THE 1970 LONGFIN SMELT SPAWNING RUN IN LAKE WASHINGTON WITH NOTES ON EGG DEVELOPMENT AND CHANGES IN THE POPULATION SINCE 1964

by

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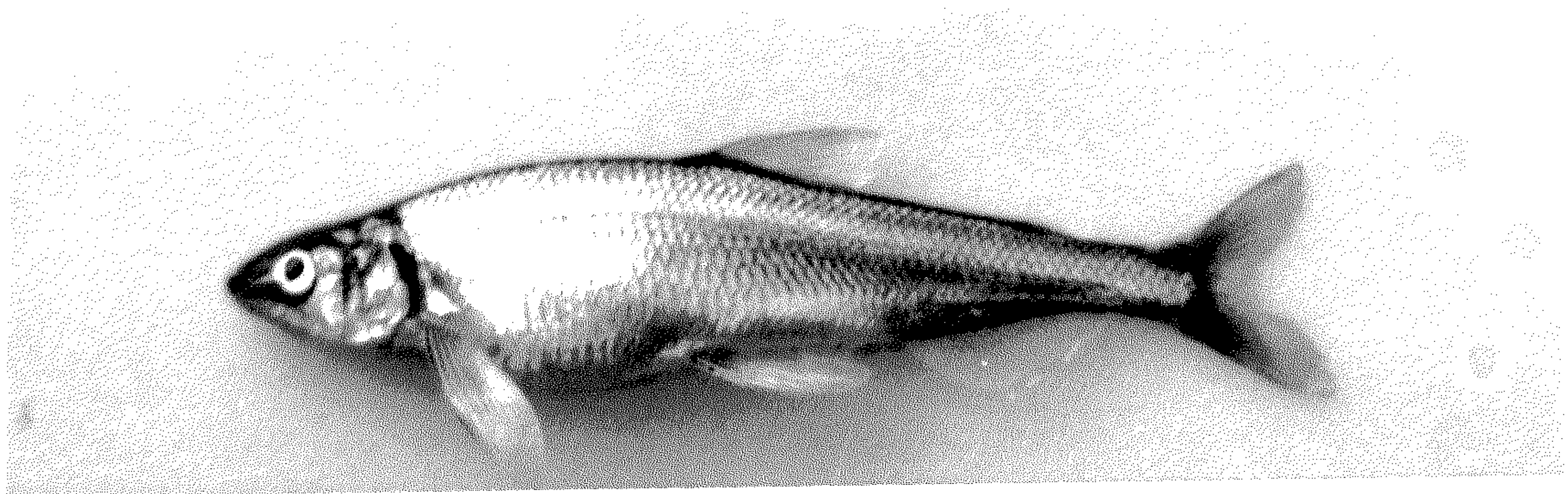
The longfin smelt, *Spirinchus thaleichthys* (Ayres).

A. 115 mm. male.

B. 112 mm. female.


a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INTRODUCTION

Dryfoos (1965) did the first study on the longfin smelt, Spirinchus thaleichthys (Ayres) in Lake Washington in 1962-64, just before the diversion of treated sewage from the lake. He described the life history of the smelt and hoped to provide a point of reference for subsequent measurement of changes in the population as the nutrient level in the lake decreased. The present study was undertaken to discover additional features in the life history of the smelt and to present some of the changes which have occurred in the smelt population since 1964.

The primary objectives of this study were to describe (1) spawning areas and time of spawning for the longfin smelt in Lake Washington, (2) movements of the smelt during the spawning run, (3) development of the smelt eggs and (4) changes in the population since Dryfoos' study.

Since no studies of this type have been done on the longfin smelt, the spawning runs described for Osmerus mordax (Mitchill) are referred to for comparative purposes. Osmerus mordax is a spring spawner, can be found as anadromous or landlocked, and has been widely studied. Spirinchus thaleichthys can also be either anadromous or landlocked, with anadromous populations spawning in the fall and winter (Hart and McHugh, 1944; Clemens and Wilby, 1961) and landlocked populations spawning in late winter and early spring (Dryfoos, 1965).

The Lake Washington longfin smelt population was characterized by Dryfoos as having a higher growth rate than any known anadromous population. There was also a high percentage of vertebral abnormalities, with over 20% of the population showing some vertebral defect. The Cedar River, at the south end of the Lake, was known to be a major spawning area as larval smelt were caught at the mouth of the river in March, 1963. Dryfoos also postulated a northern spawning area because of the early spring catch of smelt larvae in that region of the lake.

Lake Washington is 21 miles long, situated next to Seattle (Fig. 1). Before 1963, the lake had been receiving large amounts of treated sewage from the surrounding communities, which was creating nuisance conditions in the lake. Diversion of the treated sewage began in 1963 and was virtually completed by 1967. The lake has shown a remarkably fast recovery from eutrophication and is rapidly returning to a less productive state (Edmondson, 1969). At the same time the sewage was being diverted, the young sockeye salmon which utilize the lake as a nursery area were showing a tremendous increase in abundance (J. C. Woodey, personal communication). This study indicates how the smelt population has varied at the same time physical and biological features of the lake have been changing.

COLLECTING TECHNIQUES AND METHODS

Sampling Program

Two main sampling procedures were used. The first was sampling for eggs in the gravel in the streams around Lake Washington to determine when and where smelt spawning began. A 1/2-meter plankton net was held in the current and the gravel was stirred approximately three feet upstream from the net. The net was rinsed after each sample to reduce contamination. The Cedar River was the main sampling area, but every suitable stream around Lake Washington was sampled periodically during the season (Fig. 1). The dates and places of sampling are listed in Tables 3 and 4. Samples were preserved in 10% formalin immediately after collection and were later examined for eggs in the laboratory. All eggs were separated from the sand and stored in 10% formalin.

In the second major sampling procedure a frame fyke net (Fig. 2) was used for adult smelt at the mouth of the Cedar River. The net had a 3' x 6' rectangular opening, a single 28' lead, and 1/2" square mesh. The net was placed in front of the mouth of the river at an angle of approximately 45° facing downstream (Fig. 3). The trap portion of the net was placed in 12 feet of water and the 28' lead was run across the main channel. Theoretically, the smelt would move up the river channel, encounter the lead, follow it upstream and enter the net. Sampling began February 26, 1970, when the first catch of adult smelt was made. The net was set at 1800 hours and was checked and reset every three hours except once when the net could not be handled because

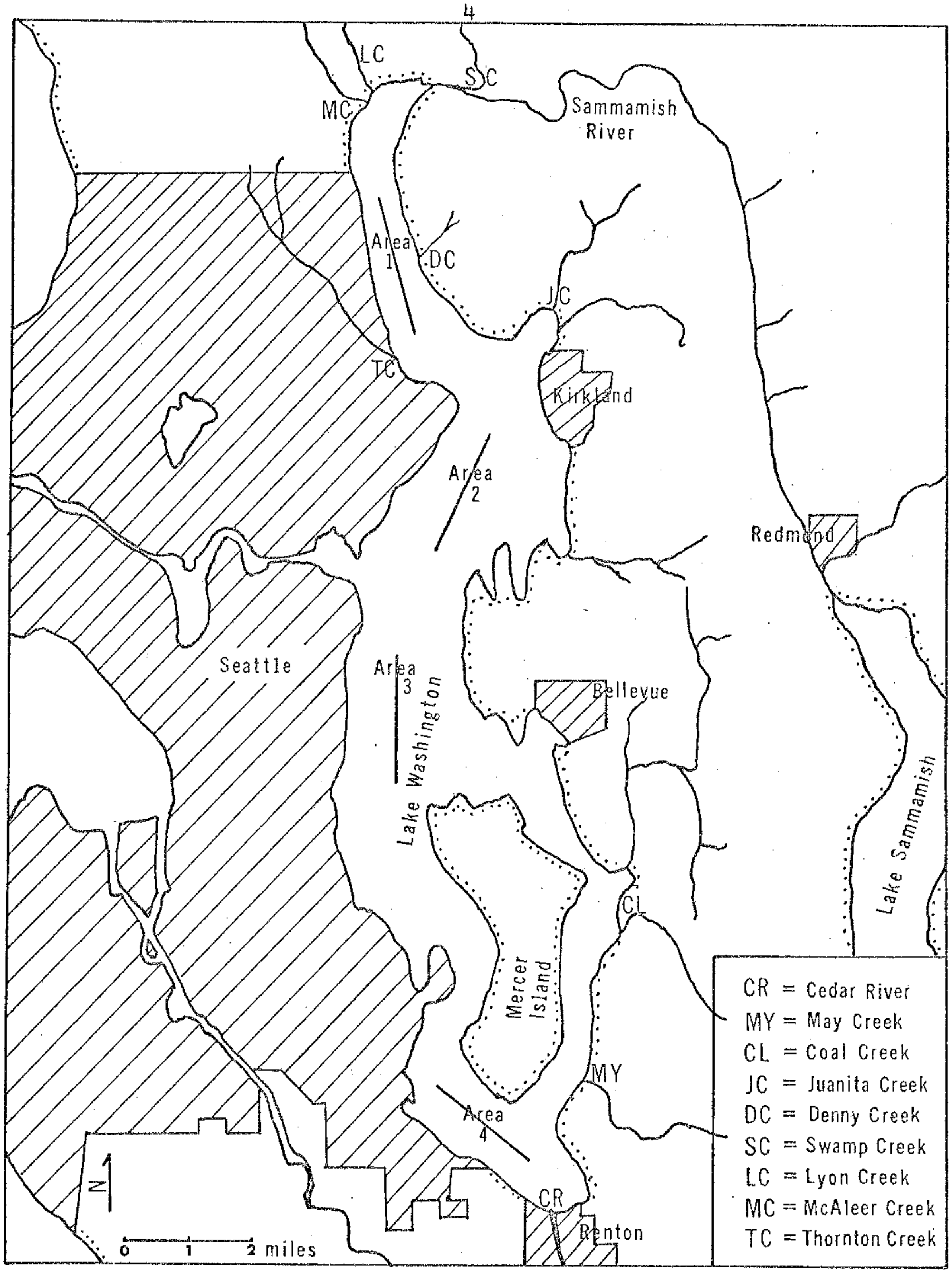

Figure 1. Lake Washington study area. Streams indicated by capital letters, limnetic sampling done in Areas I, II, III, IV.

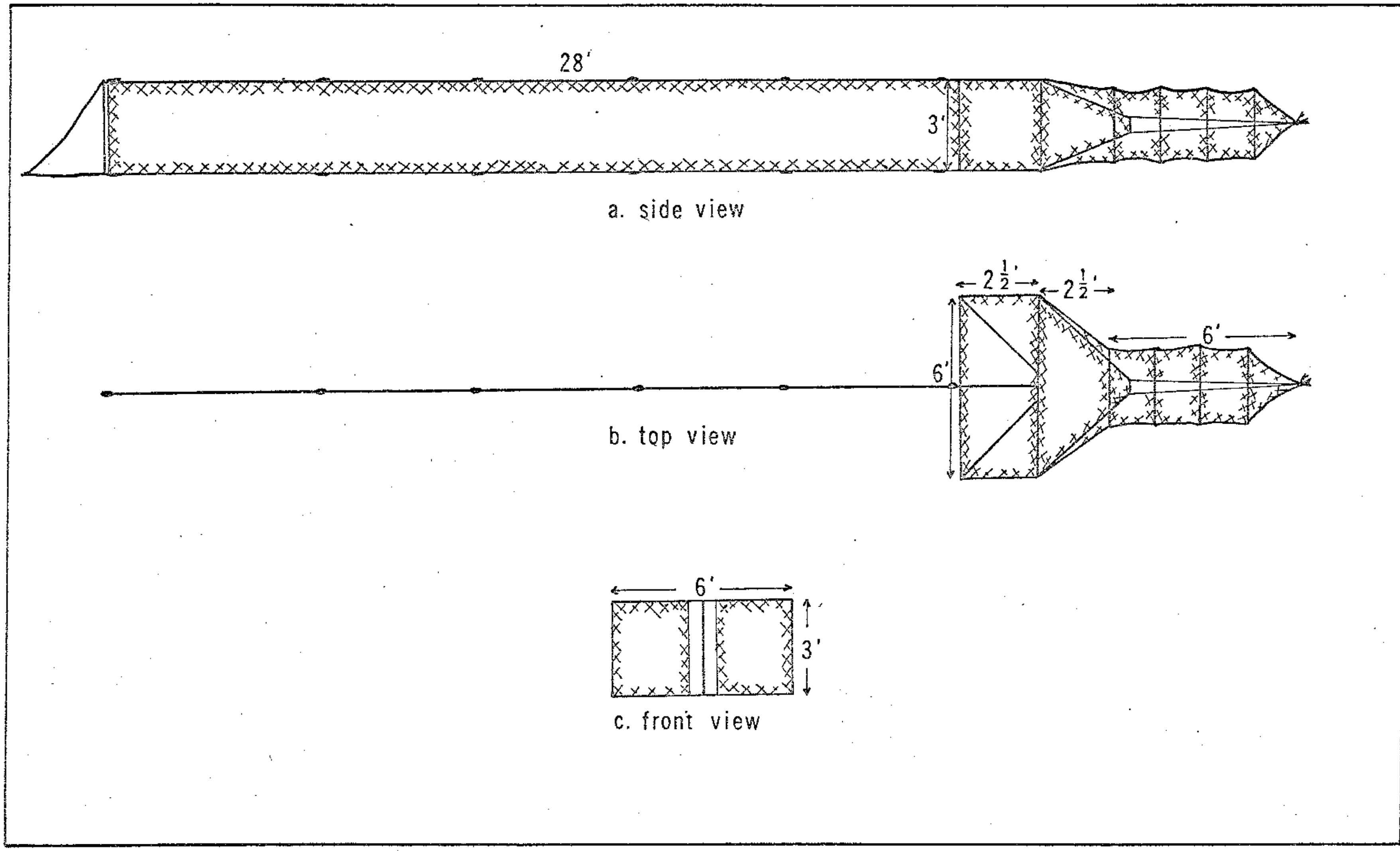

Figure 2. Frame fyke net used at mouth of the Cedar River, 1970.

