottus aleuticus* Downstream	*Cottus aleuticus* Upstream
March 1-7	12		36	
8-14	41		97	
15-21	233		318	
22-28	481		390	
March 29-April 4	315		211	
April 5-11	284		212	
12-18	326		233	
19-25	307		156	
April 26-May 2	206		160	
May 3-9	126	15	207	4
10-16	115	24	211	0
17-23	73	7	166	3
24-30	69	0	11	1
May 31-June 6	58	1	11	0
June 7-13	53	0	10	0
14-20	49	1	4	3
21-27	70	5	21	0
June 28-July 4	50	8	5	2
July 5-11	52	1	14	11
12-18	27	20	6	5
19-25	11	29	10	29
July 26-August 1	21	77	8	110
August 2-8	20	122	2	42
9-15	17	145	8	235
16-22	10	44	4	15
23-29	81	233	6	22
August 30-Sept. 5	17	72	1	2
September 6-12	8	21	3	0
13-19	19	46	4	3
20-26	13	20	5	8
September 27-October 3	3	3	1	1
October 4-10	32	70	3	11
11-17	34	57	26	13

A major portion of the age I group (as defined by otolith analysis) of both species of sculpins migrating downstream was missing (Fig. 8). Extensive seining in all sections of the stream revealed this age group to be located primarily in the lower reaches of the estuary (Fig. 3). The length frequency of *C. asper* in the estuary on June 29 and August 8, 1971 (Fig. 9) and that of *C. aleuticus* on July 27 (Fig. 10) strongly suggest that these are mainly yearlings. Up to the last week in July the estuary was the only section of the stream where fish of either species in a size range suspected to be yearlings were found in any numbers.

An upstream movement of yearlings began in late July (Table 2) during the latter summer months. From September constant monitoring of the upstream trap was not possible because of high discharge and lack of available man hours, but it was apparent that fish were still moving upstream.

Drift samplers set up in Carnation Creek in July to collect drifting insects captured numerous pelagic cottid larvae drawing our attention to their presence. The movement downstream was restricted to the darkest hours of the night, an obvious decrease in the night abundance occurred from 0 m upstream to 2400 m (Table 3). We suggest that the larvae were primarily of C. aleuticus and that a large number of larvae moved to the estuary where they settled and metamorphosed to the juvenile form. This downstream movement ended about the last week in July. Plankton tows in the estuary revealed that pelagic cottid larvae were most abundant during the darkest hours of the night when the tide was high in late May and June (Table 4). This was also the time of maximum downstream movement of cottid larvae. No cottid larvae were obtained from plankton hauls taken during the daylight hours. Plankton hauls made in Namukamis Bay at the outer edge of the estuary revealed no larvae. Drift samplers placed in the estuary to sample outgoing tides during the evenings also failed to capture any larvae.

Table 3. Dounstream migrating cottid larvae caught during day and night in Carnation Creek in 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

Table 4. Carnation Creek estuary sampling for cottid larvae in 1971.

Date	Time (hr)	Sampling method	No. cottids	Remarks
				Port Alberni tides
May 20	1345-1830	Drift sampler	0	Low tide, 1435 hr, 3.3 ft
May 24	1200-1530	Drift sampler	0	High tide, 1245 hr, 9.4 ft
May 25	0030	Plankton net	22	High tide, 2355 hr on 24/5/71, 11.8 ft
	1400	Plankton net	0	High tide, 1335 hr, 9.4 ft
	1600-2100	Drift sampler	0	Low tide, 1935 hr, 4.8 ft
May 26	0030	Plankton net	248	High tide, 0045 hr, 11.6 ft
	1515	Plankton net	0	High tide, 1425 hr, 9.3 ft
May 30	2230	Plankton net	12	Low tide, 2330 hr, 5.3 ft
				Tofino tides
June 1	2000	Plankton net	0	High tide, 1945 hr, 9.5 ft
June 3	2110	Plankton net	3	High tide, 2040 hr, 9.9 ft
June 4	1045	Plankton net	0	High tide, 1040 hr, 10.0 ft
June 8	0020	Plankton net	150	High tide, 2310 hr, 7/6/71, 11.0 ft
June 13	0400	Plankton net	40	High tide, 0250 hr, 10.6 ft
June 26	1500	Plankton net	0	High tide, p.m.
June 29	0400	Plankton net	3	High tide, a.m.

Underyearlings of both species of sculpins began appearing in the estuary in late July. Figure 11 shows the appearance, increasing relative abundances and growth of underyearling C. asper in the estuary between July 1971 and January 1972. Extensive seining during the late summer and fall revealed all underyearling cottids of both species to be located in the estuary. Some larger sculpins were also found in the estuary during this period. C. asper juveniles were more abundant in shallow back waters and quiet pools, while C. aleuticus fry were restricted to riffled areas of the survey.

The temporal and spatial distribution in Carnation Creek of C. aleuticus and C. asper is summarized in Table 5.

II. Age and growth

A. Age interpretation

The size range of downstream migrants in the early spring probably provides a good representation of the age structure of the populations except for the age I group of both species (Fig. 8). It was shown above that most yearlings were in the estuary in the spring. Figure 12 shows the approximate length ranges of C. asper underyearlings and yearlings over a 9 month period. It is apparent that in June fish less than 30 mm are yearlings (Fig. 8-12). A series of otolith microphotographs representing the age groups of C. aleuticus and C. asper are shown in Fig. 13 and 14. Results of the otolith interpretation indicate a large overlap in lengths of successive age groups (Fig. 8). The length range of each age group of C. aleuticus and C. asper in June and in August as defined by otolith interpretation emphasizes this overlap (Fig. 15). In fact age interpretation by sculpin otoliths was fairly difficult and the results given here are only provisional.

B. Growth studies

The growth of C. asper in the estuary was obscured by several factors. Differentiation of age groups with fin clips was not done, hence no direct comparison of growth between age groups could be made. Also immigration and emigration of C. asper could not be well monitored because of tidal fluctuations. A 33% return of the 364 specimens marked after 40 days indicated a minimum amount of movement out of the estuary.

Table 6 presents the mean lengths of the first four age groups of C. aleuticus and C. asper and their growth over the summer (65 days). That the 65 day growth increment does not decrease regularly with age suggests again that otolith interpretations introduced some error. However, as expected, the relative growth rate (% of absolute length increase to the initial length) decreased with increasing age in both species (Table 6, and Fig. 16).

Table 5. Summary of spatial and temporal distribution of *C. aleuticus* and *C. asper* in Carnation Creek in 1971.

		Cottus aleuticus	*Cottus asper*
Spring	Mar. Apr. May	Both sexes of at least part of the population migrate downstream together. Sex ratio of migrants 1:1. Possibly this species does not spawn in mixohaline water but at least migrates to reaches of the stream under tidal influence. The downstream movement peaks the third week in March. A large number remain upstream and possibly undergo only local migrations before spawning.	A definite downstream migration to the estuary peaks the third week of March. The sex ratio is 1:1. Spawning takes place in the lower mixohaline section of the estuary in April, May and June.
Summer	June July Oct.	Eggs hatch into pelagic larvae. The larvae from upstream passively migrate at night downstream to the estuary where they settle to the bottom and metamorphose into the juvenile form. Adults begin moving upstream. Underyearlings remain in lower mixohaline portion of estuary over winter. Yearlings, having spent one year in the estuary, migrate upstream in late summer after the adults.	Eggs hatch into pelagic larvae and remain in the estuary in this form for an unknown number of days then settle to the bottom metamorphosing into the juvenile, benthic form. Activity of larval stage is maximal at high tides and darkest hours of night. Fry remain in estuary over winter as do *C. aleuticus*. Adult *C. asper* migrate upstream to respective habitat in late July.

III. Population estimates

The two different recapture methods of night seining and electrofishing gave comparable results. That the marked specimens were redistributed randomly within the population, at least for night seining, is revealed in Fig. 17.

Night seining for recapture probably gave more accurate estimates of the population since this method was employed four hours after the marked specimens were initially released (Table 7). Electrofishing in study section "B" did not take place until the following day, and at this time of the year upstream movement of *C. aleuticus* was occurring at night.

Table 6. Summary of growth in lengths of age groups 1-4 of *C. aleuticus* and *C. asper* for June-August (65 days), 1971.

	Cottus aleuticus				*Cottus asper*			
	Age 1	Age 2	Age 3	Age 4	Age 1	Age 2	Age 3	Age 4
Absolute mean (mm growth increment	9.0	10.0	10.5	8.0	7.5	10.5	17.0	11.0
Relative growth rate %	27.7	21.3	17.6	11.2	20.0	19.1	23.4	12.6
Mean length of age class, June (mm)	32.5	47.0	59.5	71.5	37.5	55.0	72.5	87.5
Mean length of age class, August (mm)	41.5	57.0	70.0	79.5	45.0	65.5	89.5	98.5

Table 7. Population estimates for *C. asper* and *C. aleuticus* in Carnation Creek.

August 3-4, 1971

Study section			Marks out	Marks recovered	Total fish recovered	$\tilde{N}$	S.E.N.
B	Night seine	*C. asper*	22	4	23	127	52
		C. aleuticus	218	86	244	619	36
	Shocking	*C. asper*	22	1	10	220	204
		C. aleuticus	218	22	89	882	155
E	Shocking	*C. asper*	3	0	0		
		C. aleuticus	44	6	36	264	91

September 15, 1971

Study section	Species	Marks out	Marks recovered	Total fish recovered	$\tilde{N}$	S.E.N.
B	*C. asper*	28	2	32	448	295
	C. aleuticus	177	12	199	935	121

...

Table 7. Cont'd.

September 15, 1971 (cont'd)

Study section	Species	Marks out	Marks recovered	Total fish recovered	$\tilde{N}$	S.E.N.
C	*C. asper*	8	0	7	-	
	C. aleuticus	25	3	31	258	133
D	*C. asper*	4	1	1	-	
	C. aleuticus	29	3	26	251	129
E	*C. asper*	0	0	2	-	
	C. aleuticus	27	0	13	-	
F	*C. asper*	0	0	0	-	
	C. aleuticus	53	3	23	406	212

Results of the night seining gave population estimates for the 40 m section for *C. aleuticus* as 619 with a standard error of 36, and for *C. asper* 127 ± 52 (Table 7). Extrapolation for the total study section area "B" was 1855 *C. aleuticus*, and 380 *C. asper*.

Results from the electrofishing of the same area the following afternoon (all seined fish were returned) gave population estimates as: *C. aleuticus* 882 ± 115 and *C. asper* 220 ± 240 (Table 7). Estimates were of the same order for the two recovery methods, but the higher standard error for electrofishing suggests this technique is less accurate than the night seining method. Electrofishing above the 40 m release area revealed that some marked *C. aleuticus* had moved upstream. To correct for upstream movement a simple factor was calculated as described below from the numbers of marked specimens captured above the designated recapture area.

Upstream-downstream trap data suggested that migration at this time was primarily upstream. While no marked specimens were recaptured below the 40 m long release area, a 50 m section immediately above the release area was electrofished and of 81 specimens captured, 5 were marked (6.2%). If this ratio was representative of the population in the area and if the density of sculpins in this area was the same as in the 40 m release section, then 6.2% of the population in the 50 m area immediately above the release area would have been marked. Therefore, 6.2% × 629 = 38.4 marked specimens will have emigrated from point of release. This would be equal to 38.4/218 × 100% = 17.6% of the marked population. The correction for shocking would be 218 - 38 = 180 marked specimens available in the area for recapture. The corrected estimate for *C. aleuticus* for the electrofishing method would be 800 and for the total study area "B", 2400 individuals. No marked *C. asper* specimens were recovered above the release area thus extrapolation for the total study area was 660.

IV. Feeding habits

The major food items consumed by 40-70 mm C. aleuticus were immature benthic forms (Table 8). Represented were the insect orders Plecoptera, Ephemeroptera, Trichoptera, the families Simuliidae and Chironomidae of Diptera and several genera of aquatic mites and ticks in the order Acarina. Only one cottid larva was found in all stomachs sampled (99). The occasional winged adult insect taken suggests possible sporadic feeding at or near the stream surface. Sand grains were present in the stomachs of most fish sampled. These grains were probably the accumulation of decomposed caddisfly larvae cases or debris picked up while foraging for food. Feeding patterns did not significantly change from July to August, although Ephemeroptera nymphs were more abundant in C. aleuticus stomachs followed in order by Plecoptera nymphs and Trichoptera larvae.

C. aleuticus, 40-70 mm in length, appear to feed most actively between dawn and 1000 hr in both July and August (Table 9). During early summer (July) Plecoptera and Ephemeroptera nymphs were found to be most abundant in sculpin stomachs in the late evening and early morning. During the afternoon and early evening Trichoptera larvae were the major food item ingested. Chironomid larvae were an important food item during the late evening and early morning but decreased in abundance during the daylight hours. Only one cottid larva was found in all stomachs sampled (99).

DISCUSSION

Reviewing the annual migration cycle of C. aleuticus and C. asper (Table 5), it was found that although the migratory behaviour of both species of sculpins followed the general trend as reported in the literature, several major differences of temporal distribution of both species were evident.

The length frequencies of downstream migrants in Carnation Creek revealed the majority of the first age group of both species to be missing (Fig. 8). It is possible that the yearlings did not migrate downstream because of not being reproductively mature. Patten (1971b) suggests the possibility that C. asper does not mature until age 3 and C. aleuticus at age 2; this is supported by our study. However, extensive seining in May and June upstream of the trapping facilities revealed few yearling of either species of sculpin.

It is most likely, as indicated by our results, that the young of the year spend over one full year in the estuary and do not migrate upstream to their respective stream habitats until late summer of the following year as late yearlings. Extensive seining revealed large numbers of yearlings of both species located in the lower mixohaline portion of the estuary in June and July. Monitoring the movement of underyearling C. aleuticus and C. asper from the time of appearance in July 1971 to January 1972 showed this age group to be located in the same area of the estuary in which the yearlings were found (Fig. 11). These results strongly suggest that the underyearlings overwinter in the estuary.

Table 8. Feeding habits of C. aleuticus at 210 m in Carnation Creek for two 24-hour periods in the summer of 1971.

Time (hr)	2230		0500		1030		1700	
Sample size N	10		10		11		20	
Mean length of fish (mm)	56		59		47		49	
July 14-15, 1971	Freq. of occurrence %	Mean no. org./fish	Freq. of occurrence %	Mean no. org./fish	Freq. of occurrence %	Mean no. org./fish	Freq. of occurrence %	Mean no. 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

Table 8. Cont'd.

Time (hr)	2200		0530		1000		1700	
Sample size N	14		14		12		8	
Mean length of fish (mm)	68		58		50		50	
August 15-16, 1973	Freq. of occurrence %	Mean no. org./fish	Freq. of occurrence %	Mean no. org./fish	Freq. of occurrence %	Mean no. org./fish	Freq. of occurrence %	Mean no. 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) Chironomidae	22	.6	7	.4	25	.3	25	.9
Acarina	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	

Table 9. Ratios of stomach content weight/total stomach weight over a 24 hr period and seasonal change for C. aleuticus at 210 m in Carnation Creek.

Time (hr)	July 14-15	August 15-16
10:00 p.m.	.317	.170
5:00 a.m.	.361	.254
10:00 a.m.	.430	.350
5:00 p.m.	.251	.321

Adults of C. aleuticus were found to make a definite downstream movement in the early spring along with C. asper. According to Krejsa (1967), C. asper adult males set up and defend territories during the spawning and egg incubation period. If C. aleuticus spawning behaviour is similar, there is a possibility that the downstream movement of C. aleuticus is a function of available spawning habitat and the smallest individuals move the farthest downstream. However, a large proportion of the downstream migrants were of reproductive maturity and of considerable size.

There are certain differences in migrational behaviour and temporal distribution of underyearling and yearling Cottus asper as reported by Krejsa (1967) and Taylor (1966) and the results of our study. In the Little Campbell River, Krejsa reports an upstream movement of underyearling C. asper from the spawning area inundated by mixohaline water in the estuary to the lower reaches of the stream in the fall. Taylor describes a similar movement for both Cottus aleuticus and C. asper with further upstream movement to their respective habitats as yearlings. Results of the work done at Carnation Creek suggests that fry of both species of sculpins overwinter in the estuary and migrate to their respective habitats in the following fall as yearlings.

In the Little Campbell River most of the information on sculpin movement was obtained by day and night seining by both Krejsa and Taylor at permanent collecting stations. Laboratory studies complemented their work. Krejsa (1967) reports that C. asper is distributed throughout the lower four miles of the Little Campbell River. The spawning behaviour has been well documented by Krejsa. The downstream migration in the early spring is followed by a successful spawning and incubation period. An upstream migration of adults precedes that of the young of the year. Krejsa suggests this behavioural difference between adults and underyearlings to be a function of the food habits of the two groups and also a later return of the young of the year coincides with lower water levels which possibly facilitates upstream movement. During the early summer, young of the year C. aleuticus were found in the lower reaches of the river just below the spawning grounds of C. asper.

Taylor (1966) reports a similar spawning migration and behaviour of C. asper in the estuary of Little Campbell River. He also reports the possibility of some C. asper spawning upstream next to spawning C. aleuticus. According to Taylor the presence of fry of both species of sculpins in the estuary suggests a passive migration downstream of larvae hatched upstream. In the Little Campbell River fry of both species occupy the lower estuarine region during the early summer but are found principally in the upper freshwater section under tidal influence "later in the season" (Taylor, 1966). At this time they exhibit definite habitat preferences. As yearlings, C. aleuticus migrate farther upstream than C. asper: a function of available habitat and C. asper density. Taylor reports this as a true migration of yearling C. aleuticus and C. asper from the upper tidal area to their respective habitats in late summer. C. asper migrates less than 6 km; C. aleuticus less than 12 km. Krejsa (1967) does not mention this second movement. From his distribution graphs of underyearling C. asper it is obvious that these fish move up only as far as the lower reaches of fresh water that are still under tidal influences. Since this upstream movement was not to the full limit of the respective adult habitat, questions immediately arise on Krejsa's possible oversight of the full utilization of available habitat. Possibly, Taylor, working with both species, observed the second stage of C. asper movement while observing the movement of yearling C. aleuticus to their fast flowing, high gradient habitat in the middle section of the river. In Carnation Creek, an intermediate upstream movement of underyearlings was not detected.

Reviewing the temporal distribution of underyearlings and yearlings of both species of sculpin in both streams, we conclude that most pelagic larvae hatched upstream and in the estuary end up in the estuary where they settle and metamorphose into the benthic fry form. In the Little Campbell River newly metamorphosed fry do not have a specific habitat preference until "later in the season", when they migrate upstream out of the spawning area. In Carnation Creek, newly metamorphosed fry seem to have an immediate habitat preference. These fish remain in the lower section of the estuary over winter and make one long migration upstream to their respective habitats in the fall as yearlings. As underyearlings in the estuary C. asper is restricted to back waters and quiet pool areas, while C. aleuticus is principally located in the riffle areas of the main creek channel.

Assuming that the effects of intraspecific competition for the two species is the same in both streams (i.e. the interaction between adults and underyearlings-yearlings, if any, exists in both streams), it is some other factor or combination of factors that cause the observed differences in temporal distribution. In the absence of these factors the behaviour of these two populations should be similar. In an attempt to define those factors that might be causing behavioural differences of underyearling and yearling C. aleuticus and C. asper, several explanations are possible mainly regarding salinity and competition.

Salinity tolerances seem rather unlikely to be a major factor inhabiting or stimulating movements. Although both species are apparently tolerant of a wide salinity range, it seems that continually fluctuating salinities, as would occur in the estuary, would cause physiological stress and being primarily freshwater fish, both species would prefer fresh water. According to Bond (1963) C. asper and C. aleuticus are able to survive indefinitely in salt water but they can probably both exist more easily in fresh water.

In Carnation Creek estuary the fast flushing rate after a high tide minimizes the length of time that the fish is subjected to saline waters. Observation on the Little Campbell River by one of us (Ringstad) suggests that saline waters remain in the estuary for long periods of time as indicated by the presence of marine fauna (*Leptocottus armatus*, *Platichthys stellatus*, and *Balanus* sp.) at low tide. Such marine species were seldom observed in the estuarine region of Carnation Creek where the majority of freshwater cottids were found; although a few *Leptocottus armatus* specimens were found throughout the lower region of the mixohaline section of the estuary. In the Little Campbell River, this species was found throughout the entire mixohaline portion of the estuary. Thus the presence of saline water throughout the estuary even at low tide plus possible interspecific competition might well cause segregation of freshwater and marine cottids.

In Carnation Creek the presence of fresh water for longer periods of time and consequently little interspecific competition with marine cottids may possibly be reasons for the underyearlings remaining in the intertidal zone. Also the lack of a sufficient intertidal zone may minimize any late summer movement of underyearlings upstream as reported by Taylor (1966) and Krejsa (1967).

Otoliths in reflected light show a central white kernel surrounded by zones of light and dark: one dark band (winter growth) and one light band (summer growth) constituting one year's growth. In young fish the central white kernel is clearly evident but as the fish matures the kernel and ring fuse to form one slightly larger central kernel. From this base complementing dark and light bands form annuli (Fig. 13 and 14).

Since both species spend their first year in the estuary a definite change in the pattern of annuli should be evident between growth in the estuary and growth upstream. When the sculpin samples were aged the ring surrounding the central kernel evident in younger fish was ignored (Fig. 13). Otolith analysis using this technique gave results that agreed with modes in the length frequency graphs. The presence of false otolith rings cannot be explained at this time.

Results of age and growth studies revealed *C. aleuticus* to be smaller than *C. asper* for all age groups. The relative growth rate of *C. asper* decreased from 20% to 12.6% for the first four years and for *C. aleuticus* the growth rate decreased from 27.7% to 11.2% for the same age span. The majority of the population of each species is composed of the first four age groups. McLarney (1967) states the mean length of the age classes up to 6 yr + of *C. aleuticus* in the Baranoff Islands to be 44, 57, 60, 65, 83, 92, 108 mm respectively. These results are comparable to those obtained at Carnation Creek for *C. aleuticus* near the end of the summer period of 1971.

Lacking an air bladder freshwater cottids inhabit the stream bottom and are prohibited from prolonged periods of swimming or surface feeding. Being restricted to the bottom, cottids occupy an ecological niche in the stream in which interspecific competition with salmonids is minimized.

Stomach analysis of sculpins shows a diet of almost exclusively benthic insect larvae. According to Zarbock (1951) these same food items of the orders Ephemeroptera, Plecoptera and Trichoptera are important in the diet of brown trout and brook trout. Zarbock suggests that interspecific competition for food may be increased during the winter when the feeding habits of trout are restricted to bottom foraging.

In Carnation Creek the associated species of salmonids are coho age 0 and I and steelhead age 0-II. Coho are primarily drift and surface feeders while steelhead tend to forage near the substrate. The substrate inhabiting cottids are probably not in direct competition with the coho. During the winter, competition for food might increase between salmonids and cottids when stream production is minimal and all fish are seeking cover near the bottom or inside channels. However the cottids and salmonids are feeding on many of the same forms, but the former are foraging in the substrate and the latter in the drift. It is possible that under certain environmental conditions the riffle inhabiting C. aleuticus could make serious inroads on the salmonid food supply (indirect competition).

The food production in Carnation Creek is relatively low and cottids might have an important effect on the availability of food for salmonids, particularly during winter when all fish are associated with the bottom and/or heavy cover. Possibly at this time sculpins are an important competitor for available benthic living space. Thus cottids could have an important role in the overwintering survival of juvenile salmonids.

SUMMARY

1. Cottus aleuticus and Cottus asper undergo a definite downstream migration in the early spring. C. asper spawn in the upper reaches of the estuary. C. aleuticus possibly undergo only local migrations, a function of available spawning habitat upstream.

2. Successful spawning of C. aleuticus upstream results in pelagic larvae which are carried passively downstream to the estuary at night. Successful spawning of C. asper results in pelagic larvae which with C. aleuticus larvae settle to the bottom in the estuary to metamorphose into the benthic fry form.

3. Young of the year of both species, while confined to the estuary, apparently have a definite habitat preference. C. aleuticus fry are located primarily in the riffle areas of the main stream. C. asper juveniles were found in the quiet pool areas and back washes of the estuary during low tides.

4. A definite upstream migration of the adults of both species takes place in the late summer.

5. Young of the year of both species remain in the upper reaches of the estuary over winter and migrate upstream the following autumn as yearlings. Upstream movement of yearlings follows that of the adults. It is assumed that yearlings occupy the same habitat as adults upstream.

6. During the non-breeding season *C. asper* is distributed primarily in the lowest 1000 m of the stream with a few large individuals found sporadically up to 2000 m. This species is confined to deep pools and quiet areas where suitable cover is available. *C. aleuticus* are distributed throughout the entire stream up to 3100 m where a physical barrier precludes any further movement upstream. In areas where *C. asper* is present, *C. aleuticus* is restricted to riffle areas, but upstream where *C. asper* is absent, they are found to occupy both pool and riffle areas.
7. Age and growth studies reveal *C. aleuticus* to be smaller than *C. asper* for all age classes. Both species live for at least seven years. The growth rate of *C. asper* decreases from 20% in the first year to 12.6% in the fourth year. The growth rate for *C. aleuticus* decreases from 27.7% to 11.2% in the first four years of their lives. The majority of the population of each species is comprised of the first four age classes.
8. *C. aleuticus* is the more abundant of the two species of sculpins in the stream. Because of the migratory nature of both species during the study period, accurate population estimates could not be made. It is suggested that the *C. aleuticus*/*C. asper* ratio is about 4.
9. Both species feed primarily on benthic aquatic insect larvae. The most intense feeding activity takes place in the early morning. No major changes in food occurred on a seasonal basis (July-August).

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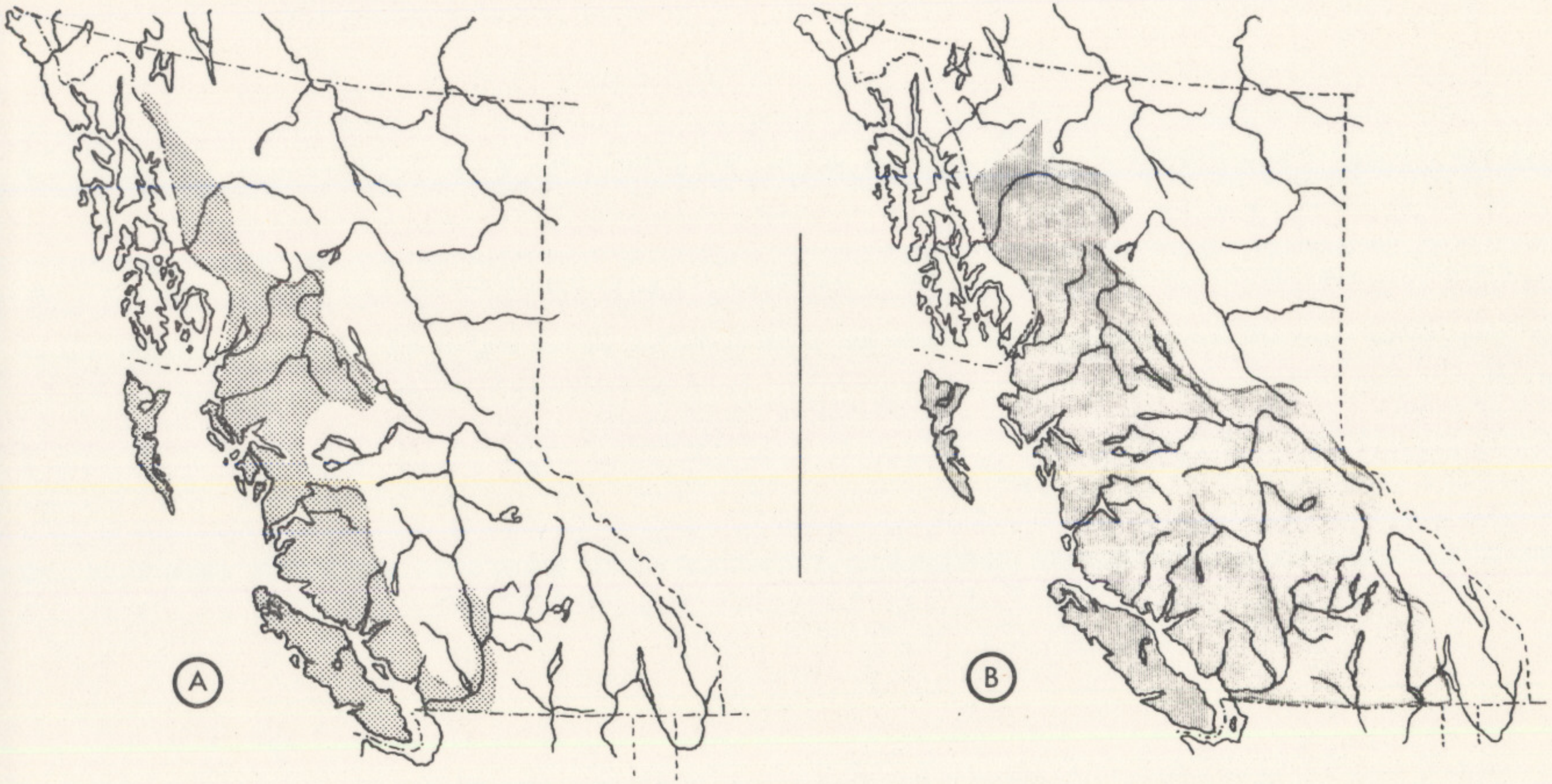

FIG. 1. Geographic distribution of Ⓐ *Cottus aleuticus* and Ⓑ *Cottus asper* in British Columbia. (after Carl, Clemens, and Lindsey 1967).