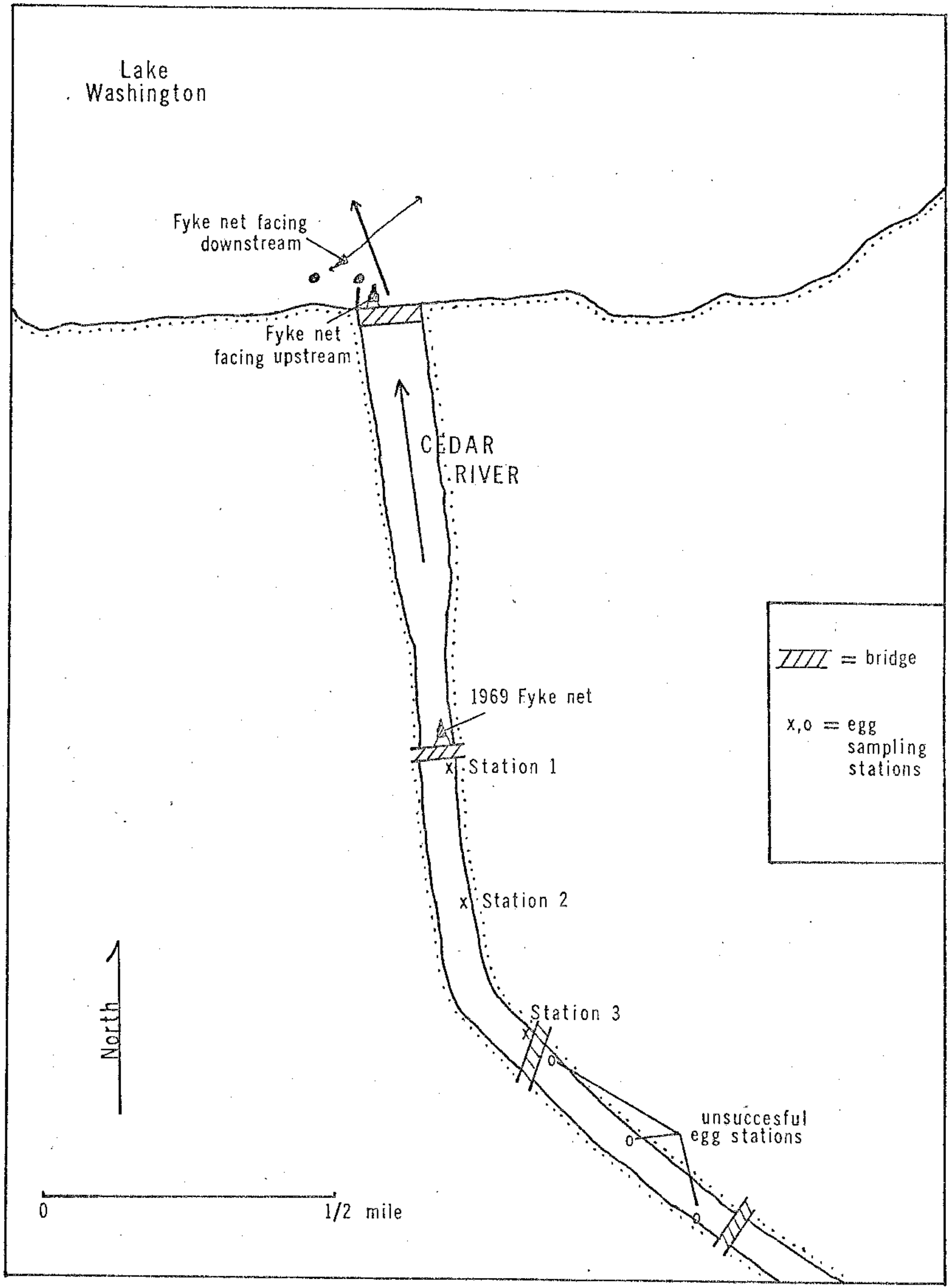

Figure 3. Position of fyke nets and egg sampling stations at the Cedar River. (arrows indicate direction of water flow)

the water was too rough. Fishing usually began at 1800 hours because this approximated the onset of darkness during the main period of sampling. The number of sets per night varied, but at least one all-night sample, i.e. four sets, was obtained once a week for the duration of the run. A complete list of sets is given in Table 1. In the table, and for the paper as a whole, a day is defined as starting at 0600 and lasting the next twenty-four hours; thus March 2, 1970, covers from 0600 on March 2 to 0600 on March 3.

The smelt were sexed according to males, ripe females and spawn-out females and preserved in 10% formalin. Males were distinguished by the enlarged anal fin, ripe females and spawn-out females were separated by the presence or absence of the body swelling caused by the eggs (frontispiece). In several cases, a few males and ripe females were artificially spawned to obtain eggs for developmental studies. Random subsamples were taken from the large catches of March 10, 17, and 25. Length, weight and stomach content were taken on squawfish caught in the net. Peamouth and largescale suckers were released; cottids and several salmonids were retained for stomach analysis.

On March 9, 1970, a fyke net similar to the one described in Fig. 2, but with the lead removed, was placed under the bridge at the mouth of the Cedar River facing upstream (Fig. 3). The net was set at 1800 and checked every hour until 0700 on March 10. On two occasions, February 13 and 18, 1970, the fyke net was placed in the river at the Boeing Company Bridge 0.8 mile from the mouth facing upstream. This gear was difficult to set and handle; there was no catch.

TABLE 1

Fyke Net Sets at the Cedar River

Date	Time of Sets	No. of Sets
22-23/1/70	1450-1100	1
23-24/1/70	1100-1100	1
28-29/1/70	2020-1420	1
26/2/70	1800-2100	1
2/3/70	1800-0600	4
3/3/70	0600-2100	5
4/3/70	1800-2100	1
5/3/70	1800-2100	1
6/3/70	1800-2100	1
9/3/70	1500-0600	5
10/3/70	0600-2400	6
17/3/70	1800-0600	4
25/3/70	1800-0600	3 (1 six hour set)
1/4/70	1800-0600	4
15/4/70	1800-2400	2

In February and March, 1969, a river fyke net modified from a mid-water trawl with a 1/4" mesh cod end was fished at the Boeing Company bridge 0.8 mile from the mouth of the river. This net was checked every fifteen minutes for periods up to four hours, but proved relatively unsatisfactory due to the large catch of sockeye fry.

Starting on January 28, 1970, several sampling trips were made with gill nets at the Cedar River. The objective of the gill netting was to get some idea of the predation pressure on the congregating adult smelt, primarily by northern squawfish, Ptychocheilus oregonensis (Richardson). The principal units of gear were two 100' monofilament variable mesh sinking gill nets with a total of eight 25' x 6' panels of mesh varying from 1 1/2" to 5" stretched mesh in 1/2" intervals. Once, January 29, a 300' monofilament gill net with 3" stretched mesh was used. The gill nets were fished for varying lengths of time, summarized in Table 2.

An attempt to collect adult smelt by electroshocking with a portable "back-pack" electroshocker was made on January 15 and 16, 1970. One person waded the stream shocking while two others held a ten foot wide net across the current, downstream from the shocker. Several cottids and a 15 mm. salmonid were taken, but no smelt were found. The current was too strong for the 1/4" mesh used in the net, but with heavier poles and a larger mesh, this method may be practical for obtaining samples.

Isaacs-Kidd midwater trawls were used to estimate relative abundance by year class of smelt. Data gathered by R. L. Dryfoos in his 1962-1964 study (Dryfoos, 1965) and by J. C. Woodey in the

TABLE 2

Gill Net Sets at the Cedar River

Date	Time of Set	Feet of Net
28/1/70	2030-0030	100
29/1/70	1400-2100	500
6/2/70	0030-0330	200
12/2/70	0600-0900	200
9/3/70	1800-2100	200
10/3/70	0315-0615	200
	0940-1200	100
	1200-1500	100
15/4/70	1930-2300	200

study of Lake Washington sockeye were used for these estimates. Beginning September, 1967, to August, 1970, twenty-seven sampling trips have been made on the MV COMMANDO, the primary piece of gear being a 10' Isaacs-Kidd midwater trawl. Ten-minute tows were made at various depths, times of day, and all months of the year. Since these trips were primarily for sockeye investigations, their utility for estimating smelt abundance was limited and necessitated certain adjustments made with respect to the depth distribution and vertical migration described by Dryfoos (1965). Primarily, only day hauls between 18 and 56 meters and night hauls between 9 and 36 meters were used in measuring relative abundance. In the fall, however, the juvenile smelt are closer to the surface so for October through December, day hauls to 14 meters were also used.

Incubation

The first time artificial fertilization of smelt eggs was attempted, males and females were transported to the Bureau of Commercial Fisheries Montlake Laboratory (hereafter BCF) Fish Holding Room. Eggs were extruded into a 9" x 13" x 1 1/2" glass dish, the bottom of which was lined with glass microscope slides. Testes were removed from the males and crushed in a small jar of water to liberate the sperm. The diluted sperm were mixed with the eggs as the eggs were extruded into the water. New glassware was used at all times. Later attempts at artificial fertilization were done at the Cedar River catch site and the eggs returned to the BCF Fish Holding Room in the glass trays for incubation. The trays were placed in rectangular fiberglass troughs with a moderate current flowing over the eggs. The water was dechlorinated city water, in effect, Cedar River water as the Cedar River is the Seattle water supply. The temperature was checked periodically and recorded to the nearest 0.1°C.

Photographs were taken at various stages of development. A compound microscope was used when photographing the live eggs. The camera was a single lens reflex with Panatomic-X film, ASA 32. For observation and photographing, a slide with live eggs was removed from the incubation tray and placed in a Petri dish of water. Preserved larval stages were photographed with the same camera through an extension tube.

Laboratory Procedures

Fish preserved were stored for a period of at least three weeks to allow complete penetration of formalin. They were then measured and weighed, using standard length to the nearest millimeter and round weight to the nearest 0.1 gram. The air bladder was lanced before weighing to allow a more complete drainage of fluid. The length-weight data were analyzed by the CDC computer system at the University of Washington Computer Center using the FRG 703 packaged program.

RESULTS

Location of Spawning Areas

Nine of thirteen tributaries to Lake Washington were sampled for smelt eggs to locate spawning areas. Of the nine streams sampled, four yielded smelt eggs and five were barren. The four yielding smelt eggs were the Cedar River, May Creek, Coal Creek, and Juanita Creek. A list of the results for each stream follows. These results, except for the Cedar River, are summarized in Table 3. The Cedar River sampling was more intensive and is shown in Table 4.

Cedar River. There were four basic sites for sampling: (1) Station 1, the Boeing Bridge 0.8 mile from the mouth; (2) Station 2, behind the Renton Stadium 1.0 mile from the mouth; (3) Station 3, the first public highway bridge crossing the river 1.25 miles from the mouth and (4) behind the Stoneway Plant on the Maple Valley Highway approximately three miles from the mouth. Other sites between the last two were also sampled. Smelt eggs have been collected at Station 1 since 1968. In that year P. Sommani[1] found and described smelt eggs from that site. The Cedar River results will be covered in the next section.

May Creek. May Creek was sampled on February 26, 1970 at the second bridge across the stream, approximately 100 yards from

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[1] Sommani, P. 1968. Characteristics of the eggs and larvae of the longfin smelt (*Spirinchus thaleichthys*) and *Cottus* sp., and some aspects on their spawning ground in the Cedar River. Unpublished manuscript.