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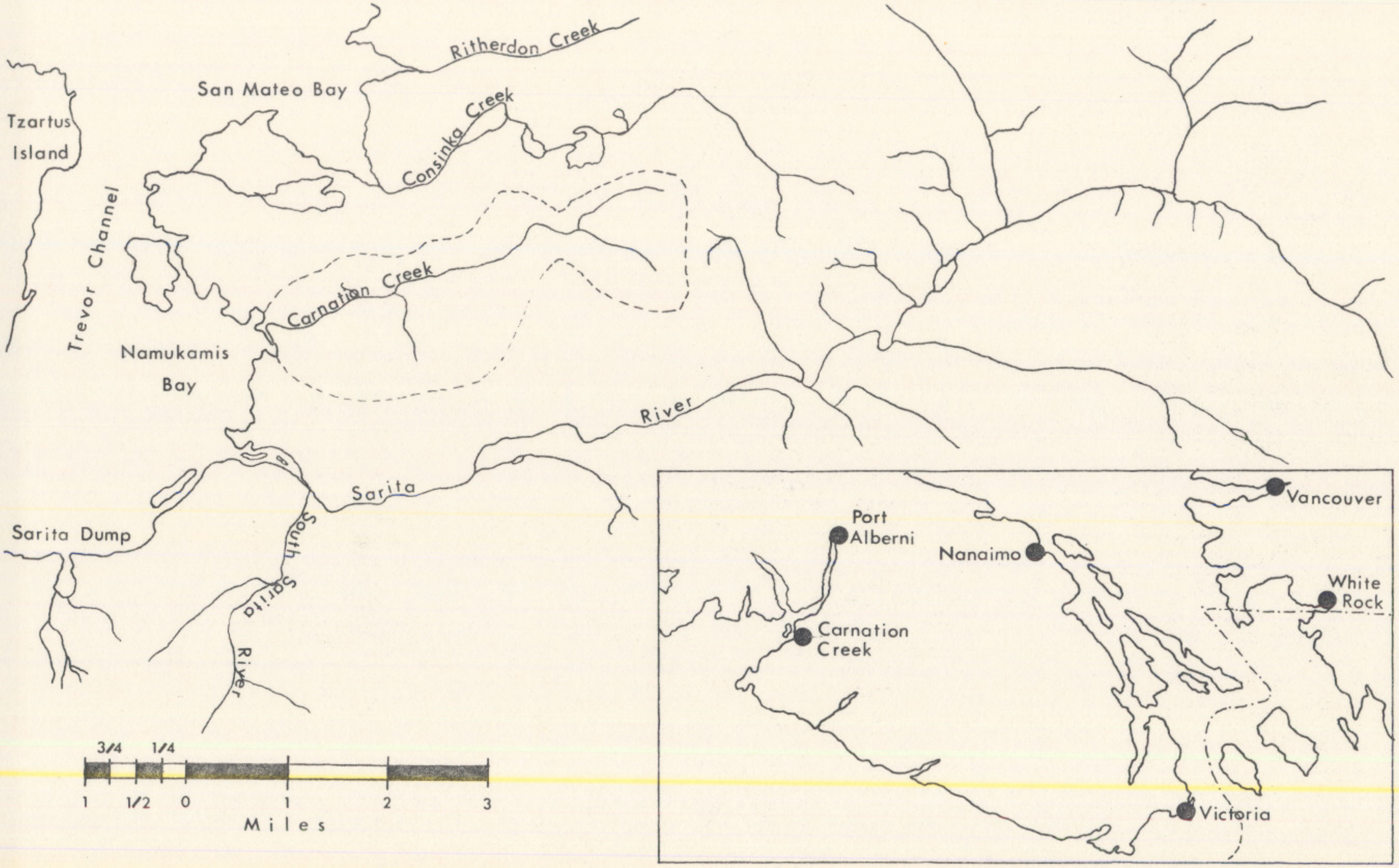

FIG. 2. Carnation Creek watershed with Vancouver Island inset.

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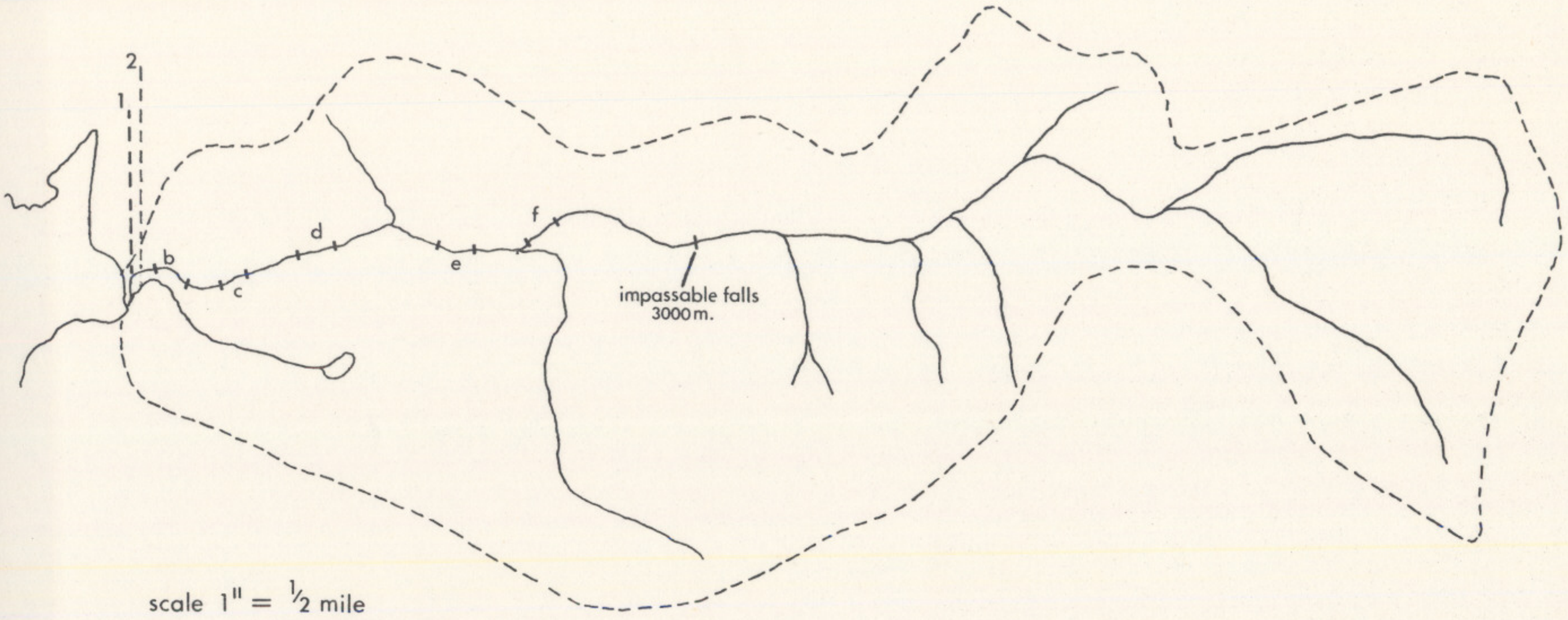


scale 1" = ½ mile

1 upstream trapping facilities
2 downstream trapping facilities
b – f study sections (see table 2 of text)

FIG. 3. Carnation Creek showing sampling stations and study sections.

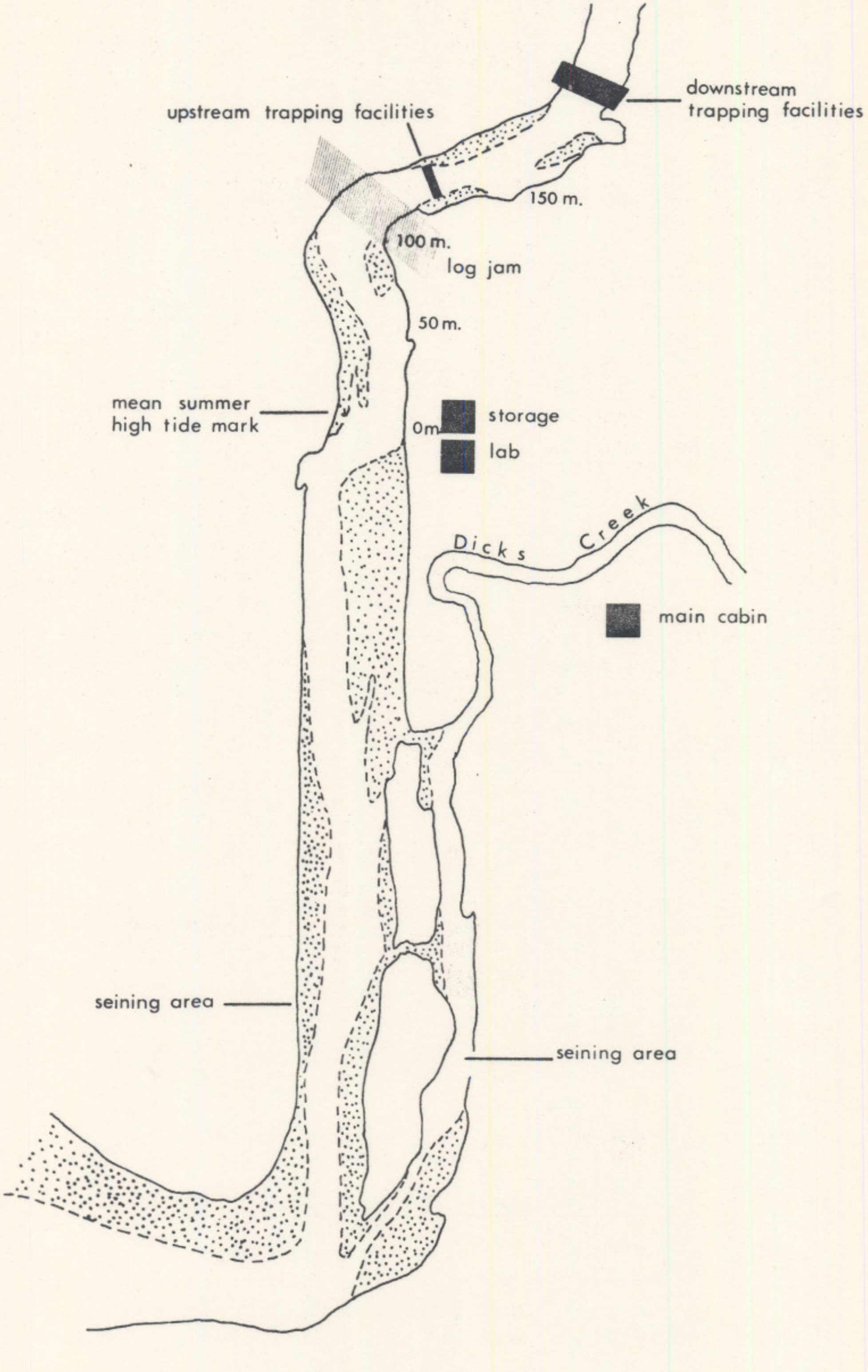
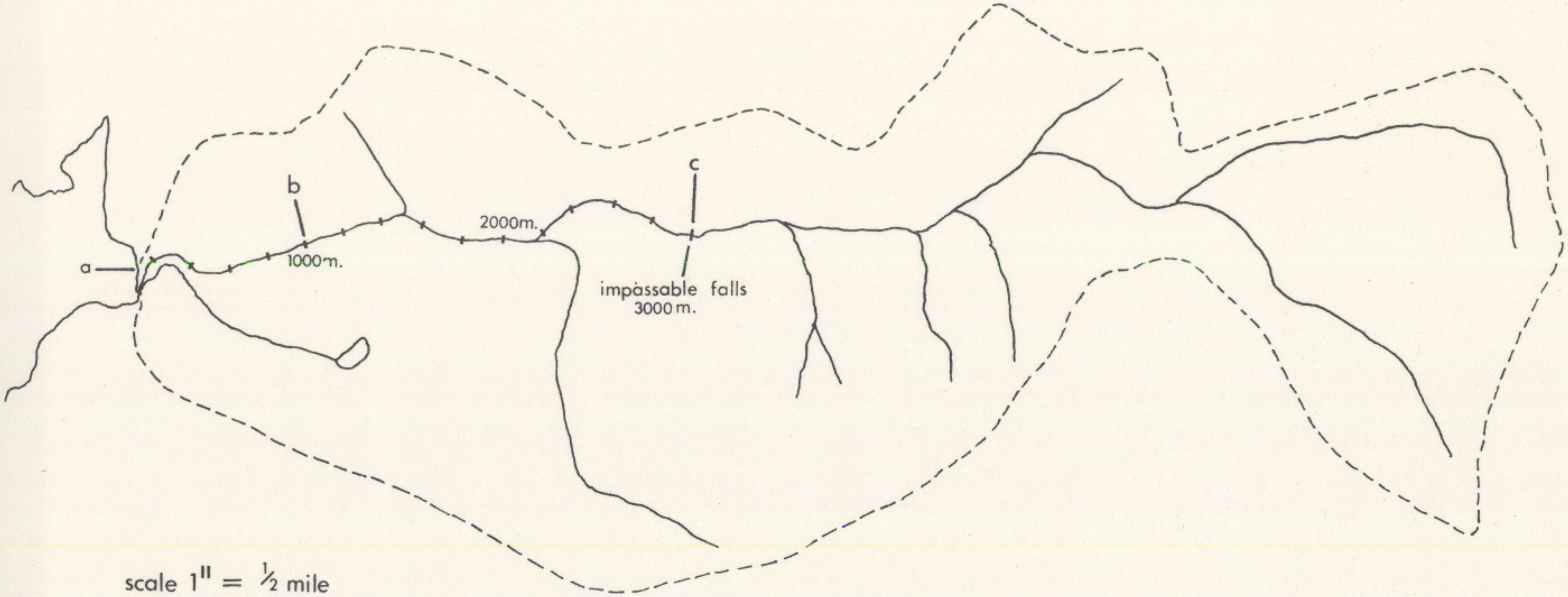