TABLE 3

Egg Distribution (Non-Cedar River)

Stream	Date	Location	Smelt Eggs
May Creek	26/2/70	second bridge	4
	14/3/70	second bridge	2
		RR bridge	0
		bet. 3rd & 4th bridge	0
	7/4/70	third bridge	1
Coal Creek	26/2/70	hwy bridge near RR bridge	0
		culvert near mouth	0
	14/3/70	hwy bridge near RR bridge	0
		culvert near mouth	2
	7/4/70	first hwy bridge	1
		pipe below 1st hwy bridge	0
		second culvert from mouth	0
Juanita Creek	7/4/70	below first hwy bridge	5
	13/4/70	above first hwy bridge	0
Thornton Creek	13/2/70	Matthews Pk. Pumping Sta.	0
	16/3/70	Matthews Pk. Pumping Sta.	0
	13/4/70	Matthews Pk. Pumping Sta.	0
McAleer Creek	18/1/70	first hwy bridge	0
	13/2/70	first hwy bridge	0
	16/3/70	first hwy bridge	0
	13/4/70	first hwy bridge	0

TABLE 3 (cont.)

Stream	Date	Location	Smelt Eggs
Lyon Creek	18/1/70	30 yds. from mouth	0
	13/2/70	30 yds. from mouth	0
	16/3/70	30 yds. from mouth	0
	13/4/70	100 yds. from mouth	0
Swamp Creek	18/1/70	twin culverts	0
	16/3/70	twin culverts	0
	13/4/70	first hwy bridge	0
O. O. Denny Pk.	13/4/70	near mouth	0

the mouth. Four smelt eggs were found, two with embryos in early stages of development (eyes unpigmented) and two undeveloped fertile eggs. On March 14, samples were taken at (1) the second bridge again, (2) the railroad bridge, 1/4 mile from the mouth, and (3) halfway between the third bridge and the railroad bridge, about 300 yards from the mouth, where there was a gravel bar which appeared suitable for spawning purposes. Two dead smelt eggs were taken at the second bridge, none at the other sites. On April 7, an undeveloped fertile smelt egg was taken at the third bridge, the only site sampled that day. It appears as though smelt would be blocked at the railroad bridge as there is a fishway (for salmonids) which is too high for smelt to negotiate. Thus spawning in May Creek would be limited to the lower quarter mile of stream bed.

Coal Creek. Coal Creek was sampled at two sites on February 26 without success: (1) the highway bridge immediately below the railroad bridge, about two miles from the mouth and (2) the large culvert near the mouth of the stream, about 100 feet from the mouth. On March 14, the same two sites were sampled; this time two dead smelt eggs were taken at the second site. On April 7 samples were taken at (1) the first bridge across the creek, 1/4 mile from the mouth; (2) a pipe crossing the stream about 300 yards from the mouth and (3) the second culvert from the mouth, about 200 feet from the mouth. One undeveloped fertile egg was found at the first site.

Juanita Creek. Juanita Creek was sampled April 7 at a gravel bar approximately 100 yards from the mouth, immediately below the first highway bridge. Five smelt eggs were found, of which three were dead, one was fertile but undeveloped and one had an early embryonic stage (embryo just visible). A sample from April 13 about 100 feet above the first site yielded no eggs.

Thornton Creek. On February 13, March 16, and April 13, gravel samples were taken at the Matthews Park Pumping Station approximately 300 yards from the mouth. No smelt eggs were taken.

McAleer Creek. Four gravel samples were taken, one each on January 18, February 13, March 16 and April 13 at the first highway bridge, approximately 50 yards from the mouth. None of the samples contained smelt eggs.

Lyon Creek. Lyon Creek was sampled on the same dates as McAleer Creek, the first three dates at a point 30 yards from the mouth and on April 13 at a point 100 yards from the mouth. No smelt eggs were taken.

Swamp Creek. Gravel samples were taken on January 18, March 16, and April 13. The first two samples were taken at twin culverts approximately one and a half miles from the mouth while the third sample was taken at the first highway bridge, about 2 miles from the mouth of the creek. No smelt eggs were taken. The lower reaches of the creek were quite silty and unsuitable for smelt spawning.

Denny Creek. This small creek running through O. O. Denny Park was sampled without success on April 13 about 30 yards from the mouth.

Eggs from other species were taken in all streams, primarily eggs from cottids, Cottus sp. and largescale suckers, Catostomus macrocheilus Girard. Mercer Slough, the Sammamish River and other slough areas were not sampled as the substrates were silty and unsuitable for smelt eggs, which require swift currents with good aeration (McKenzie, 1964).

The above results indicated at least four spawning areas, one of which, Juanita Creek, can be classified as being in the north end of the lake. This could be the northern spawning area postulated by Dryfoos (1965). On July 8, 1968, 51 larval smelt were taken in a 10' Isaacs-Kidd midwater trawl in tows north of Sand Point, and on June 16 and July 16, 1970, 2 and 36 larval smelt, respectively, were taken under similar conditions. This is a large number for this area so early in the year and may indicate (1) that Juanita Creek supports a good sized run, (2) there is another, as yet undetected, spawning area in the north end, or (3) there is a sizeable and rapid northward migration from the Cedar River area. The third possibility has support in that the young sockeye salmon from the Cedar River move northward at a rapid pace and are extremely concentrated in the north end by mid-July (J. C. Woodey, personal communication). Since the smelt are somewhat associated with the sockeye (Dryfoos, 1965), they may exhibit a similar migration pattern. With the smelt larvae, however, we are dealing with a smaller, younger fish which may not be capable of extended migrations. A minimum travel of sixteen miles is required to reach the area where they were taken.

From the stage of development of the eggs taken, it appears as though spawning took place on at least three occasions in May Creek, twice in Coal Creek and three times in Juanita Creek. In no cases were large numbers of eggs found outside the Cedar River. All eggs were found within 1/4 mile of the lake. The homing abilities for the longfin smelt are not known, so there is the possibility that a few smelt from the Cedar River population may have strayed into the smaller streams.

Cedar River Migration

Egg Distribution

The distribution of smelt eggs in the Cedar River is shown in Table 4. Data from a preliminary study carried out during the 1969 spawning run are included. The distances upstream for the major sites are given in the previous section.

Dryfoos caught smelt larvae in the mouth of the river in March, 1963 (Dryfoos, 1965) and as mentioned before, Sommani found smelt eggs in the river in 1968, so the river was known as a smelt spawning area before this study was begun. Sommani only found eggs at Station 1. In 1969, I found eggs at Stations 1, 2, and 3, but not farther upstream. In 1970, I again found eggs at the lower three stations, but in no other areas. Mr. Robert Brown of Renton, an employee of the Stoneway Plant, reported seeing many smelt in March or April, 1969, behind the Stoneway Plant at lunch hour and gave an accurate description of the smelt (Robert Brown, personal communication). For this reason, the area around and below the Stoneway Plant was sampled extensively. No indication of spawning in this area was detected in 1970. From the available data, it appears as though spawning was limited to the lower 1.25 mile of the river in 1970.

It could be that the smelt congregate near the mouth of the river with a few moving in to spawn early. In mid-November, 1969, a male and female smelt in near-spawning condition were caught in a 10' Isaacs-Kidd midwater trawl in the vicinity of the Cedar

TABLE 4

Egg Distribution in the Cedar River

Date	Station 1	2	3	Stoneway	Other
14/2/69	14	4	-	-	-
15/2/69	16	-	3	-	Renton Library-0 bet. 1st & 2nd hwy bridges-0
21/2/69	7,7[a]	-	-	-	-
18/3/69	-	-	37 (2 larvae)		-
15/1/70	10	5	0	-	-
16/1/70	0	0	-	-	-
1/2/70	0	0	0	0,0[a]	-
13/2/70	0	0	0	-	-
18/2/70	0	-	-	0	2nd RR bridge-0
23/2/70	0	0	0	-	-
1/3/70	17	0	0	0	-
8/3/70	149	138	324	0	2nd RR bridge-0 Renton Library-0
15/3/70	1896	173	97	0	bet. 1st & 2nd hwy bridges-0
16/4/70	35 (8 larvae)	-	-	-	100' above Sta. 3-0

[a]two samples

River. This was three months before the major spawning run. Eggs were taken at two sites on January 15, 1970. This would seem to indicate an early spawning run, except that no further eggs were taken until March 1, even though the sampling procedure was identical throughout. During the interval a good number of ripe smelt were found in the stomachs of squawfish caught off the Cedar River. This seems to suggest a trickle of spawning up to two or more months before the peak.

The fertility of the eggs taken from the Cedar River was high, as can be seen from Table 5. A fertile smelt egg is here defined as one showing no precipitated yolk, which shows up as a white mass in the egg, and a clearly defined perivitelline space. Since infertility is only one of perhaps many causes of death in the eggs, the fertility percentage represents a minimum estimate.

Timing of the Spawning Run

The approximate timing of the spawning run was known from Dryfoos' catches of mature smelt and the appearance of larval smelt in March (Dryfoos, 1965). Sommani helped to further set the time of spawning with his egg data from the Cedar River. The 1969 and 1970 egg data from my study give a much better idea of the onset and increase in spawning activity, but this is still an indirect measure of the spawning run. A more direct measure comes from catches of ripe adult fish as they enter the Cedar River.

In February and March, 1969, a modified river fyke net was hung from the Boeing Bridge 0.8 mile from the mouth of the river. A total of twenty smelt were taken, sixteen males, two ripe females and two spawn-out females, on four days of fishing. The catches

TABLE 5

Fertility of Cedar River Eggs

Date	Station	Live	Dead	Total	% Fertile
15/1/70	1	8	2	10	80.00
	2	3	2	5	60.00
1/3/70	1	10	7	17	58.82
8/3/70	1	133	16	149	89.26
	2	123	15	138	89.13
	3	318	6	324	98.15
15/3/70	1	1648	248	1896	86.92
	2	143	30	173	82.66
	3	81	16	97	83.51
16/4/70	1	30	5	35	85.71
Total	-	2497	347	2844	87.80%

increased from two smelt on February 15, 1969 to seven on February 20 and eleven on March 7. A complete list of the data is given in Appendix I.

The first adult smelt from the 1970 spawning run were taken on February 26, 1970, between 1800 and 2100 hours. Nine smelt were taken in a small experimental gill net and twenty-five in the fyke net facing downstream. The fyke net was used for the duration of the study. A sample for each day of the week March 2-6 was taken for 1800-2100 hours to check daily fluctuation. After this, weekly 12-hour (4 sets) trips were made until the run was over. Figure 4 presents the catch data by date. The catch per effort is based on the number of smelt caught per hour of soak. There is a steady increase, except for March 9, to a peak on March 17, then a rapid drop, so that by April 1, few smelt were spawning. A final check on April 15 yielded eight males and one ripe female during 2100-2400 hours. A complete list of catch by date and time is given in Appendix II.

The 1970 catch data, along with the 1969 catch data, 1968, 1969 and 1970 egg data indicate the main spawning run begins in mid-February, reaches a peak in mid-March and tapers off into April. The early discovery of eggs in mid-January, 1970 and the few adults taken in mid-April indicate a prolonged spawning period, at least four months, with intensive spawning confined to a one month period. In 1970, this period of intensive spawning ran from approximately the last week in February to the last week in March.