FIG. 4. The upper Carnation Creek estuary at low tide indicating seining areas and stream trapping facilities.



scale 1" = ½ mile

a -- upper limit of estuary. 0 m. reference

b -- upper limit of C. asper distribution. A few large individuals found up to 2000 m.

c -- upper limit of C. aleuticus

FIG. 5. Carnation Creek showing meterage, estuary limits, and spatial distribution of *Cottus aleuticus* and *C. asper.*

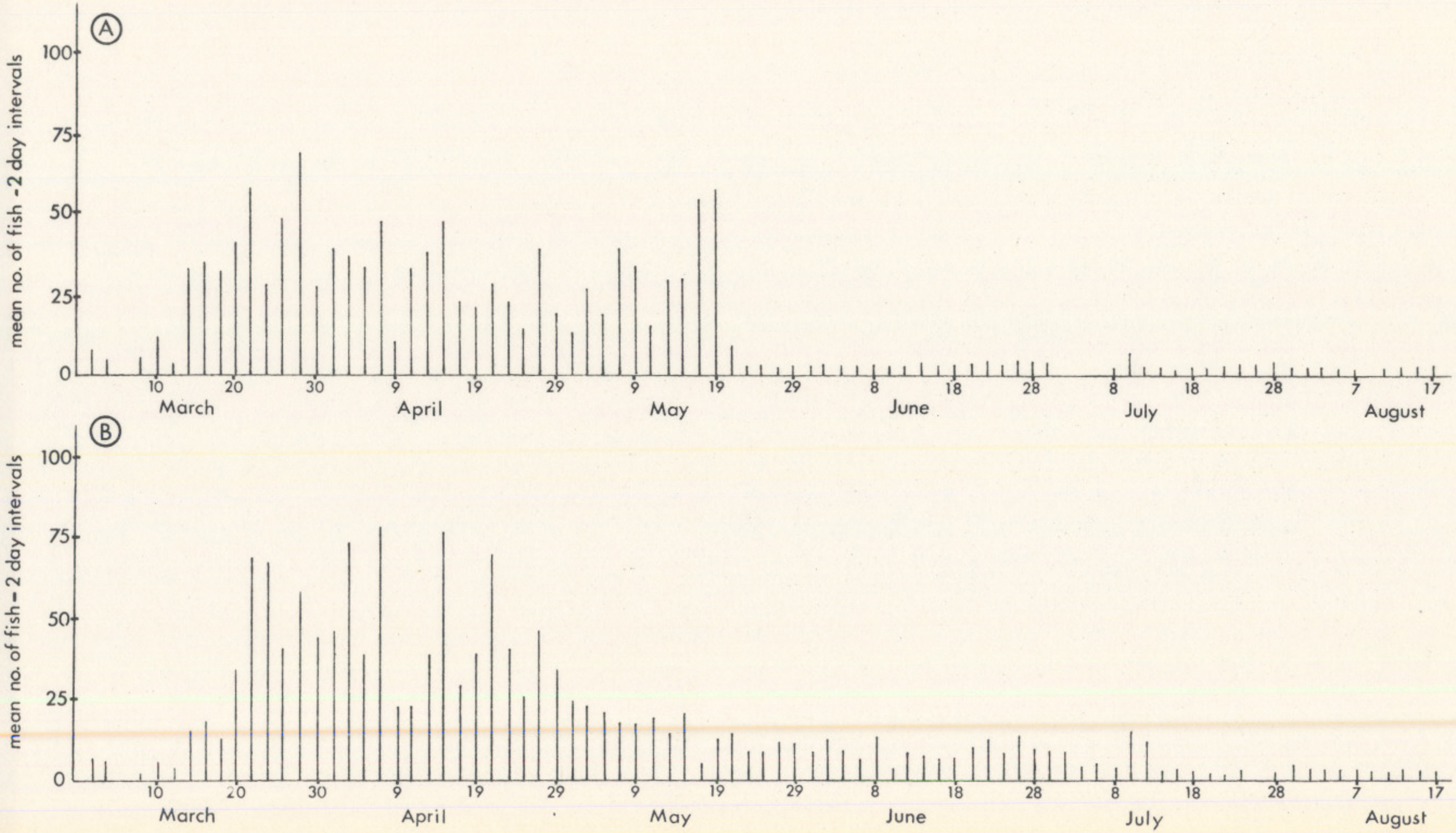


FIG. 6. Downstream movement of Ⓐ *Cottus aleuticus* and Ⓑ *C. asper* March – August 1971

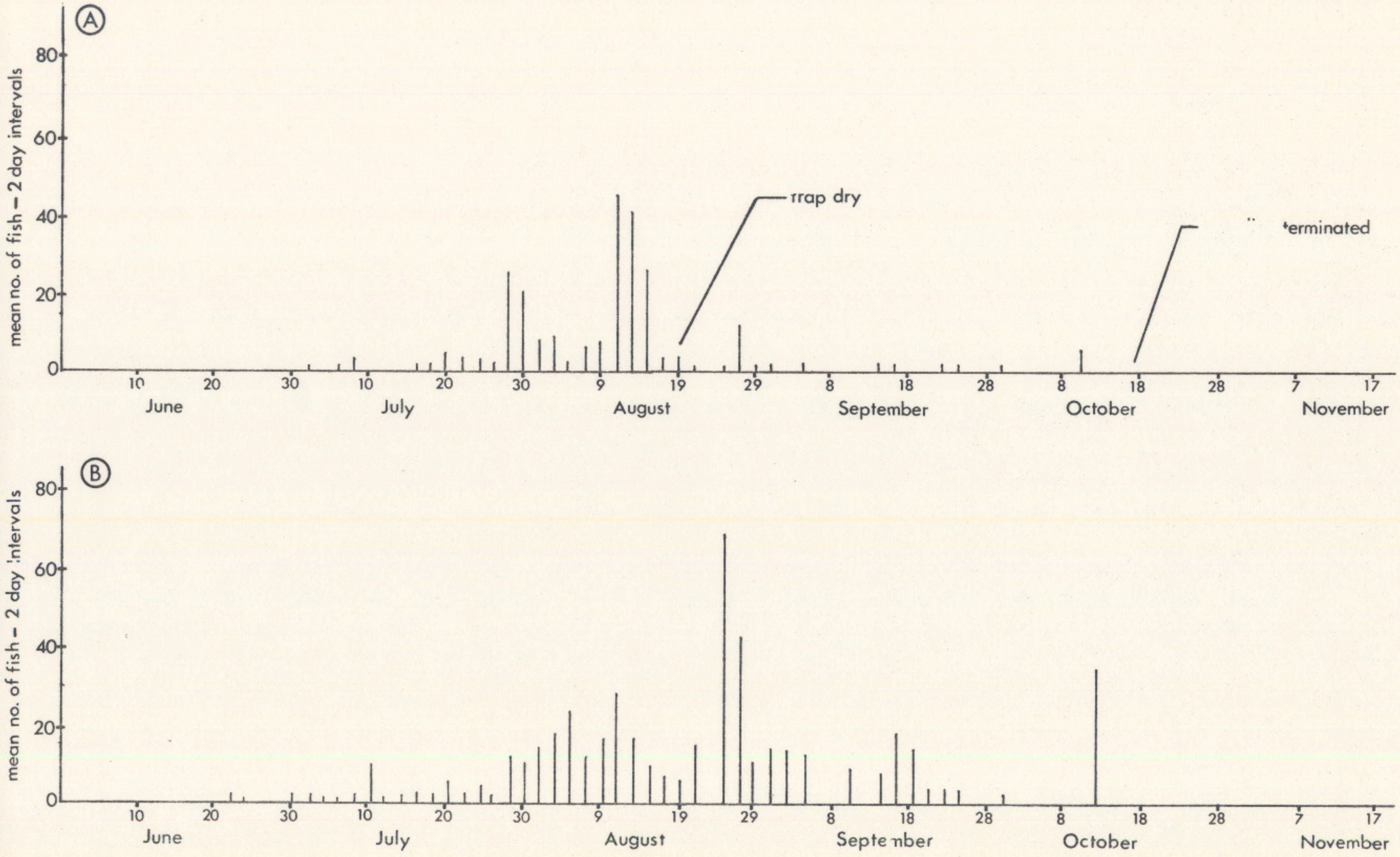


Fig. 7. Upstream movement of all age groups of (A) *Cottus aleuticus* and (B) *C. asper* (June-October 1971).

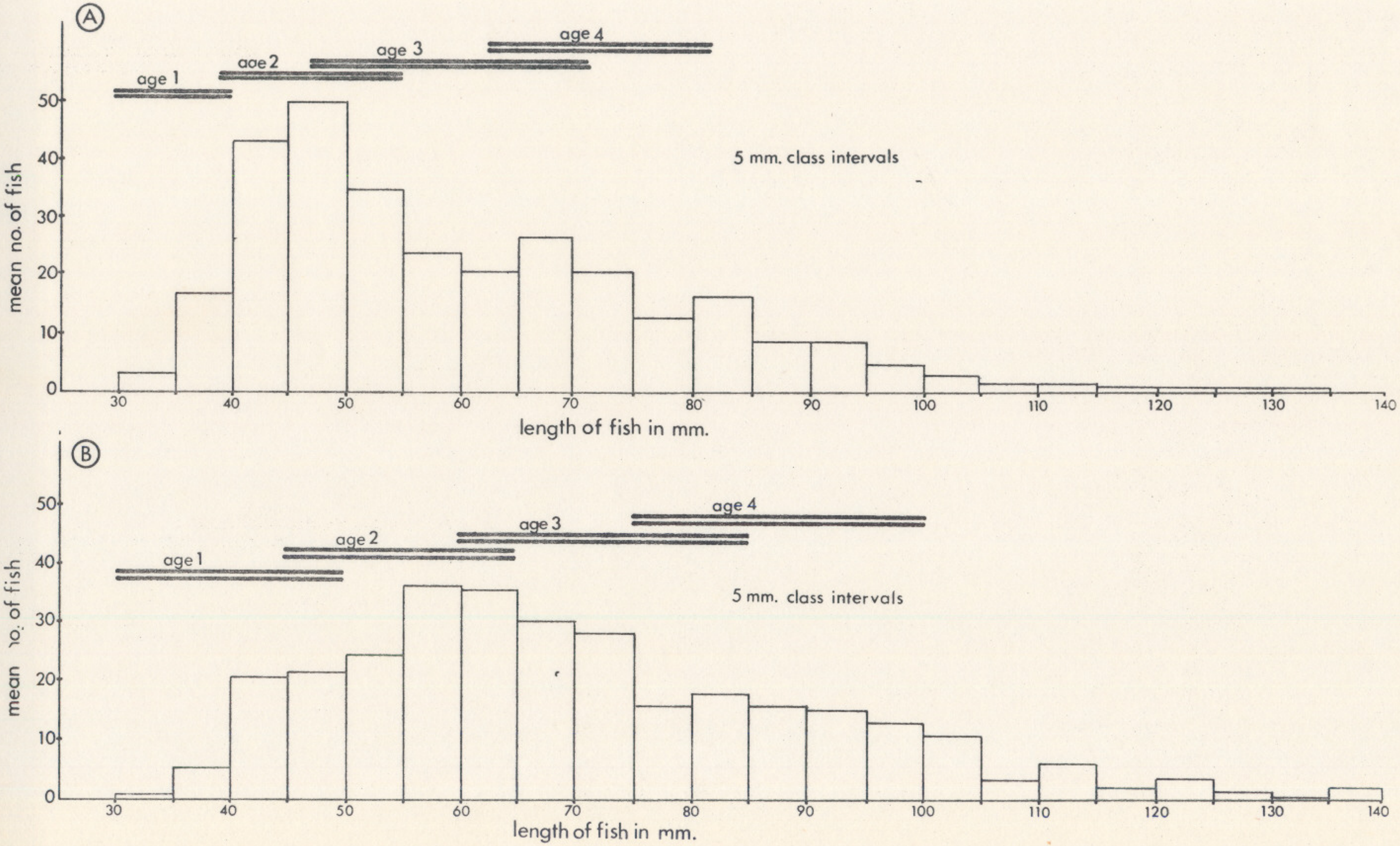


FIG. 8. Length frequency of downstream migrants of (A) *Cottus aleuticus* (March to May 1971), and (B) *C. asper* (March to July 1971). Superimposed are age groups as indicated by otolith interpretations.

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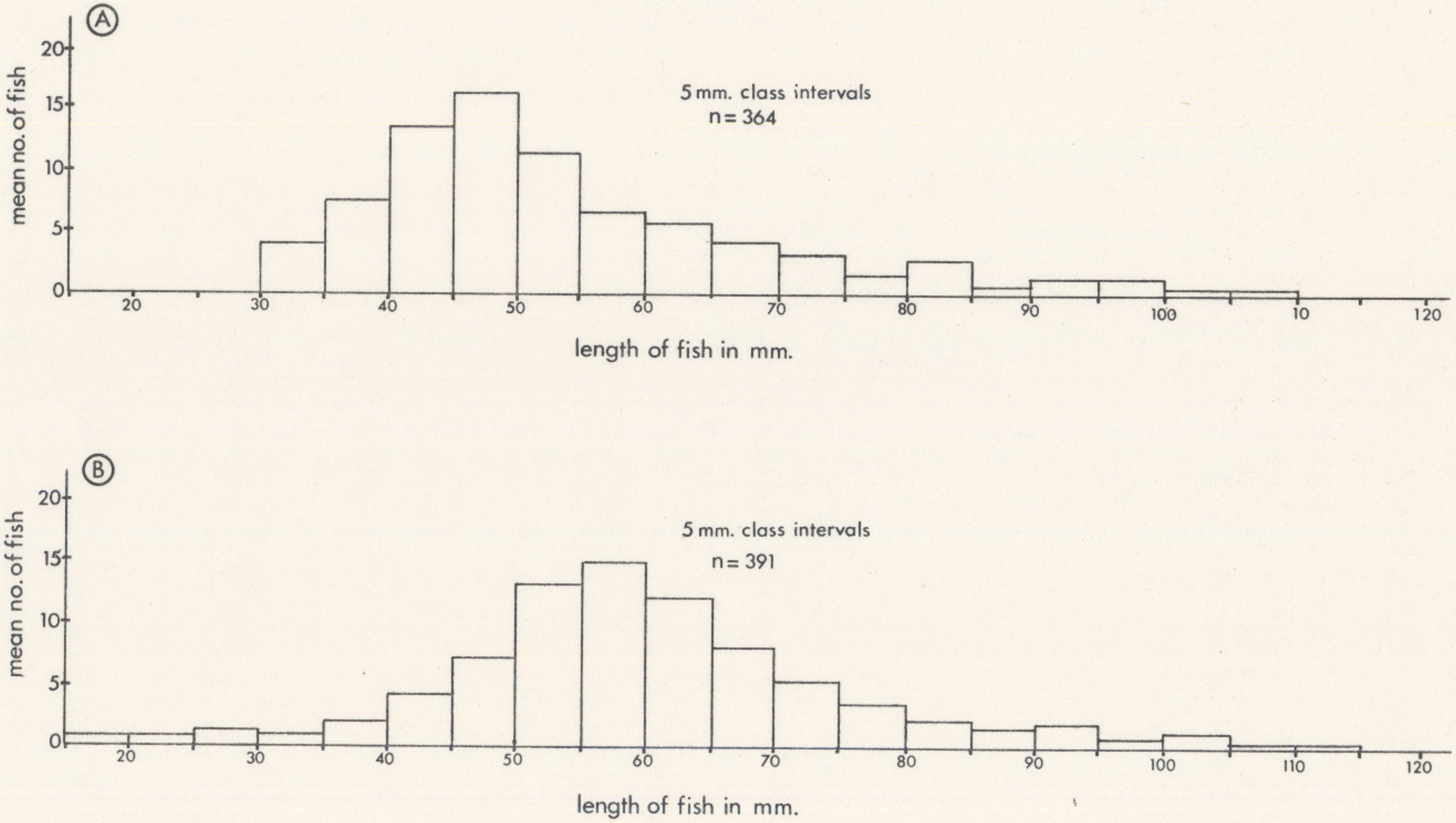


Fig. 9. Length frequency of Cottus asper in estuary for (A) June 29, and (B) August 11, 1971.

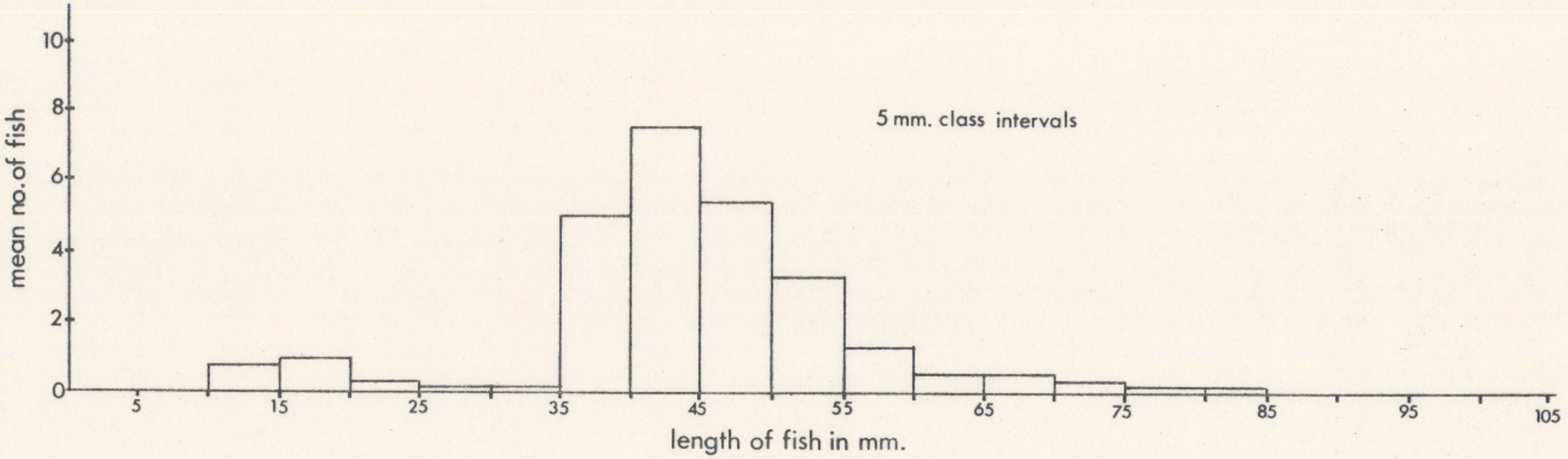


FIG. 10. Length frequency of Cottus aleuticus in the estuary July 27, 1971.

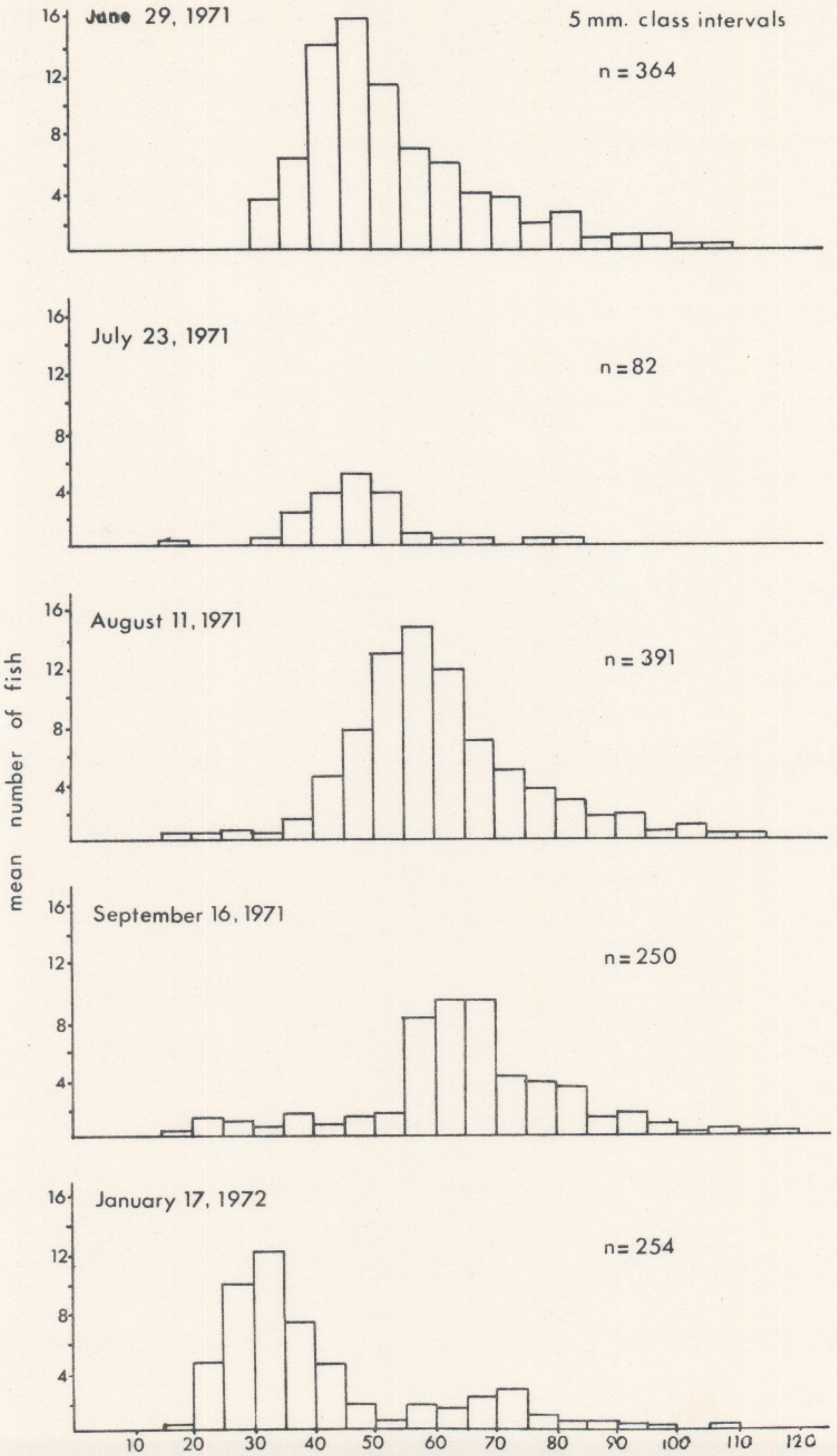


FIG 11. Length frequency of Cottus asper in Carnation Creek estuary May 1971 to January 1972

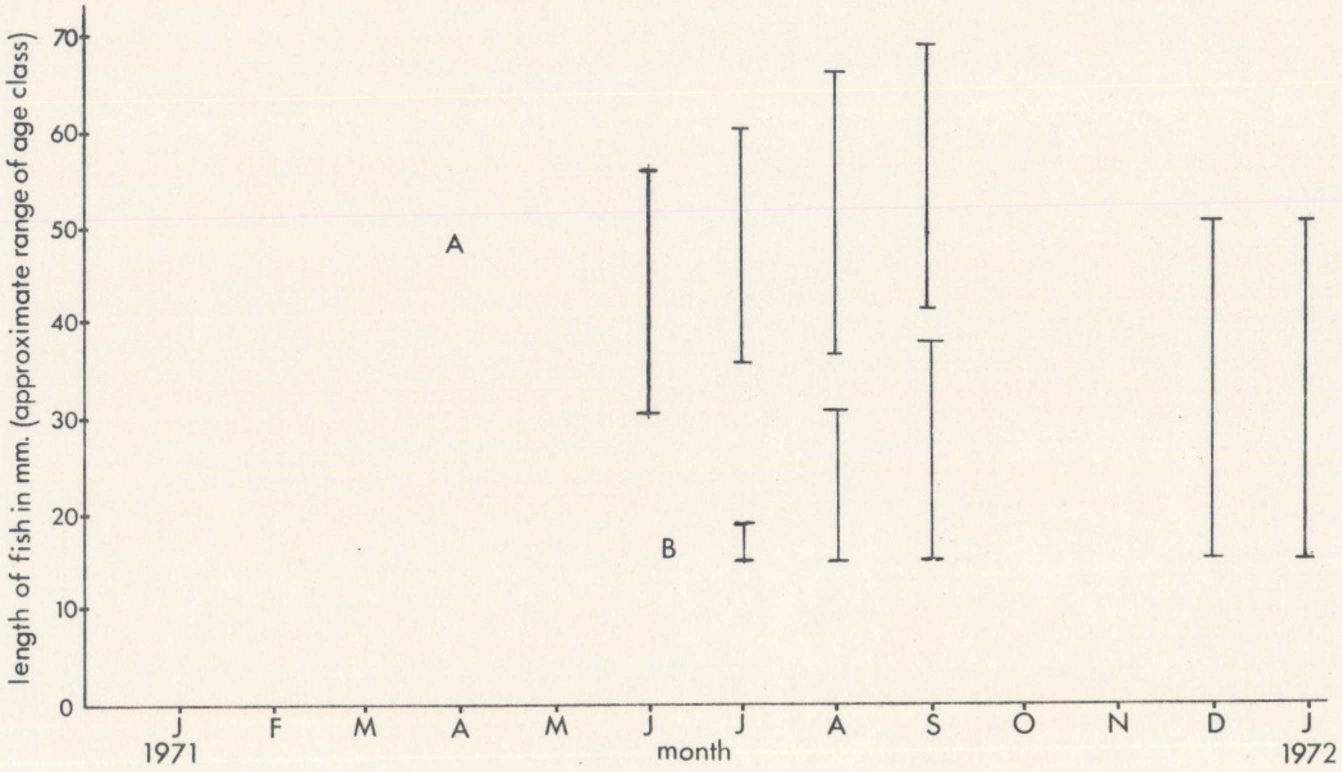
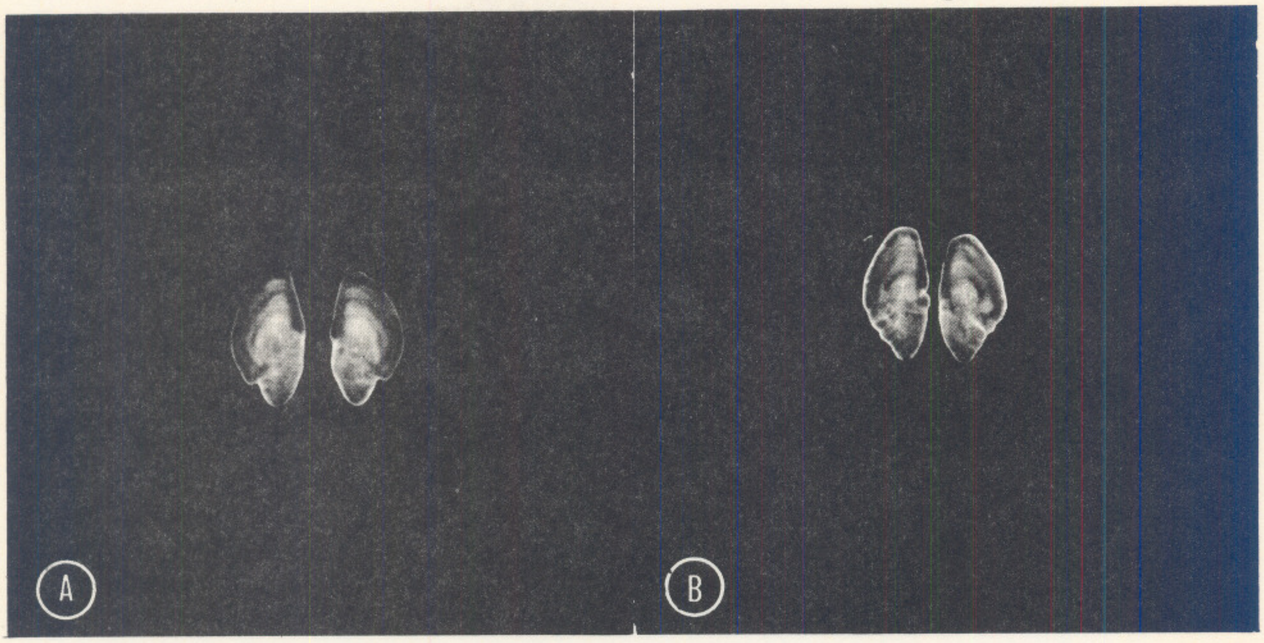


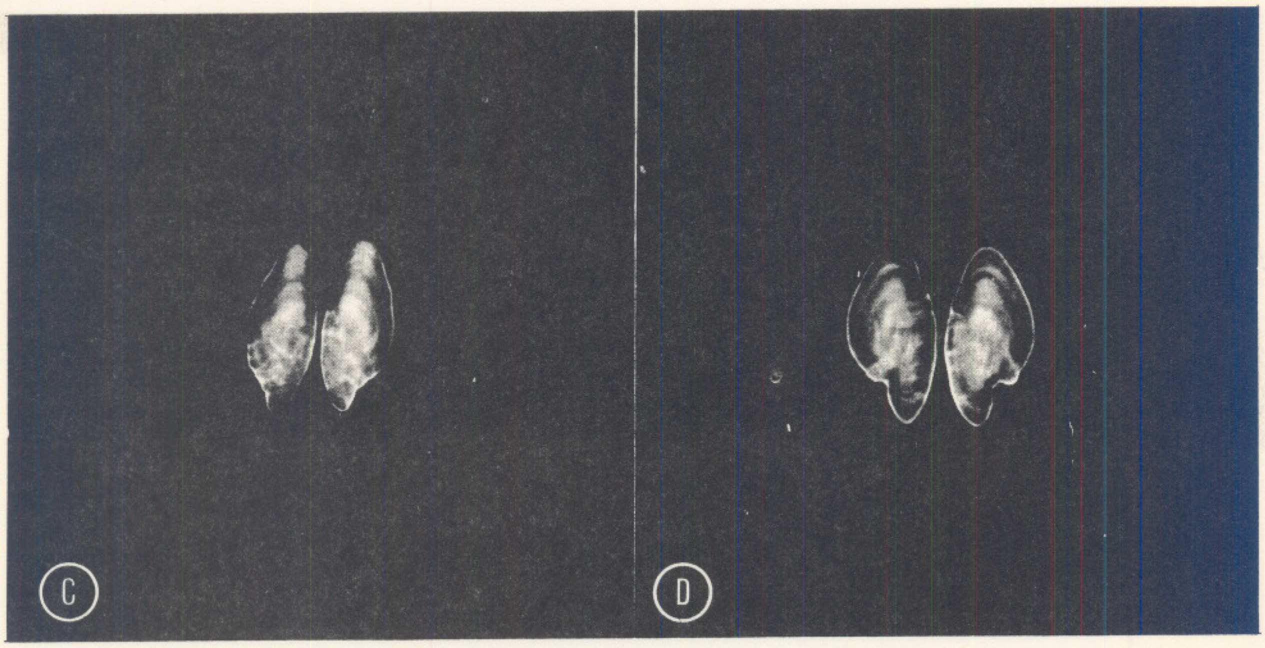
Fig. 12. Growth of (A) yearlings, and (B) underyearlings of Cottus asper in the Carnation Creek estuary.

mag. = X 16



length 37 mm. – age 1.

length 38 mm. – age 1.



length 41 mm. – age 2.

length 48 mm. – age 2.