One of the mechanisms which controls the timing of the spawning runs in _Osmerus mordax_ (Mitchill) and _Thaleichthys pacificus_ (Richardson) is generally agreed on as being the

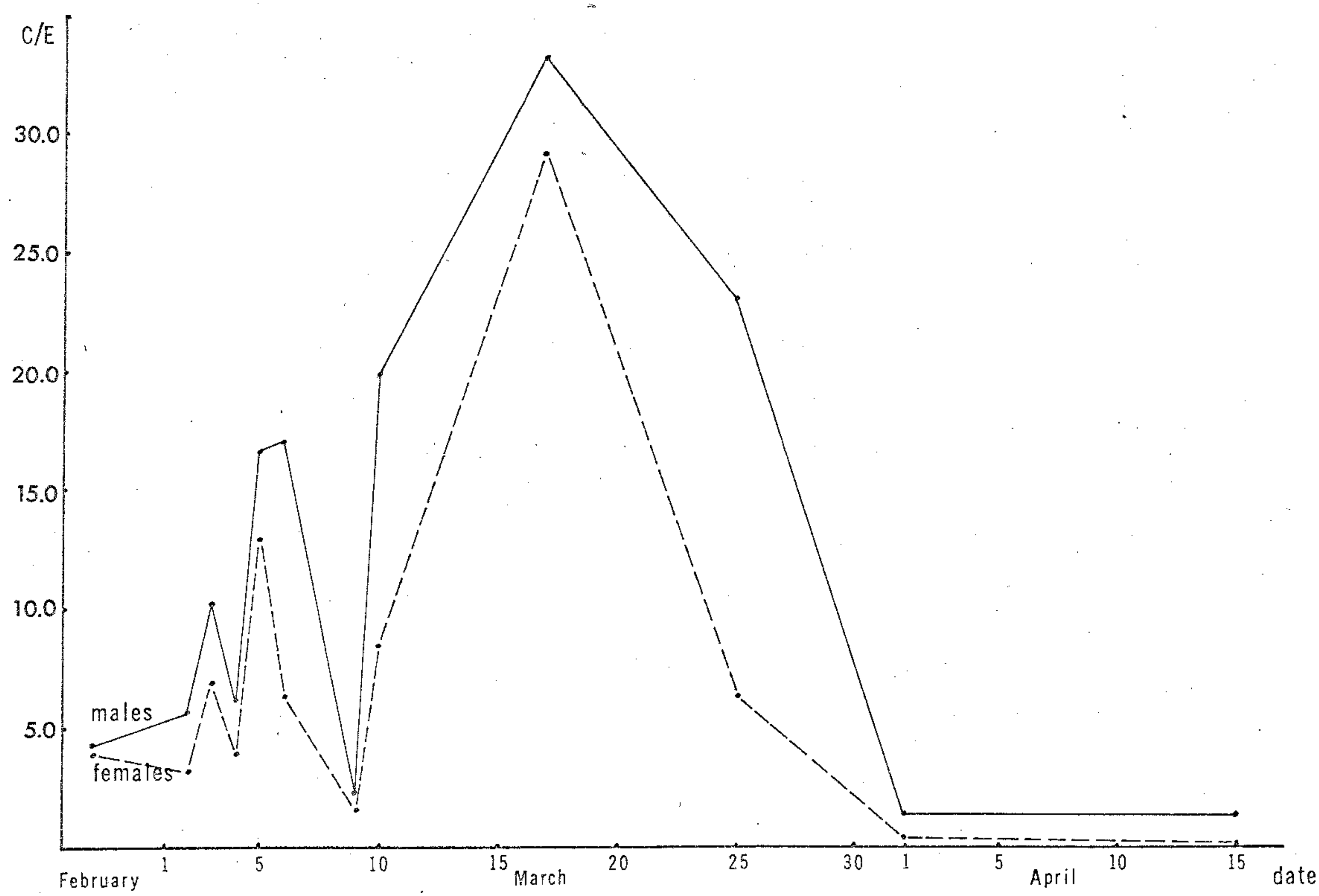


Figure 4. Fyke net catch per effort by catch date for males and total females, Cedar River.

increasing water temperature in the spring (Kendall, 1927; Langlois, 1935; Smith and Saalfeld, 1955; McKenzie, 1964). The general rule is that smelt ascend the rivers as the rivers clear of ice. To see if Spirinchus thaleichthys in Lake Washington behaves in a similar manner, the total catch per effort by day, the river temperature, and the water flow were plotted on the same graph (Fig. 5). The river temperatures (°C at the Landsburg Station) were averaged over three day periods, arbitrarily beginning on February 13. The water flow is the daily discharge of the Cedar River at Renton in cubic feet per second. Temperature and water flow data are courtesy of the U.S. Geological Survey, Tacoma, Washington.

The increase in catch per effort is accompanied by an increase of water temperature from about 4.4° to 7.2°C. The temperature during the main spawning period ranged from 5.6° to 6.7°C (Fig. 6). This range is basically the same as the range found by McKenzie (1964) for Osmerus mordax in the Miramichi River of New Brunswick and by Smith and Saalfeld (1955) for Thaleichthys pacificus in the Cowlitz River, Washington. The 1969 Cedar River smelt catches were made in the same temperature range.

The catch per effort fluctuates in an almost direct response to water flow during the period of increasing temperature. Major exceptions are March 5 and 9, where catch increases with a decreasing water flow for March 5 and the catch decreases with an increasing water flow on March 9. The peak of the run corresponds to the high water flow on March 17, after which both the run and river discharge decrease. There seems to be an anomaly on March

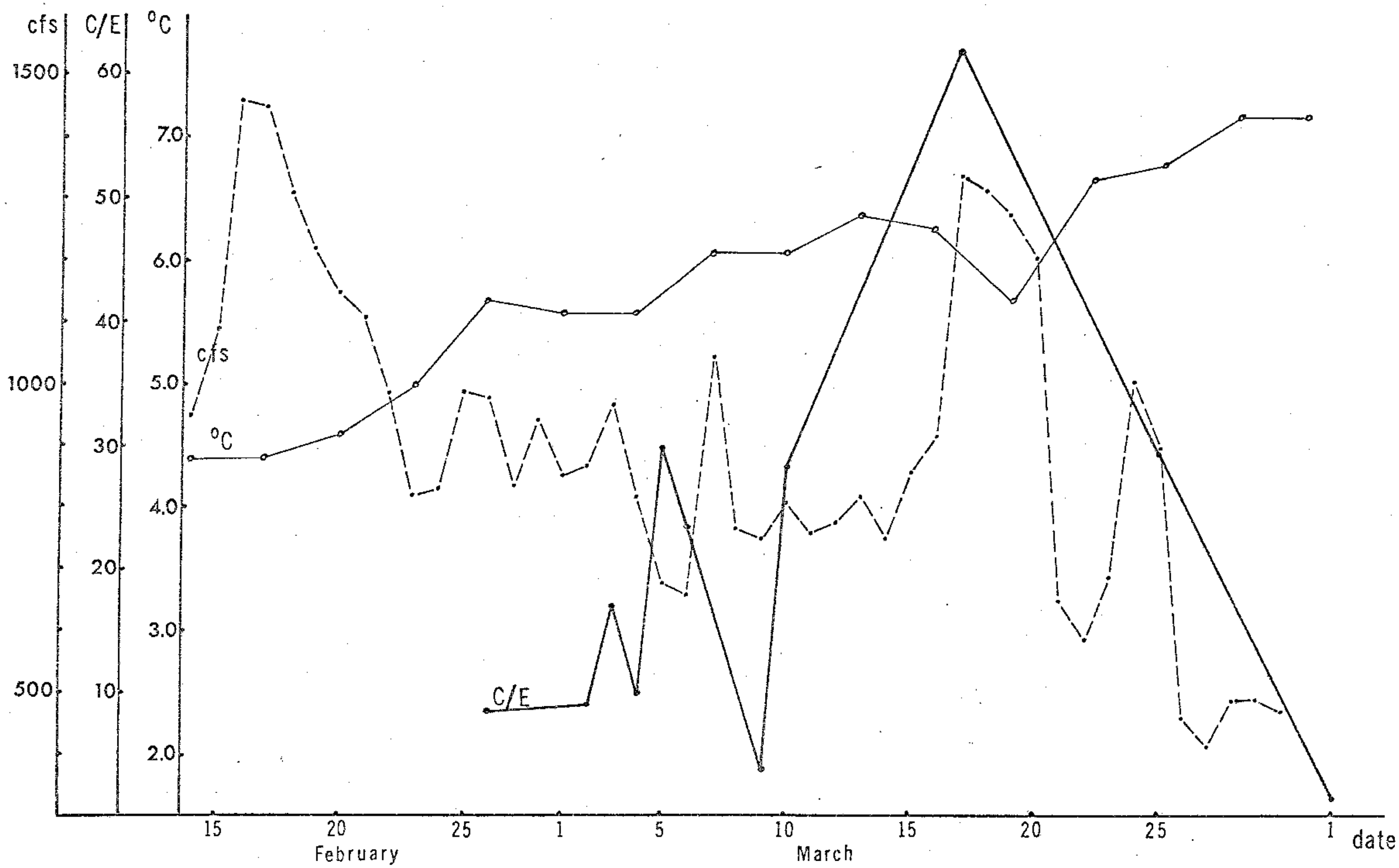


Figure 5. Relationship between catch per effort, river temperature and water flow.
C/E = catch of males + females per hour of fyke netting
°C = temp. at Landsburg Station, Cedar River
cfs = cubic feet per second at Renton Station, Cedar River

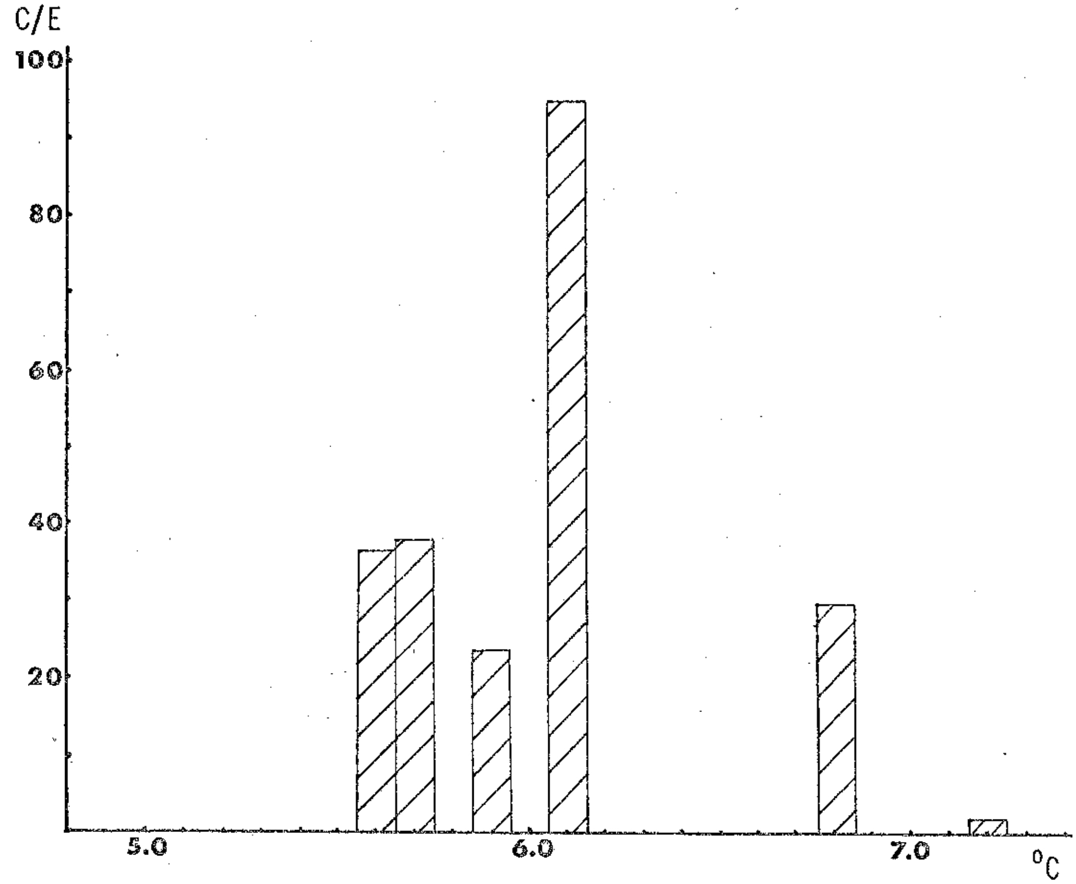


Figure 6. Relationship between catch per effort and river temperature, catch dates combined.

9, but the high water flow on March 7 may have influenced the catch on March 9. The March 9 catch was well below the expected catch throughout the night (Appendix II). The high water flow on March 7 and the subsequent drop could have affected the run in such a way that relatively few smelt ran on the night of March 9. The next night, March 10, the water flow increased and the catch returned to a high level.

The relationship between water flow and catch based on the 1970 catch data should not be regarded as significant due to the sporadic nature of the sampling. There are too many exceptions early in the run and the decline after March 17 may be caused by the inevitable decline of the run and may not be related at all to declining water flow. More observations of this kind over a number of years are needed before anything definite can be said about the relationship between water flow and timing of the run.

Diel Movements of Spawning Adults

To determine when the smelt were entering the river, the fyke net facing downstream was fished continuously for 27 hours and checked every three hours on March 2-3. Table 6 shows the results. Only one smelt was caught in a daylight set and this individual could have been caught in the semi-darkness of early dawn just after the net was set. No smelt were taken during the rest of the day. A good number of coho smolts were taken throughout this period, so the net was apparently fishing properly. As a result of these catches, 1800 hours (around dusk) was chosen as the time to begin fishing. A 33 hour period (11 sets) was fished from 1500 on March 9 to 2400 on March 10 to check the

TABLE 6

Catch of Smelt on March 2-3, 1970

Date	Time	Males	ripe Females	spawn-out Females	Others
March 2	1800-2100	50	12	5	1 squawfish 1 cottid
	2100-2400	6	1	0	1 coho smolt
	0000-0300	1	13	1	7 coho smolts
	0300-0600	12	0	7	-
March 3	0600-0900	1	0	0	1 coho smolt
	0900-1200	0	0	0	-
	1200-1500	0	0	0	12 coho smolts
	1500-1800	0	0	0	-
	1800-2100	31	20	1	6 coho smolts

result of March 2-3. A similar pattern of migration was found (Appendix II).