FIG.13 A Otolith series – Cottus aleuticus June 1971.

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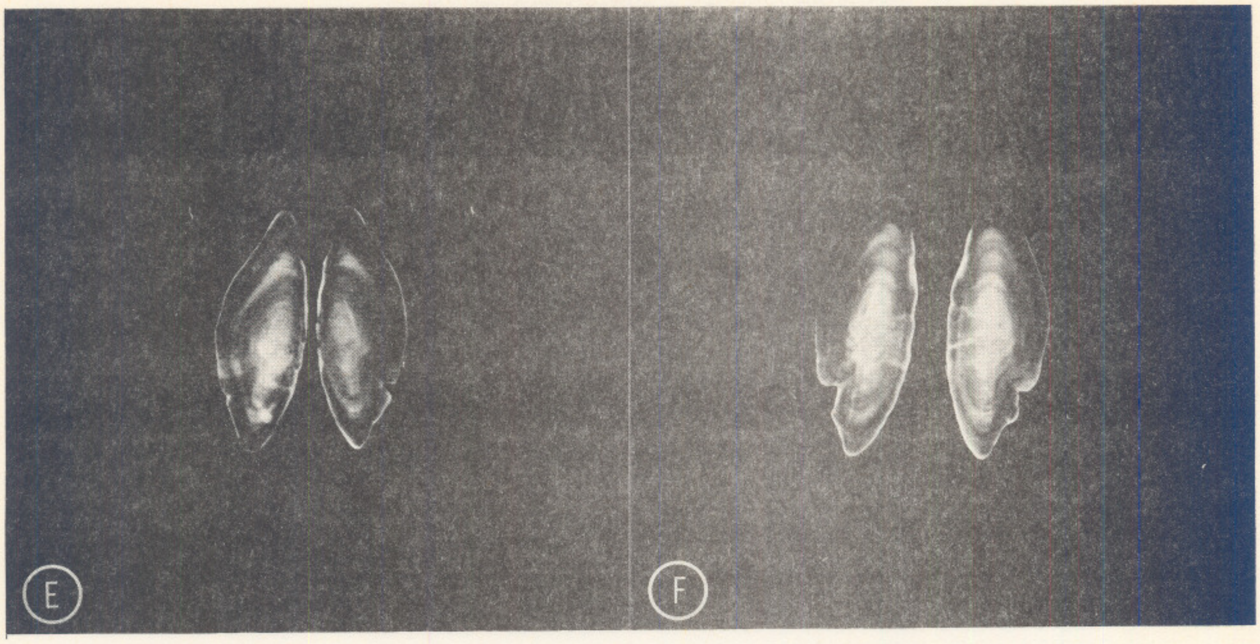
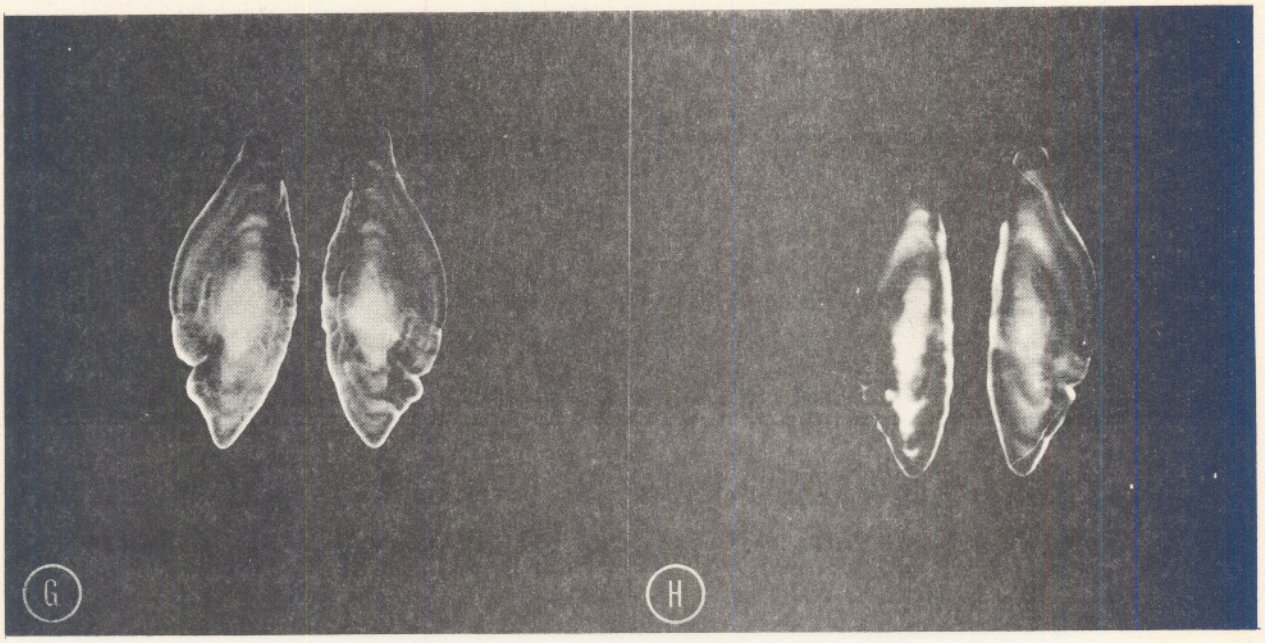
mag. = X 16



length 54 mm. – age 3.

length 65 mm. – age 3.

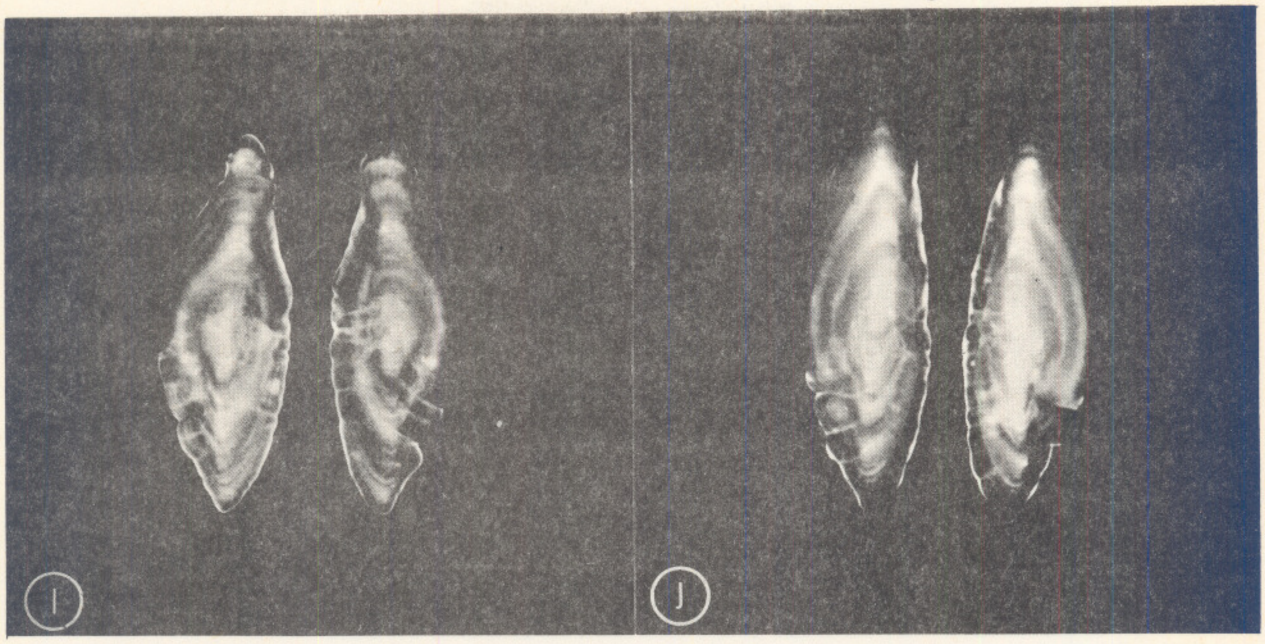


length 70 mm. – age 4.

length 80 mm. – age 4.

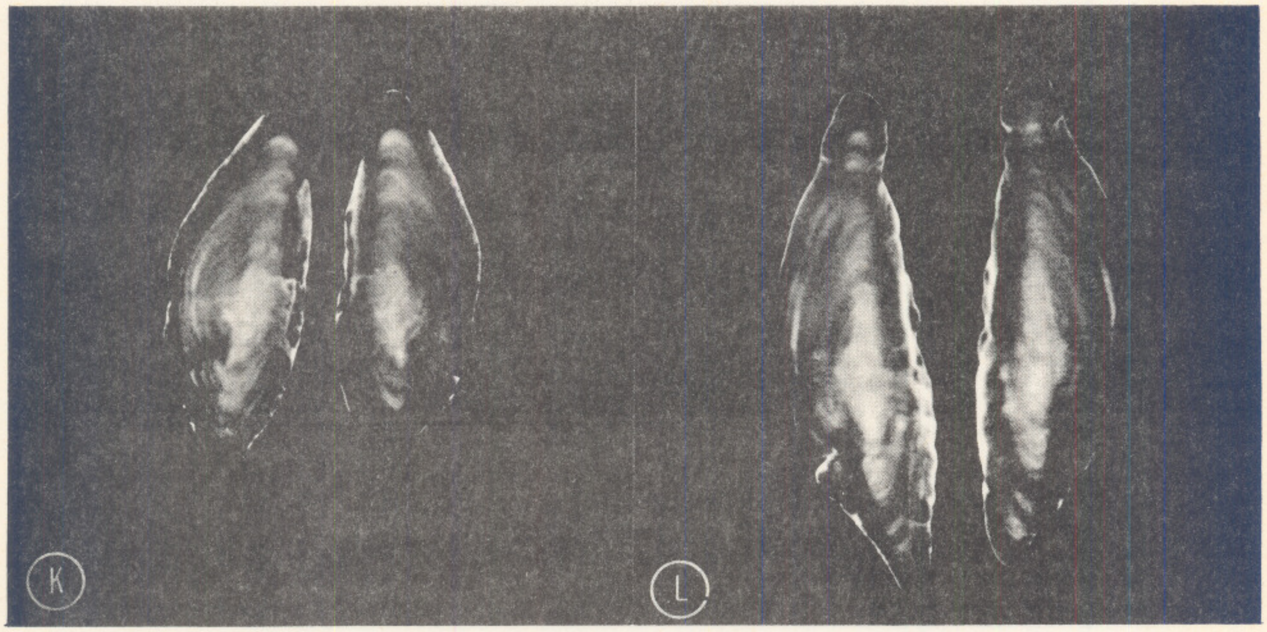
FIG. 13 B Otolith series – Cottus aleuticus June 1971.

mag. = X 16



length 83 mm. – age 5.

length 92 mm. – age 5.

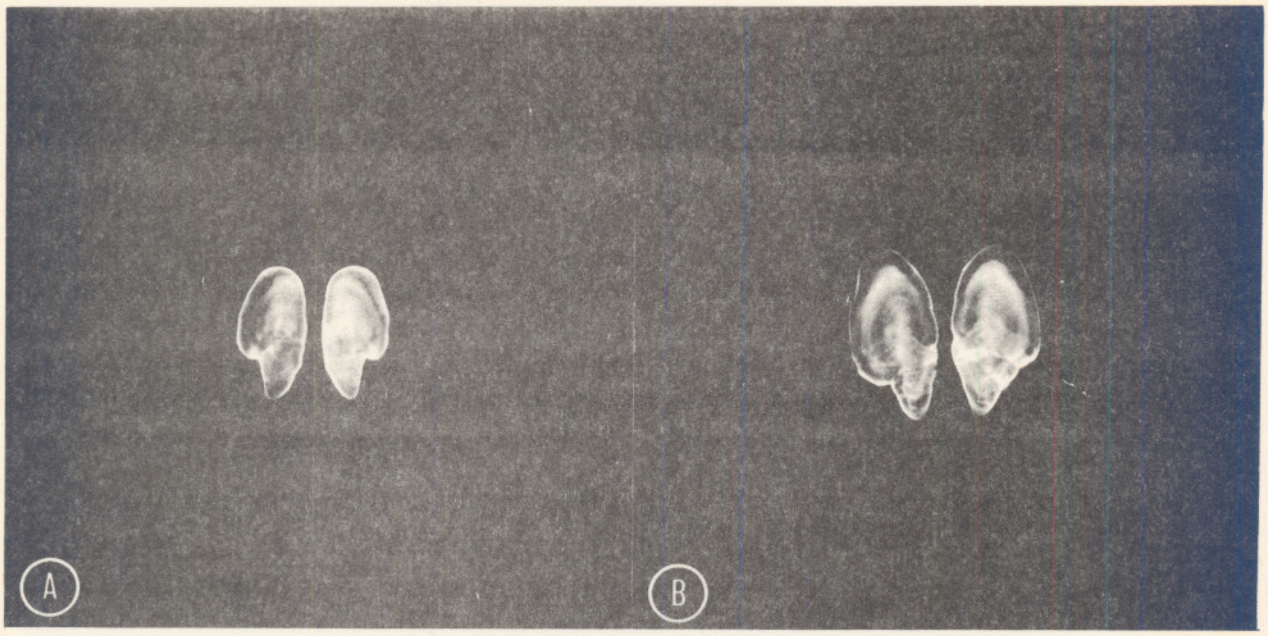


length 98 mm. – age 6.

length 105 mm. – age 6.