The catch per effort by time period for each date of fishing is shown for males in Fig. 7, ripe females in Fig. 8, and spawn-out females in Fig. 9. Early in the run, especially for the males, 1800-2100 hours shows the greatest catch. As the run progresses, 2100-2400 hours becomes dominant. For males, 1800-2100 remains second in catch, but for the ripe females, 0000-0300 hours brings the second highest catches. The spawn-out females follow the same general trend as the ripe females, but on a smaller scale (note change of scale on ordinate).

The shift in timing of the peak from 1800-2100 to 2100-2400 and 0000-0300 could be due in part to longer hours of daylight later in the run. The catches of males for 1800-2100 do not drop, however, but remain fairly constant throughout the run.

The large catches for 1800-2100 and 2100-2400 for males and 2100-2400 and 0000-0300 for females indicate that the males enter the river first in early evening while the females ascend the river later. This is consistent with findings by other investigators for the American smelt, Osmerus mordax (Hoover, 1936). The percentage of the total catch for each sex group, i.e. males, ripe females, and spawn-out females, by time period shows more clearly the fluctuation of sex ratio (Fig. 10). In this figure all catch dates are combined. Again the males are dominant in the 1800-2100 catches. The percentage of ripe females remains relatively constant for 1800-2400, becomes dominant in 0000-0300, then drops off drastically in 0300-0600. The percentage of spawn-out females is low and constant over the first three time periods, then rises

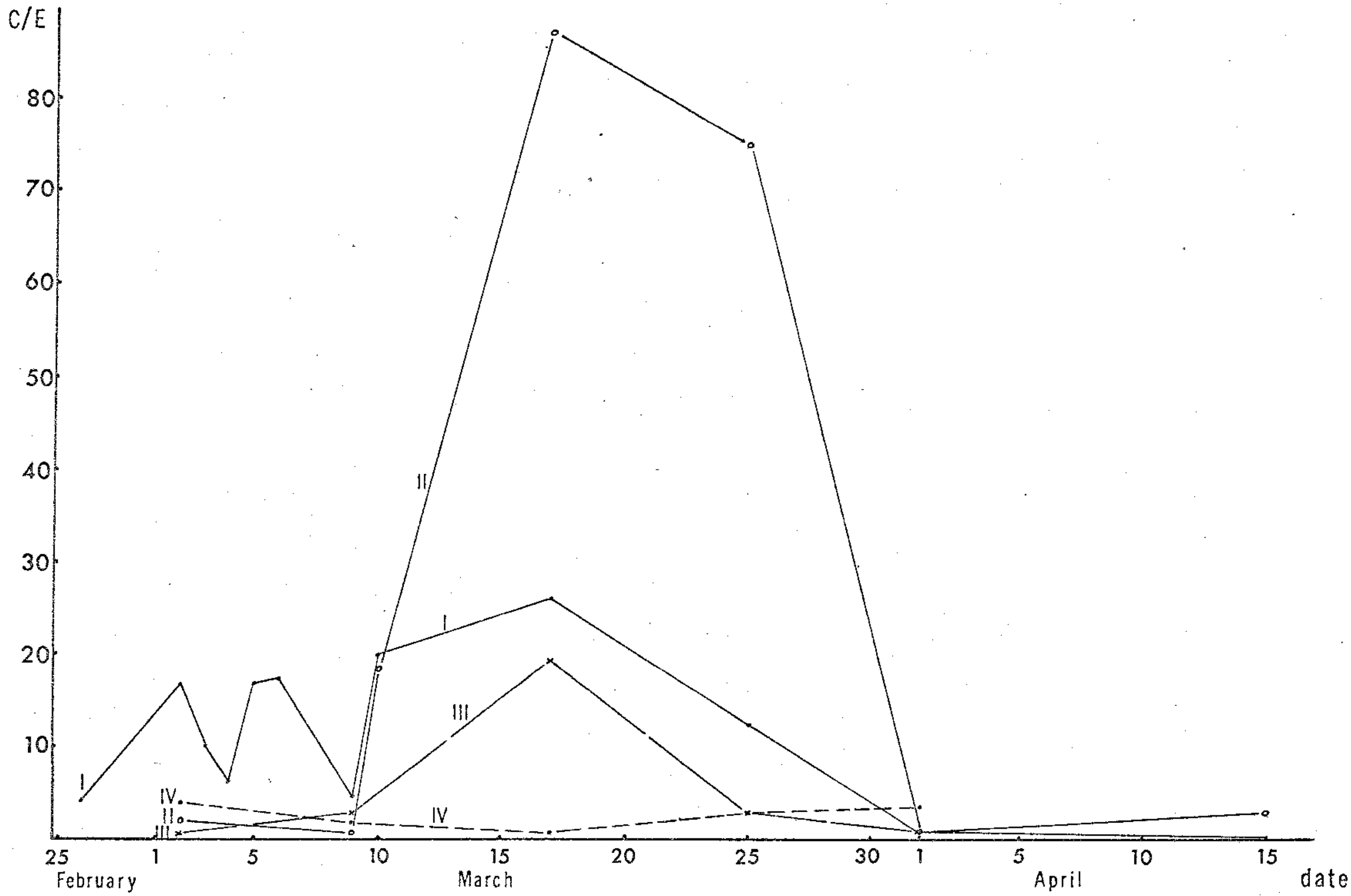


Figure 7. Catch per effort of male smelt by time period from February 26 to April 15, 1970.

I 1800-2100 = —•—•—

II 2100-2400 = —o—o—

III 0000-0300 = —x—x—

IV 0300-0600 = —•— —•—

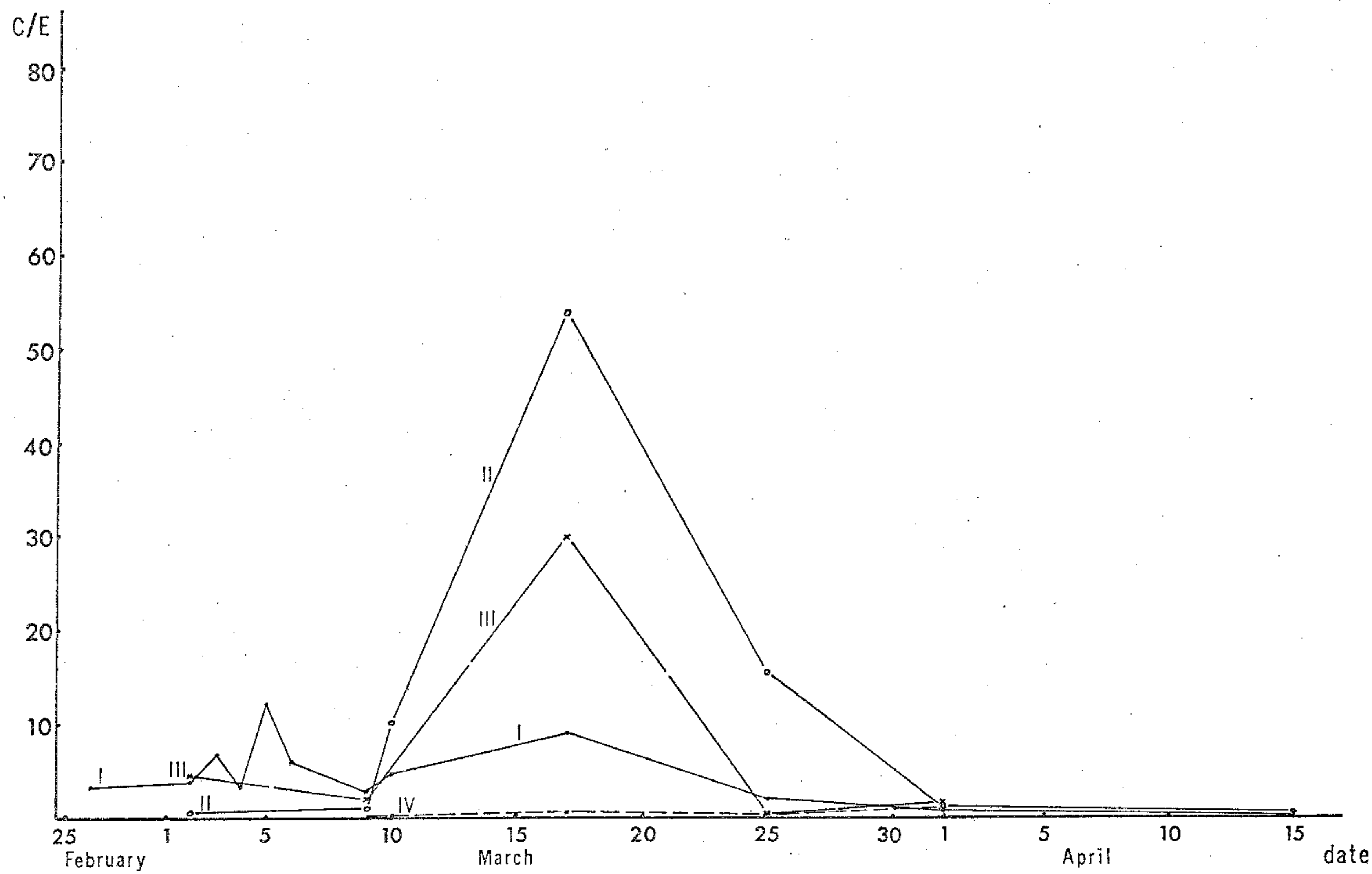


Figure 8. Catch per effort of ripe female smelt by time period from February 26 to April 15, 1970.

I 1800-2100 = —•——•—
II 2100-2400 = —o——o—
III 0000-0300 = —x——x—
IV 0300-0600 = --•----•--

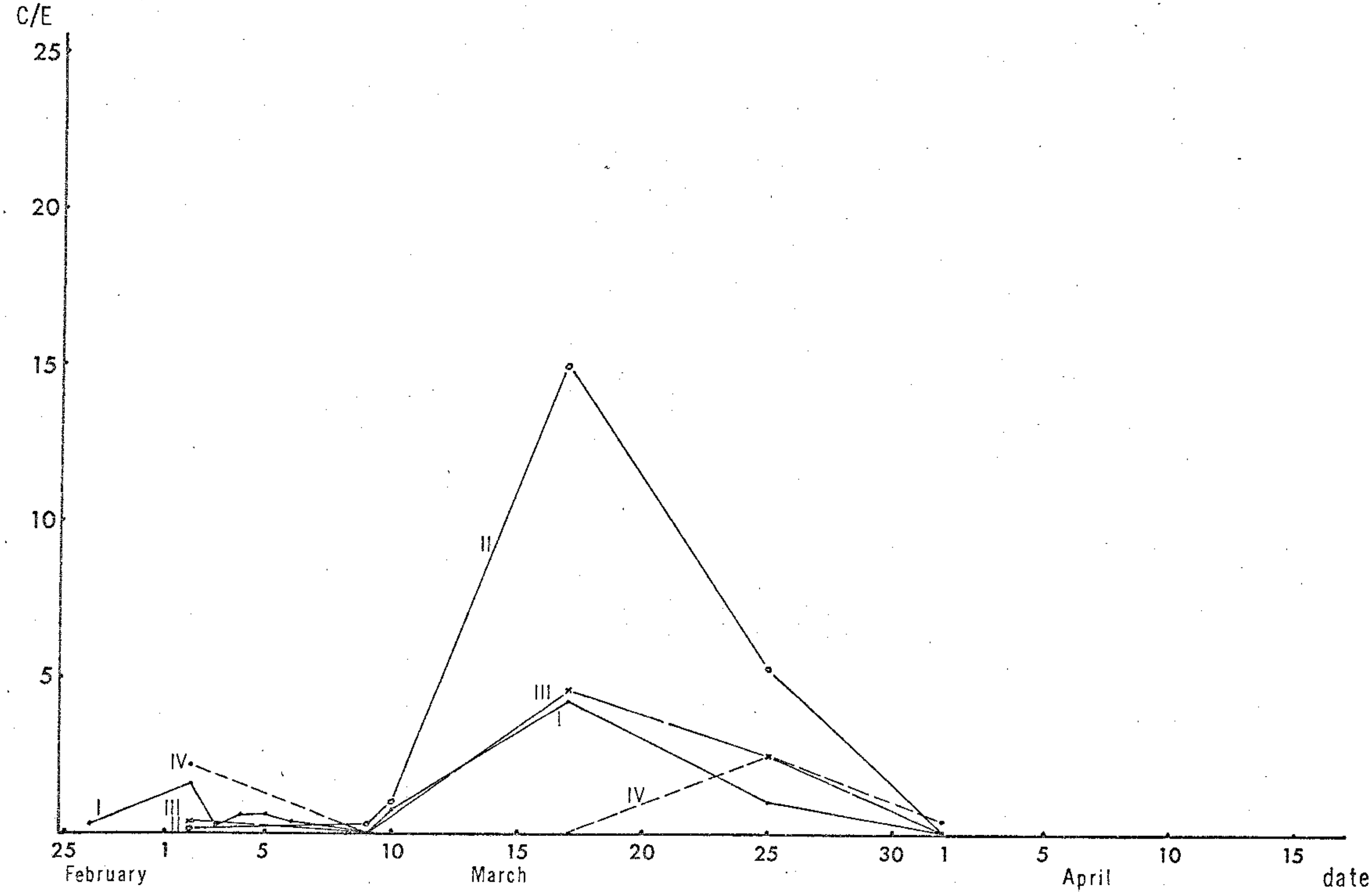


Figure 9. Catch per effort of spawn-out female smelt by time period from February 26 to April 15, 1970.