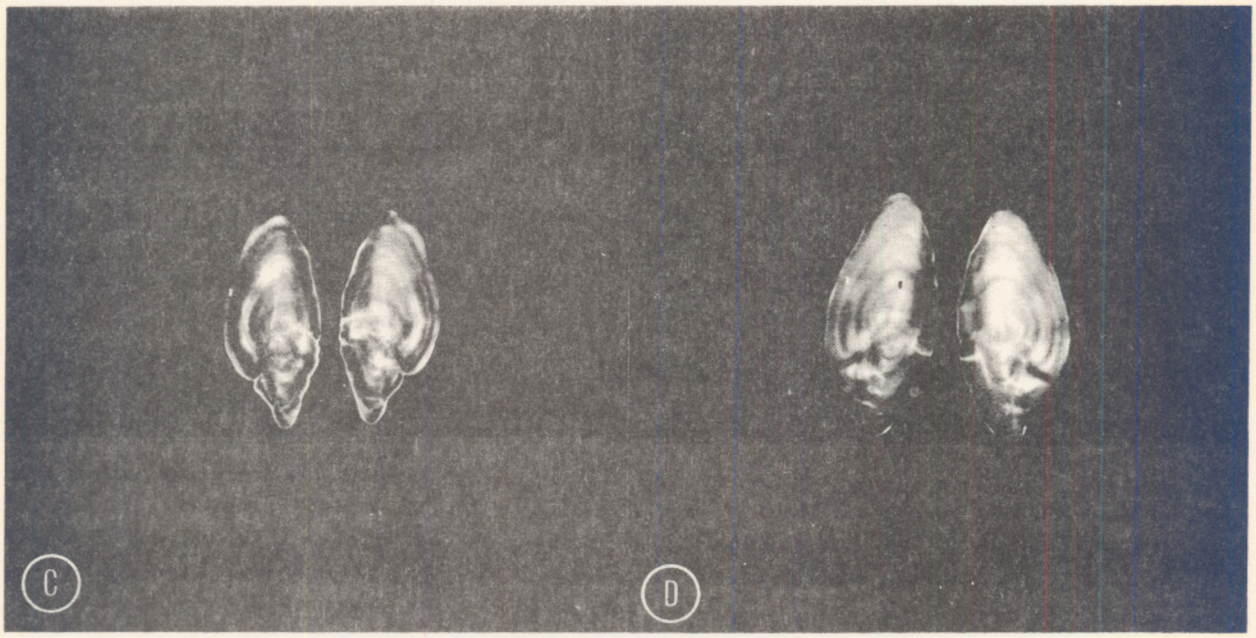
FIG. 13 C Otolith series – Cottus aleuticus June 1971.

mag. = X 16



length 34 mm. – age 1.

length 40 mm. – age 1.



length 48 mm. – age 2.

length 53 mm. – age 2.

FIG. 14 A Otolith series – Cottus asper June 1971.

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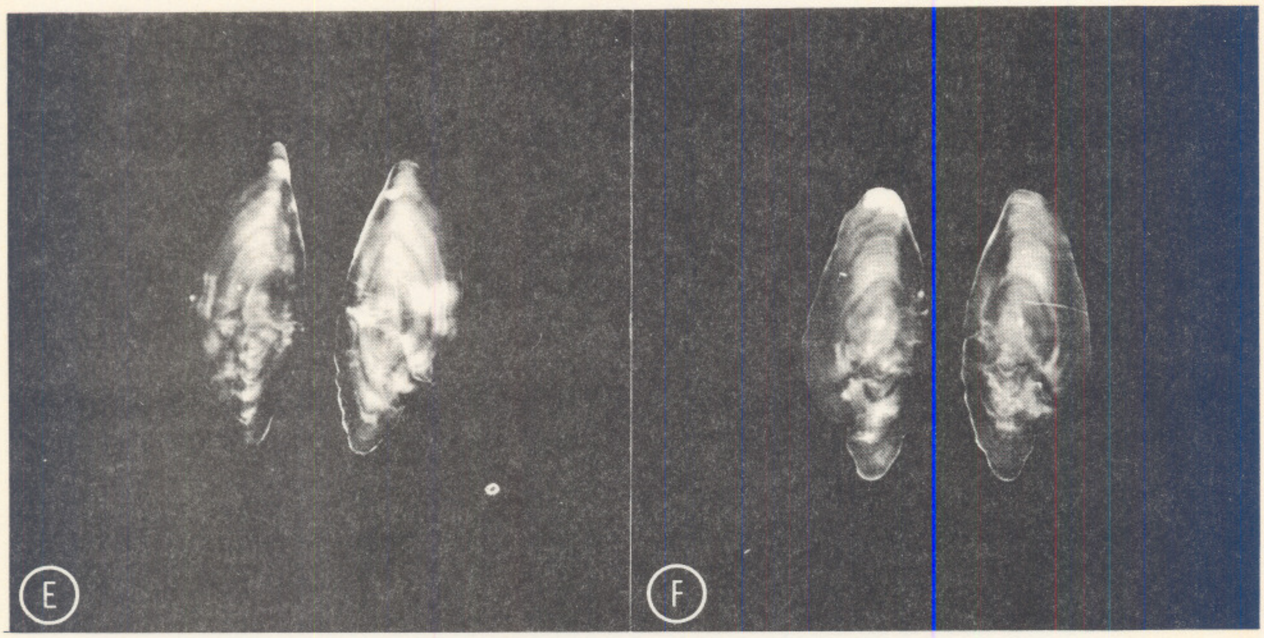
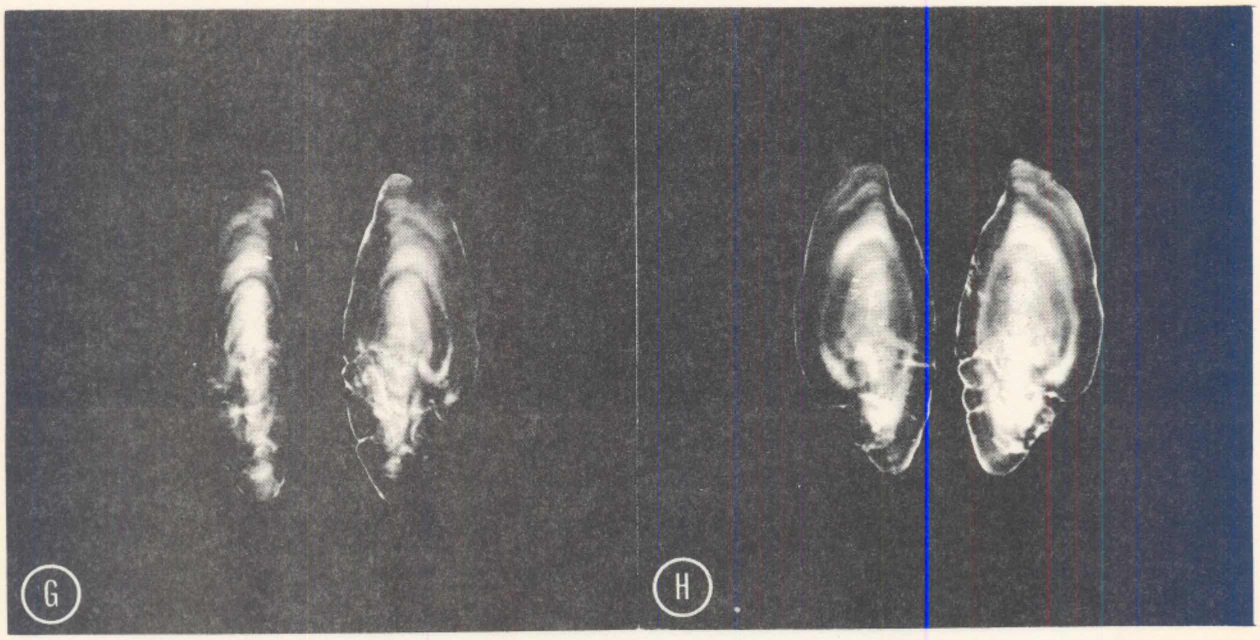
mag. = X 16



length 60mm. – age 2.

length 65mm. – age 2.

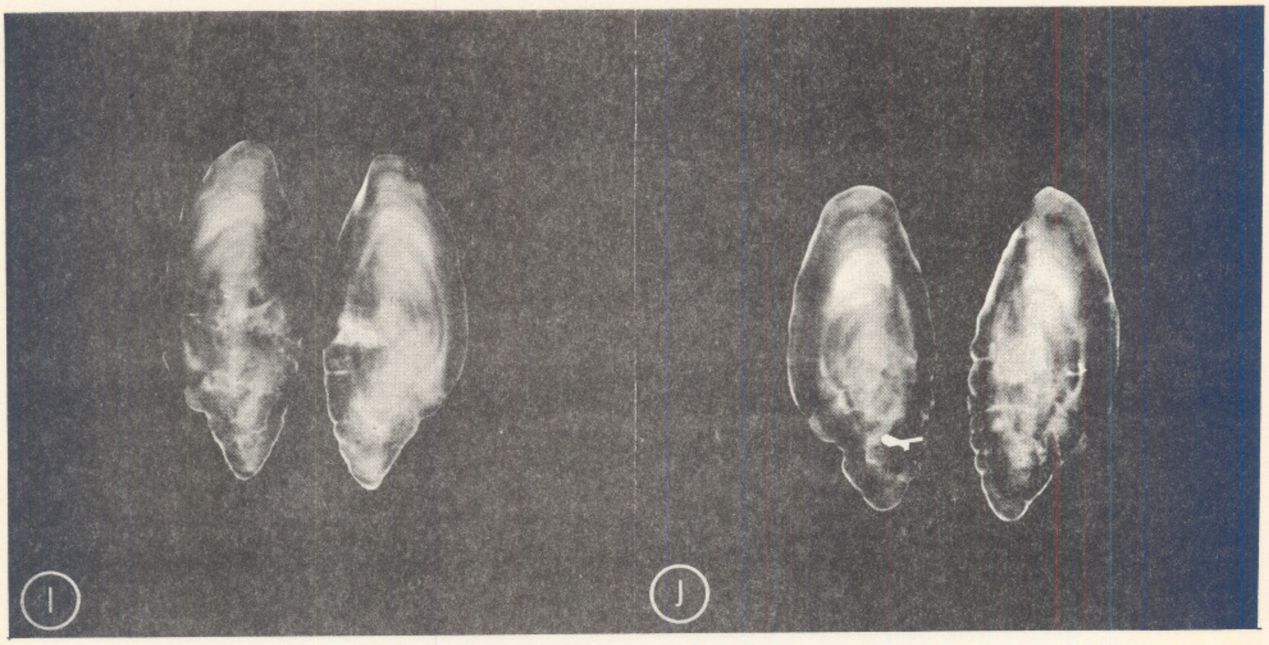


length 71mm. – age 3.

length 76mm. – age 3.

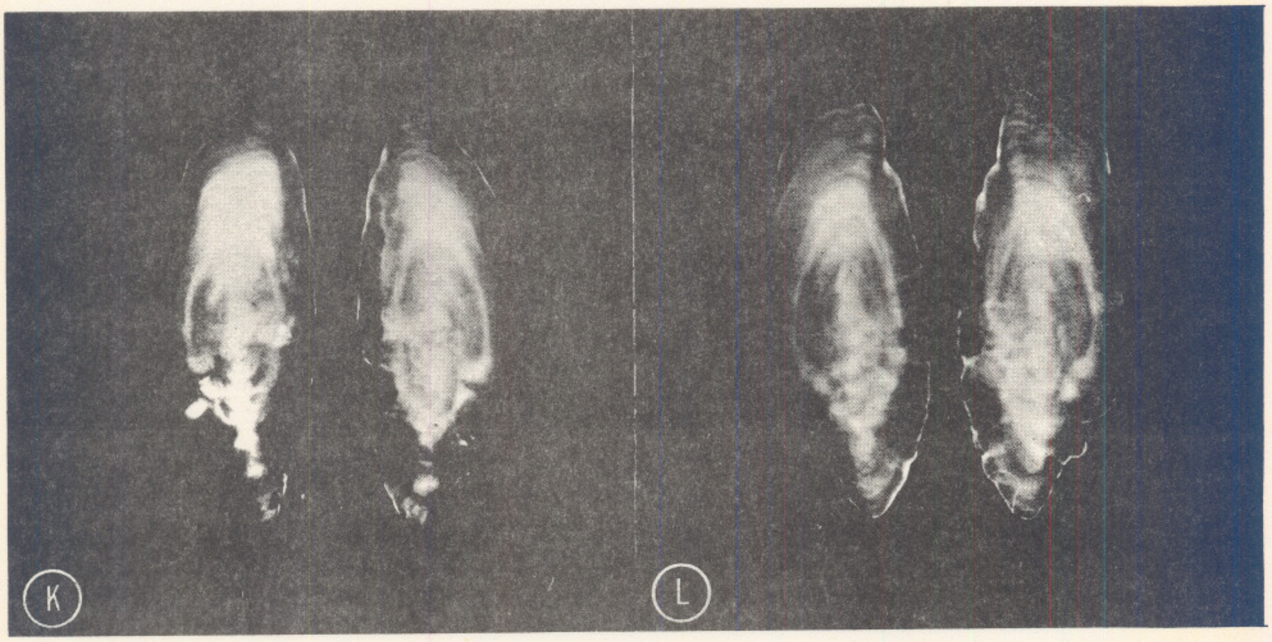
FIG. 14 B Otolith series – Cottus asper June 1971.

mag. = x 16



length 80mm. – age 3.

length 79mm. – age 4.