I 1800-2100 = —•——•—
II 2100-2400 = —o——o—
III 0000-0300 = —×——×—
IV 0300-0600 = —•— —•—

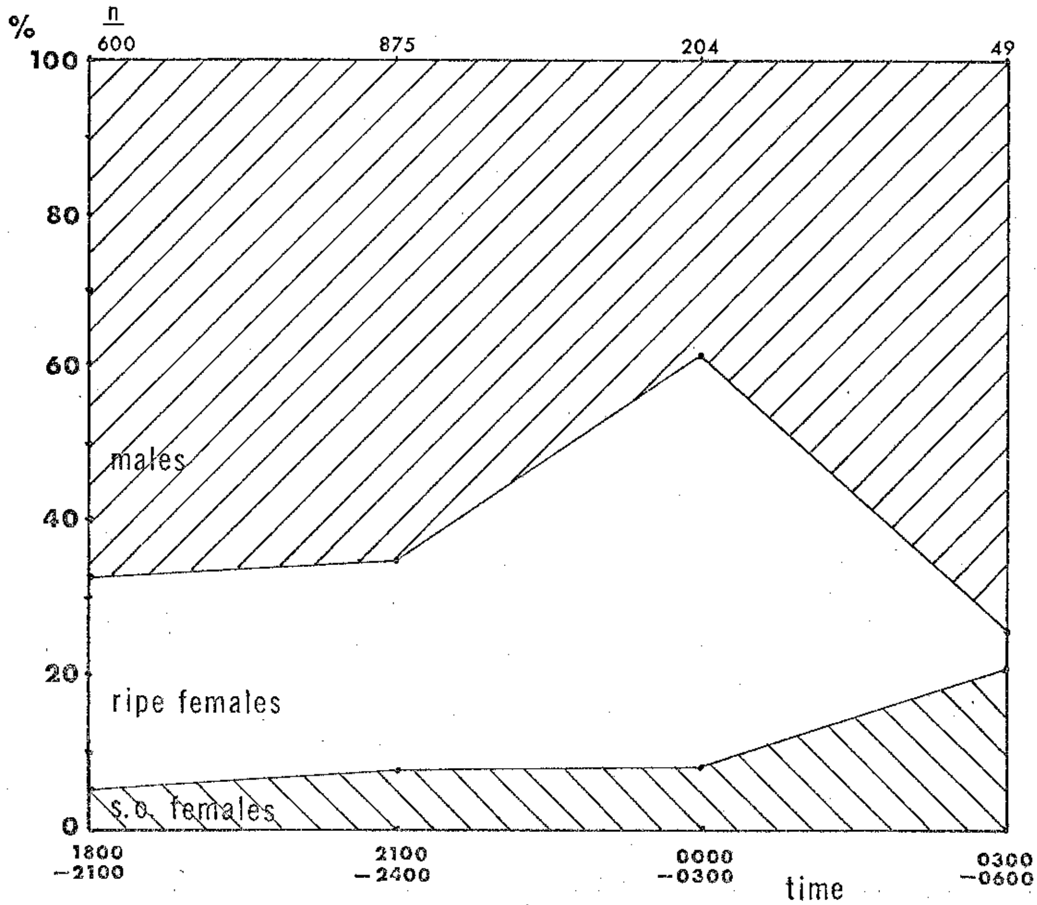


Figure 10. Sex composition as percentage of total catch by time period, with sample size indicated by n. (s. o. = spawn-out)

in 0300-0600. This supports the hypothesis that the majority of the males ascend first, followed by the main group of females. The males and spawn-out females caught in 0300-0600 could be dropping out of the river as spawning is completed.

The total catch of smelt at the mouth of the river produced a sex composition of 62.4% males and 37.6% females (ripe + spawn-outs). There is a bias in this figure as more samples were taken from 1800-2100 than any other time period, which would raise the percentage of males. To correct this, the sex composition was calculated for the five days in which sampling of all four time periods took place. This corrected catch gives an overall composition of 61.1% males and 38.9% females (30.2% ripe and 8.7% spawn-out) (Fig. 11). The ratio is closest to 1:1 at the peak of the run on March 17 where 53.3% were males. After the peak, the percentage of females dropped off to 21.2% and 22.7% on March 25 and April 1, respectively. A similar pattern was found for Osmerus mordax in Lake Superior by Bailey (1964), but in this case the females dominated the run after the peak.

The sex ratio in the lake is 1:1 (Dryfoos, 1965). In the spawning smelt, I found the sex ratio is more than 3:2 overall (males to females). This discrepancy could be accounted for if the male smelt remained in the spawning area longer than the ripe females. At no time were partially spawned females found. The indication is that an individual ripe female enters the river and spawns only once whereas a male smelt may enter the river on several occasions. The fact that the sex ratio approaches 1:1 at the peak of the run could be accounted for if the females showed a greater specificity for spawning conditions, i.e. temperature and

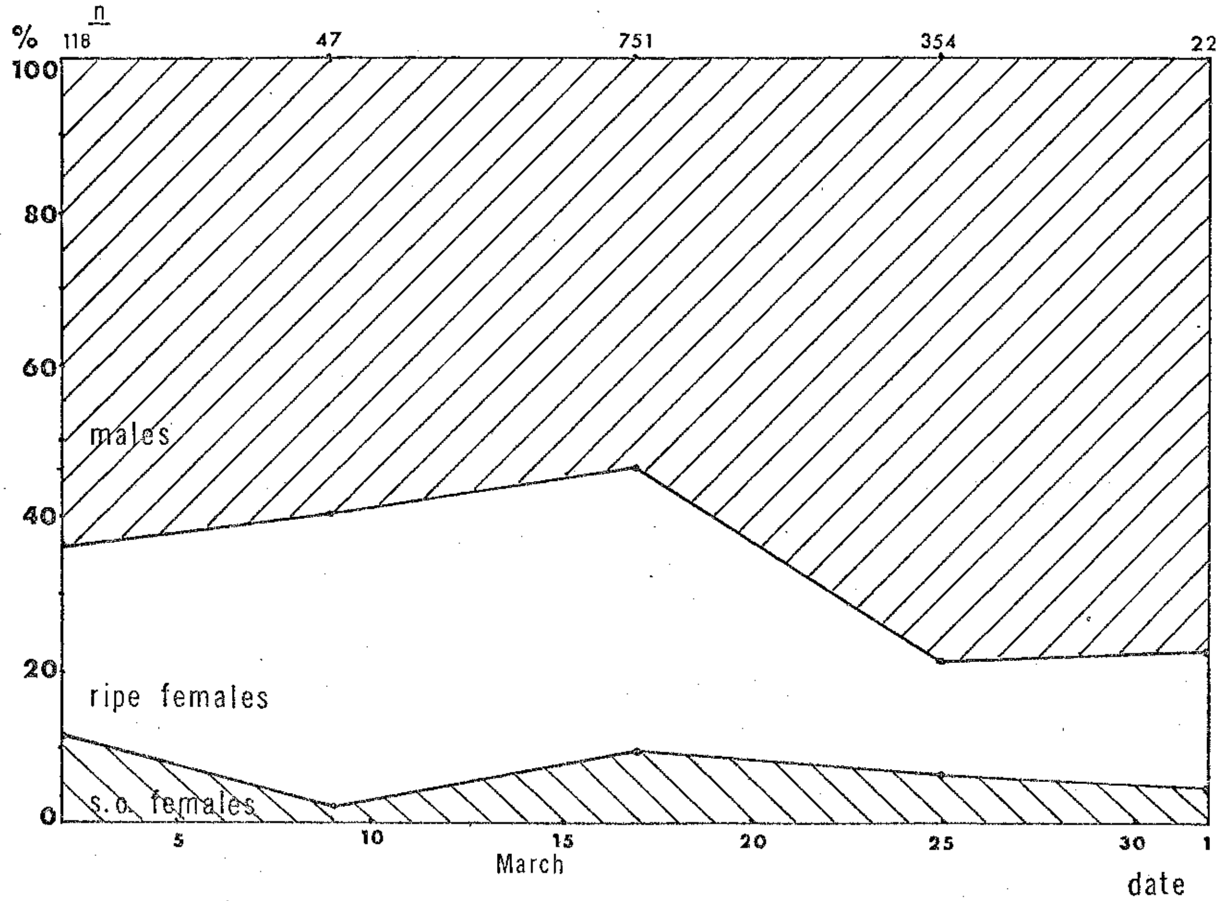


Figure 11. Sex composition as percentage of total catch by catch date, with sample size indicated by n. (s.o. = spawn-out)

water flow, and ascended the river over a shorter span of time than did the males. This is supported by the sex composition data of Fig. 12: there is a steady rise in the percentage of females as the peak nears, then a rapid decline.

In an attempt to determine when the smelt were leaving the river, a frame fyke net was placed under the bridge at the mouth of the Cedar River facing upstream on March 9-10, 1970. Fig. 12 shows the results. A few fish ascending the river were undoubtedly caught as they worked their way upstream; this is suggested by the sporadic small catches early in the night. The spawn-out females appeared first at 2300-2400 and continued at a low, steady level for the next eight hours (2300-0700). The males appeared suddenly at 0400-0500, ran strongly for the next hour, then tapered off rapidly. No ripe females were taken after 0200 and only four of forty-six females taken were ripe. These four could have been caught as they were ascending the river. The results indicate that the females drop out of the river as the spawning act is completed, while the males remain on the spawning grounds until dawn, at which time they also leave the river. The catches of spawn-out females in 1800-2100 and 2100-2400 with the fyke net facing downstream could be females which spawned on a previous night but continued to ascend the river. That no ripe or partially spawned females were taken after 0200 would indicate that the females spawned completely on their first ascent and any further returns to the spawning grounds by females were non-productive.

Large numbers of adult smelt were observed on March 10, 17 and 25 between 2030 and 2330 at Station 1. On March 10, the smelt

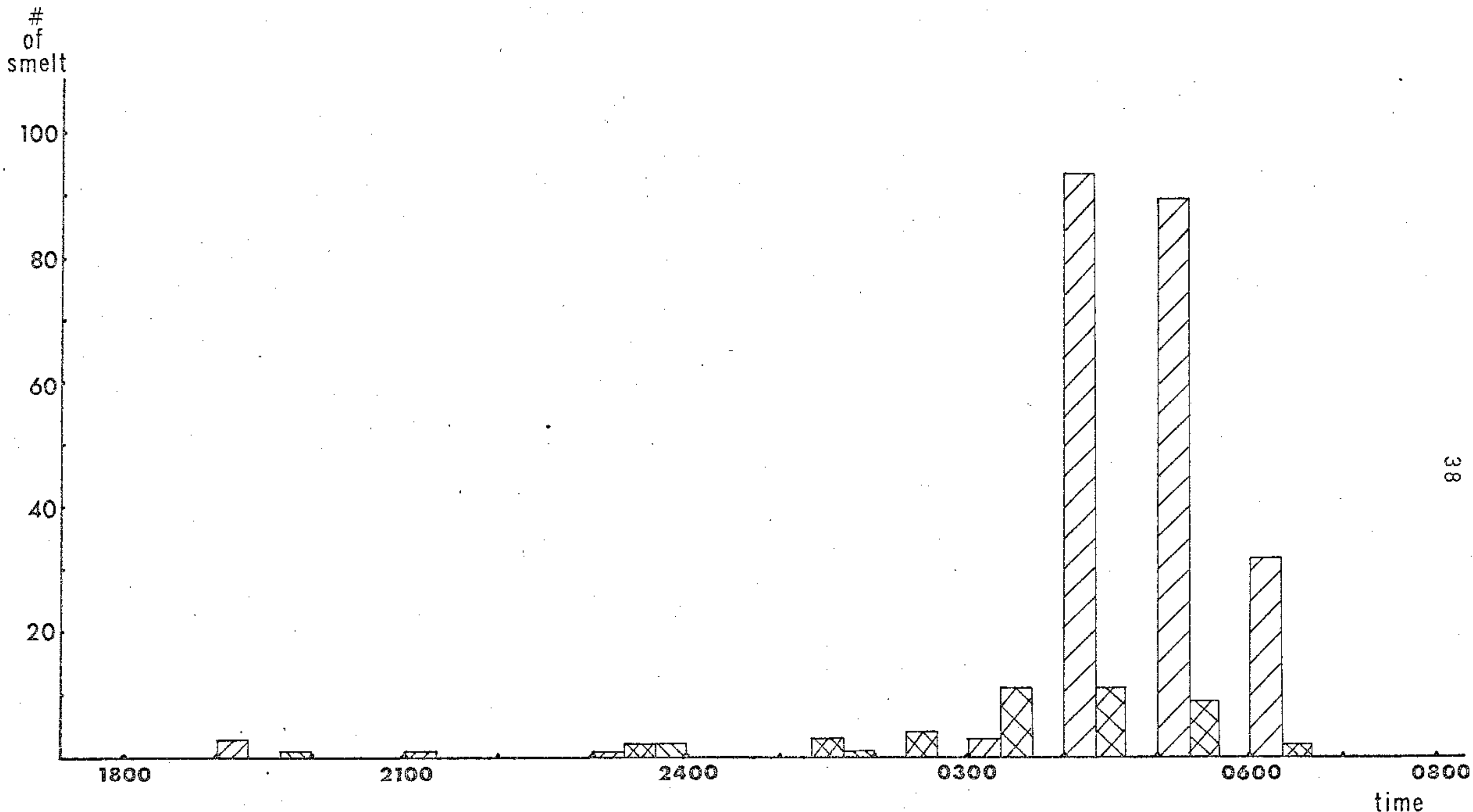


Figure 12. Catch of smelt by fyke net set to catch fish moving downstream under bridge at mouth of Cedar River on March 9-10, 1970.

males =
ripe females =
spawn-out females =

formed small schools approximately four feet offshore and appeared to be spawning. An effort was made to catch some with a dip net but only a few were taken as the mesh in the net was too large. On March 17, the smelt were much more numerous and were observed swimming slowly upstream near the banks of the river, thus forming two bands, one on each side of the river. Movements on the bank did not appear to distract them. A similar behavior pattern was observed on March 25.

The average lengths of both males and ripe females (Fig. 13) decreased as the run progressed. This phenomenon has been found by McKenzie (1964) and Bailey (1964) for *Osmerus mordax*. In addition, the males were consistently larger than the females with overall average lengths of 107.3 mm. (range: 92-122 mm.) for 598 males and 102.3 mm. (range: 89-113 mm.) for 267 ripe females. In *Osmerus mordax*, the males are smaller than the females of comparable age (Beckman, 1942; Bailey, 1964; McKenzie, 1964). The length frequency for each sex category is shown in Fig. 14. The average length of 76 spawn-out females was 103.6 mm., slightly greater than the ripe females. The lack of shorter spawn-out females is the probable cause of this size difference; this lack seems to indicate a selectivity by the fyke net for the larger individuals as the smaller spawn-out females can go through the meshes. A list of sample size, average lengths, average weights, and condition factor K (Carlander, 1969) is given in Appendix IV.

There is no evidence of age II fish in the length frequency distribution. The catch of adult smelt in the lake dropped off after February. Six adults were taken in Areas 2 and 3 (Fig. 1)

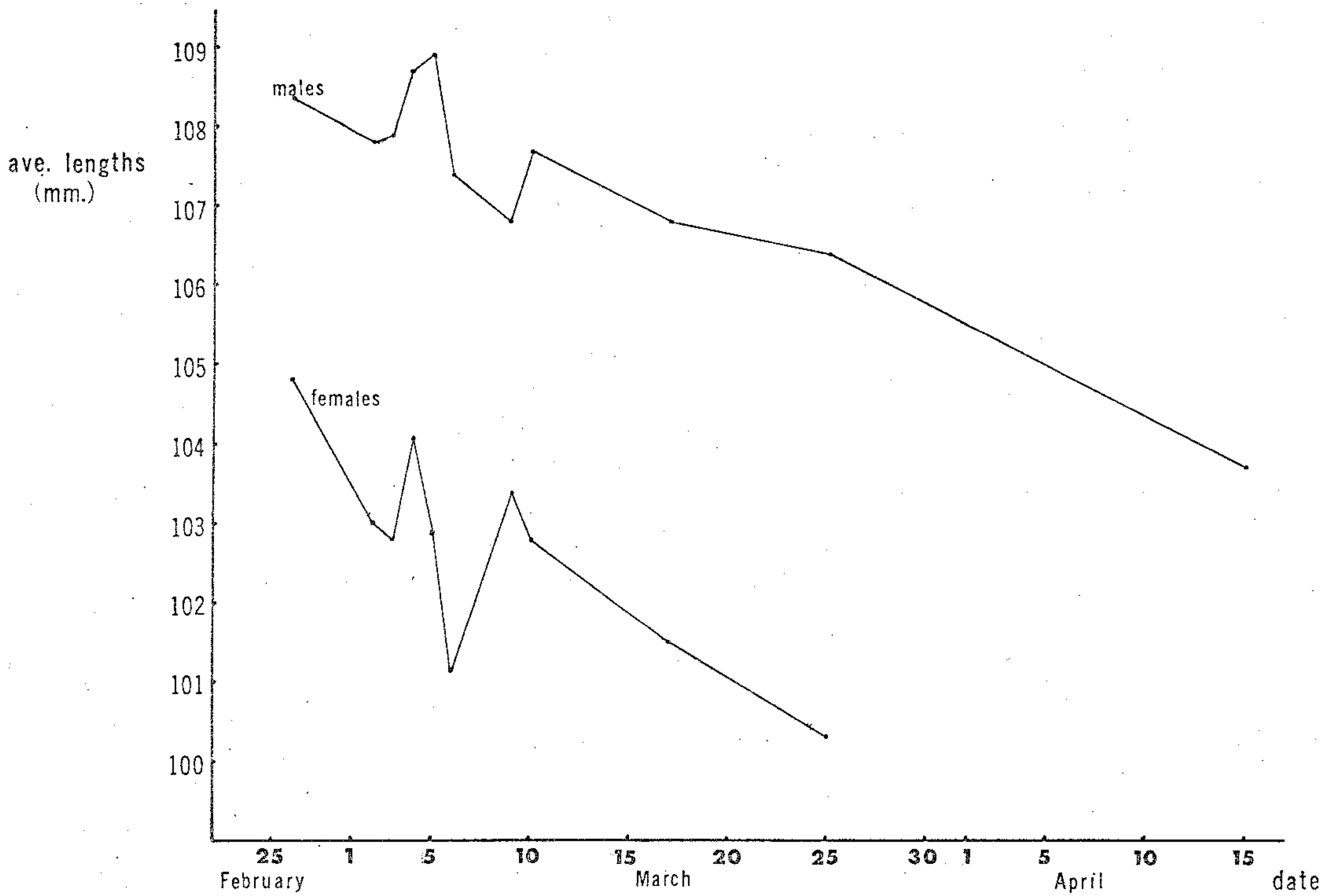
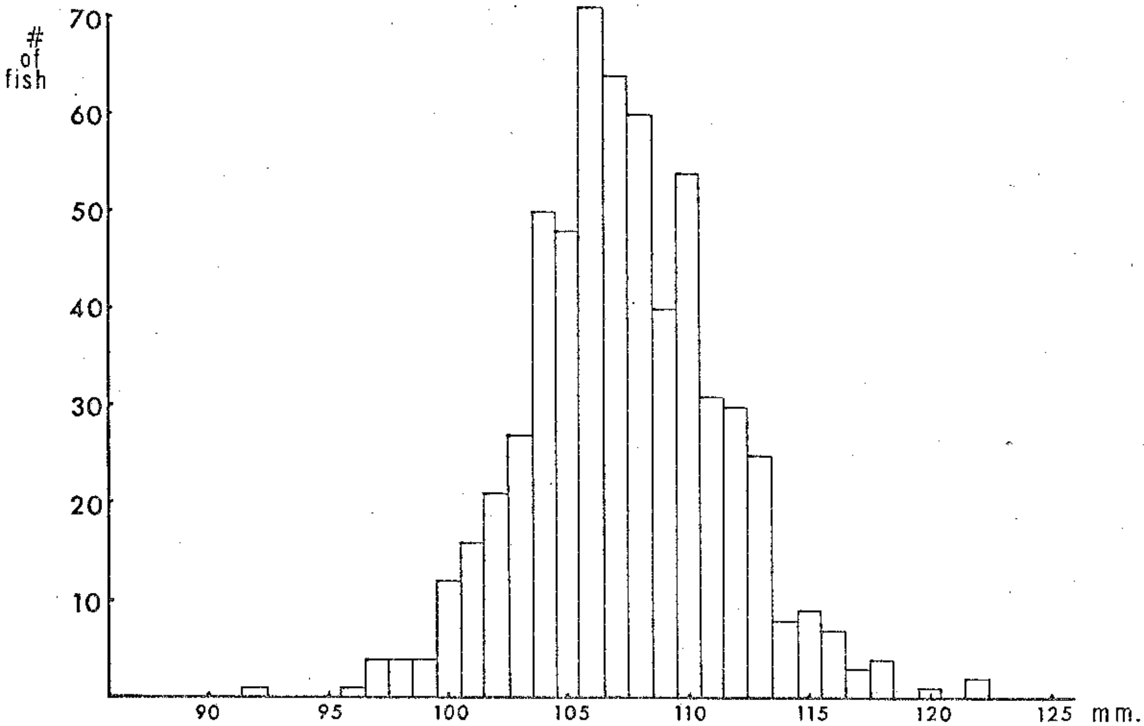
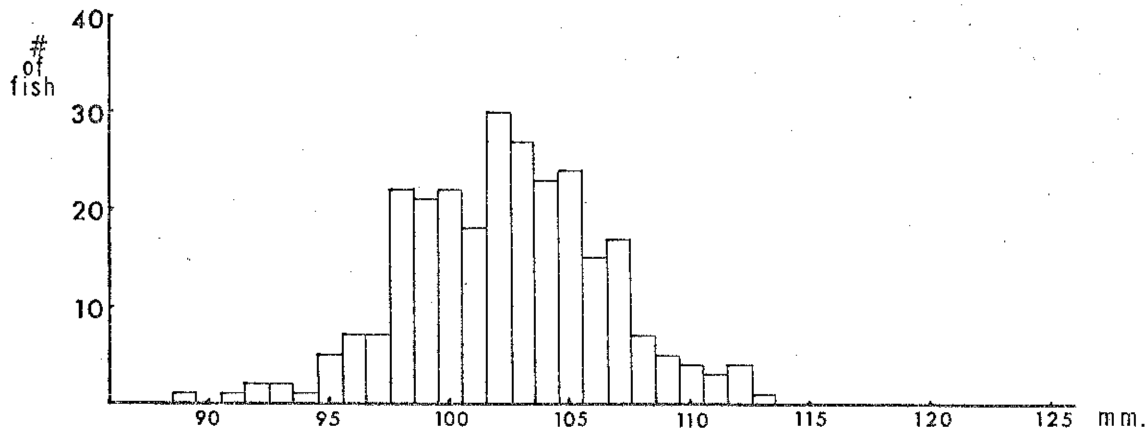


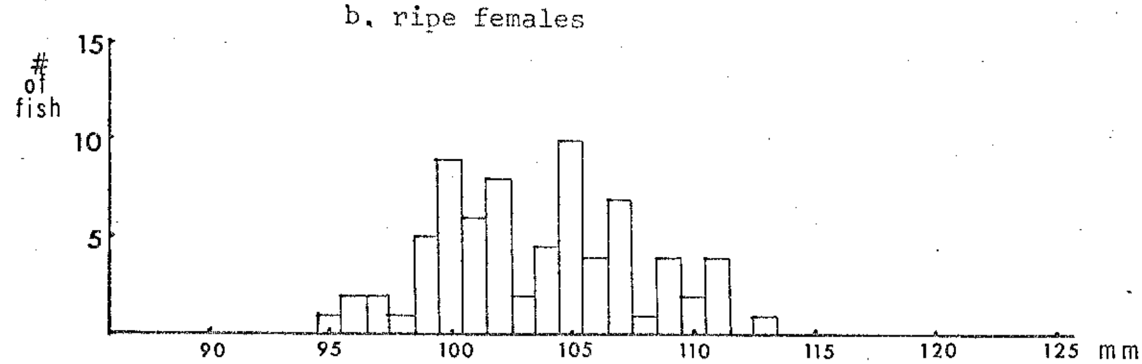
Figure 13. Average lengths of males and ripe females by catch date.



a. males



b. ripe females



c. spawn-out females

Figure 14. Length frequency of 1970 spawning smelt by sex category.

in June, 1970 and one in June, 1969. All these fish seem to be sterile as there was no gonadal development. In addition, several maturing smelt of the 1968 year class were taken in Areas 3 and 4 in August and October, 1970. These 29 and 31-month fish (using Dryfoos' convention of March as month 0) are the oldest taken to date and indicate that occasionally there may be some hold-over. The scales of these fish showed no spawning check and the fish were in good condition. The most likely explanation is that they failed to mature until the third year.