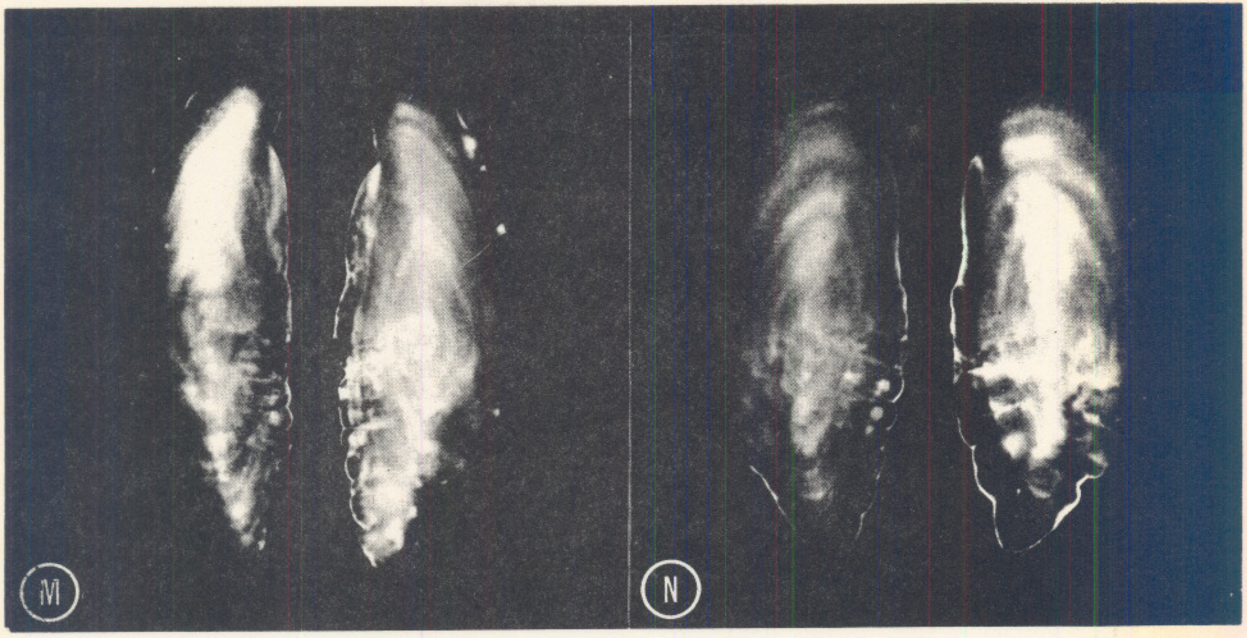


length 89mm. – age 4.

length 95mm. – age 5.

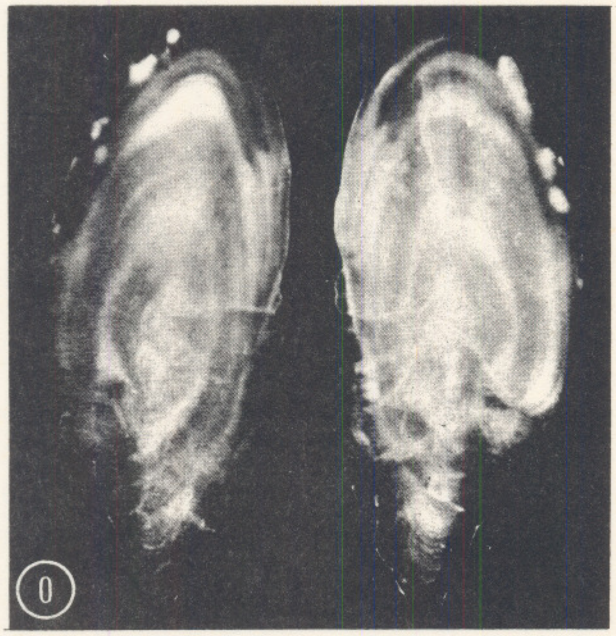
FIG. 14 C Otolith series – Cottus asper June 1971.

mag. = x 16



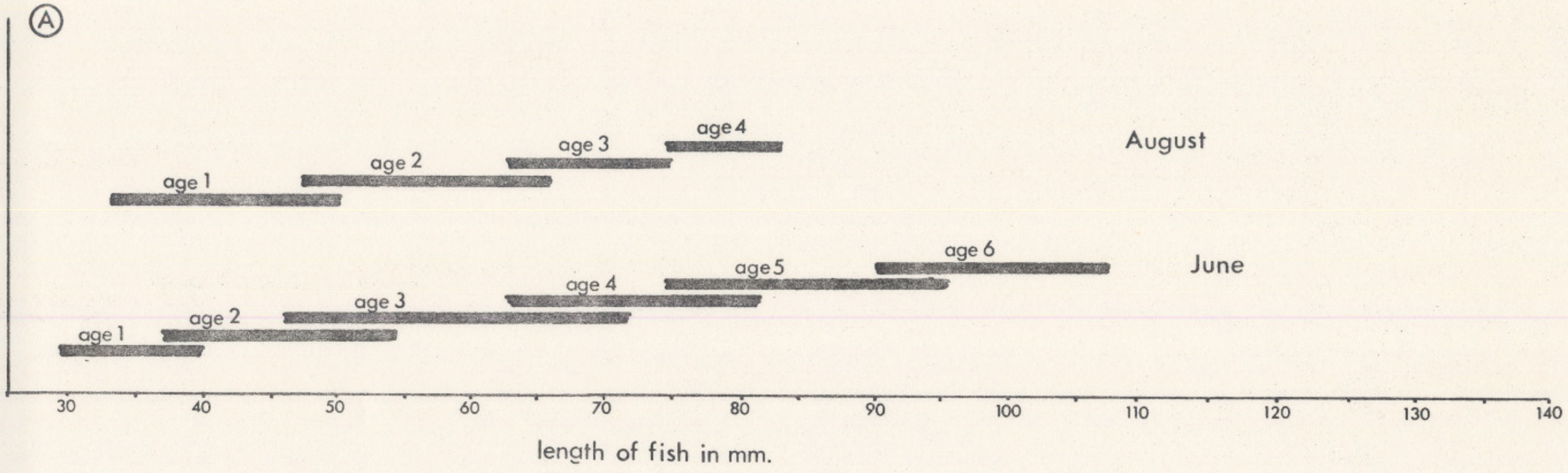
length 110 mm. – age 5.

length 113 mm. – age 6.



length 144 mm. – age 7.

FIG. 14 D Otolith series – <u>Cottus asper</u> June 1971.



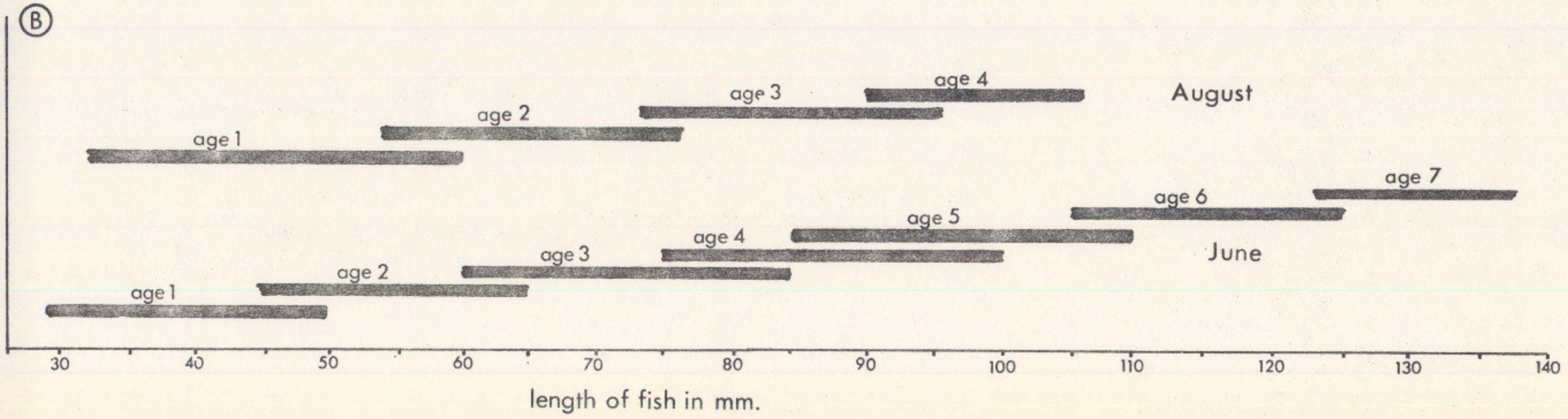


Fig. 15. Diagrammatic representation of age groups and summer growth as defined by otoliths of (A) *Cottus aleuticus* and (B) *C. asper*.

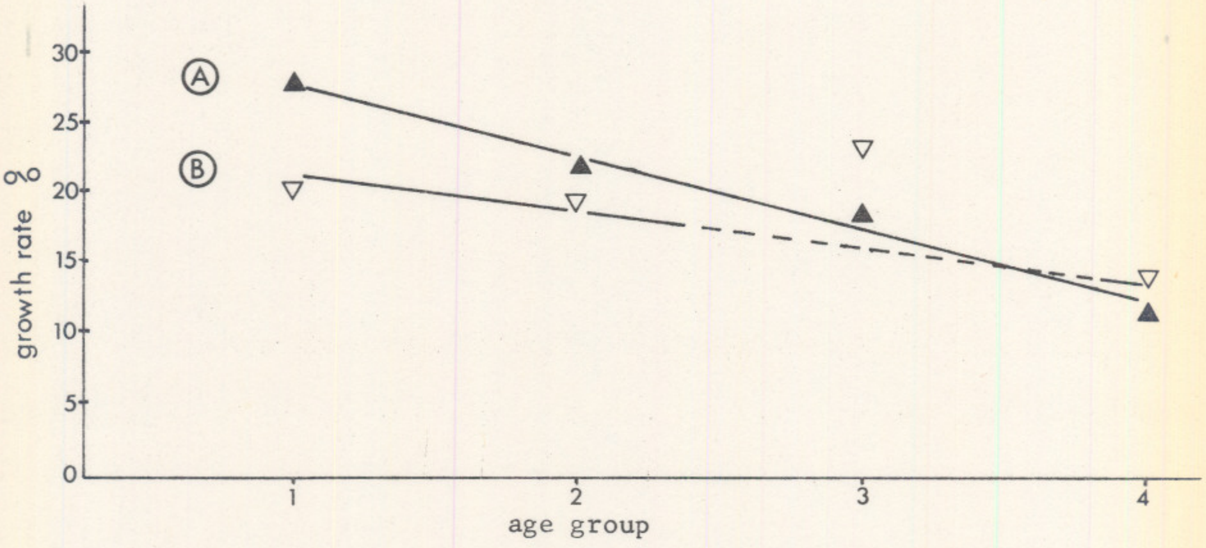


Fig. 16. Summer relative growth rates (65 days) indicated by otoliths of (A) Cottus aleuticus and (B) C. asper of the first four age groups.

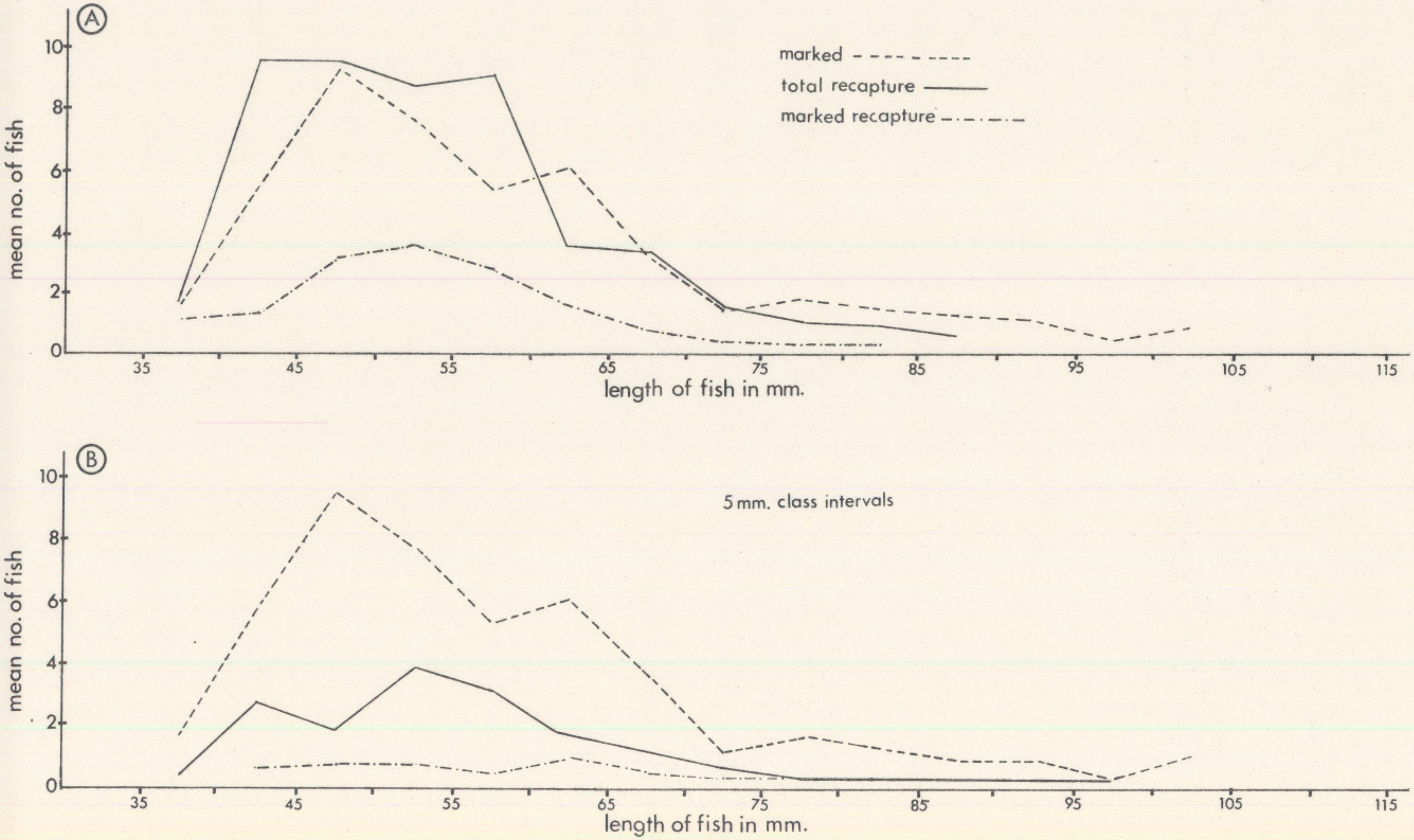


Fig. 17. Gear selection and recovery efficiency of (A) night seining and (B) electrofishing of *Cottus aleuticus* at 300 m.