Evidence of Predation on Smelt Eggs and Adults

Many small cottids were taken during the egg sampling in the Cedar River. These were measured and examined for stomach content. The primary food was insect larvae and nymphs of various kinds, but a few were taken containing smelt eggs. Table 7 summarizes the data pertinent to this study. Before February 26, all cottids were combined in one jar so the date the one containing smelt eggs was caught is not known. After February 26, all cottids were analyzed by date and station. The data suggest that when smelt eggs are abundant, cottids readily feed on them. The data also support the hypothesis that spawning is limited to the lower 1.25 mile of the Cedar River as no cottids above this distance contained smelt eggs. In addition, one cottid was taken from May Creek containing five smelt eggs.

On January 22, 1970, two northern squawfish, *Ptychocheilus oregonensis* (Richardson) were taken in the fyke net facing downstream at the mouth of the Cedar River; both of the fish contained freshly eaten smelt. As a result of this catch, several gill net

TABLE 7

Predation by Cedar River Cottids on Smelt Eggs

Cottids caught 15/1/70-26/2/70 at Stations 1, 2, or 3

Date	No. Cottids	No. w/smelt eggs
15/1/70-26/2/70	37	1 (2 eggs)

Cottids caught after 26/2/70 at Stations 1, 2, or 3

Date	No. Cottids	No. w/smelt eggs
1/3/70	8	0
8/3/70	1	1 (33 eggs)
15/3/70	3	3 (5, 10, 11 eggs)

Cottids caught after 26/2/70 in areas other than Stations 1, 2, or 3

Date	No. Cottids	No. w/smelt eggs
1/3/70	0	0
8/3/70	10	0
15/3/70	6	0

trips to the Cedar River area were undertaken to try to get some idea of the predation pressure on the smelt adults. A complete list of species caught in the gill nets is given in Appendix V. All squawfish subsequently caught in the fyke net were analyzed. The results of this study are given in Table 8. The majority of the squawfish (56%) were not feeding, but when they did feed, 70% were taking smelt. The gill net catches indicate a fairly large squawfish population in the area so the predation pressure on the adult smelt is probably high. In addition, one rainbow trout was taken containing two smelt adults. Other predators which are not readily caught by gill nets or trap nets may be present but were not detected.

Development of Eggs and Early Larval Stages

The development of Spirinchus thaleichthys eggs has not been described. Photographs were taken of live eggs incubated at the BCF Fish Holding Room in dechlorinated city water. The temperature range during the period of development was 9.6-10.6°C, shown in Fig. 15. The eggs are characterized by the large number of oil globules in the yolk and the anchor membrane used for attachment to the substrate. These characteristics are typical for eggs of the smelt family (Ehrenbaum, 1894; Hart and McHugh, 1944; Smith and Saalfeld, 1955; Hikita, 1958). McKenzie (1964) gives a good description of the way in which the anchor membrane attaches to the substrate and holds the egg up in the current. Fig. 16C and D show the anchor membrane intact and descended, respectively. The anchor membrane of S. thaleichthys becomes adherent approximately 5 seconds after the addition of water. McKenzie reports

TABLE 8

Predation by Northern Squawfish on Smelt Adults

in the Vicinity of the Cedar River

Date	no. of Squawfish	Squawfish w/Fish Remains	Squawfish w/Smelt	Other Fish Remains
22/1/70	2	2	2	1 w/brook lamprey
29/1/70	22	6	5	2 w/cottids 1 w/crayfish
6/2/70	2	1	0	1 w/cottid
12/2/70	9	6	3	2 w/salmonids 1 w/cottid
2/3/70	1	0	0	-
5/3/70	1	1	1	-
9/3/70	7	3	3	-
10/3/70	1	1	1	-
15/4/70	17	7	4	2 w/cottids 1 w/unident. fish
Total	62	27	19	6 w/cottids 2 w/salmonids 1 w/brook lamprey 1 w/crayfish 1 w/unident. fish

TABLE 8 (cont.)

	Squawfish	Squawfish w/Fish Remains	Squawfish w/Smelt
% of Total	100%	43.5%	30.6%
% of those feeding	-	100%	70.3%

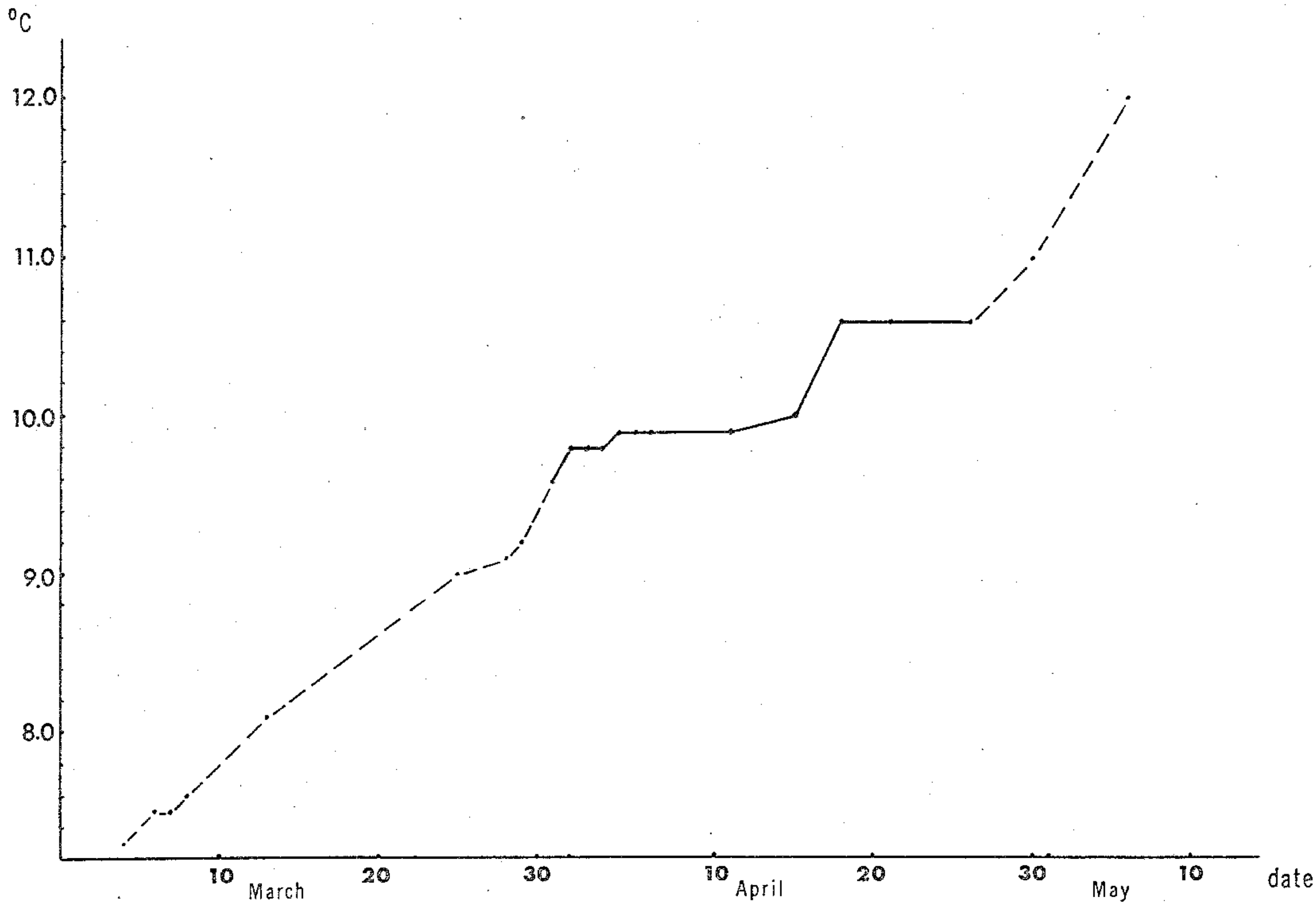


Figure 15. Water temperature in incubation trays during egg development.
(solid line = time of egg development)

15-20 seconds for eggs of Osmerus mordax. The anchor membrane gradually loses its tackiness so that by the 15th day of development it has lost most of its adherency, except at the site of attachment.

All the trays of artificially fertilized eggs showed a high percentage (90-95%) of abnormal development (Fig. 16A and B). The first two attempts at recording development failed as the abnormally developing eggs died after 48 hours and became covered with a fungus which spread to the normal eggs. The abnormal eggs were removed during later attempts and survival of the normal eggs was high.

The site at which the anchor membrane is attached to the egg is reported to be the micropyle (Ehrenbaum, 1894; Hikita, 1958). The uncleaved blastodisc was oriented opposite this site (Fig. 16C and D). In later stages the yolk and blastoderm shifted position as oil globules merged to form larger droplets. The initial cleavage occurred after 7 hours at 9.6° (not photographed) and by 9 hours, all were in the 4 cell stage (Fig. 17A). The cleavages to the 64 cell stage occurred at 2 hour intervals (Fig. 17B, C, D; 18A). The blastoderm began moving down over the yolk at 48 hours (Fig. 18D). The blastopore neared closure at 85 hours and was completely closed by 96 hours (Fig. 19C, D). The embryo was first discernible at 108 hours (Fig. 20A) and by 5 days was readily recognizable (Fig. 20B). At this stage the optic lobes were apparent and the otolith just visible. The brain increased in size over the next 24 hours (Fig. 20C) and by 8 days the eye lenses and the divisions of the brain were noticeable (Fig. 20D). Slight movements began during the 10th day and in the 11th day the eyes became pigmented (Fig. 21A). The heart beat was first noticed on the 13th day. After this, the embryo increased in length from a full circle on the 11th day to 1.5 circles on the 15th day (Fig. 21B) and 3 circles on the 18th day (Fig. 21C). The embryo coils around several times in the shell so that by hatching, here 25 days, the embryo shows about 4.5 curls. Complete hatching occurred on the 25th day, after the eggs were agitated slightly. The larvae were around 7.5 to 8.0 mm. total length while the eggs just prior to hatching were 1.067 mm. in diameter.

The larvae were placed in quart jars and daily samples were taken until the 11th day, when all had died. Feeding was not attempted. The photographs were taken of preserved larvae. At the time of photographing, the larvae were approximately 8.0 mm. total length.

The pigmentation of the larval smelt was found to be in agreement with Dryfoos' description (Dryfoos, 1965). For 23 larvae, the range in the number of melanophores between the gut constriction and the anus was found to be 7-12, with an average of 8.8. Dryfoos found 8 to 10, but the melanophores are often difficult to count due to merging in some individuals, so the differences could result from counting procedures. The larvae gradually became emaciated as the yolk was absorbed (Fig. 22A, B, C). The larvae were quite active for the first six days, after which many dropped to the bottom of the jar and swam sporadically. Many were dead by the tenth day and only one was living on the eleventh day at a temperature of 12.0°C.

The development of the eggs at a temperature range of 9.6 to

10.6°C took 25 days. Dryfoos found development took 40 days at 7.0°C. The 25 day development at 9.6-10.6°C represents an accumulation of 253 Centigrade temperature units while the 40 day development at 7.0°C represents 280 C.t.u. This compares to 205 C.t.u. in *Thaleichthys pacificus* (Richardson) (Smith and Saalfeld, 1955) and about 180 C.t.u. in *Osmerus mordax* (McKenzie, 1964).

Dryfoos' larvae died within four days of hatching while the larvae in this study survived for eleven days on two different occasions. It is possible that Dryfoos' larvae were attacked by a pathogenic organism as they were incubated in the lake, hence more exposed to disease organisms.

Figure 16. Early developmental stages of eggs. 22.5X

A. 24-hour abnormal development.

B. 48-hour abnormal development.

C. 4-hour with anchor membrane intact.

D. 4-hour with anchor membrane descended.

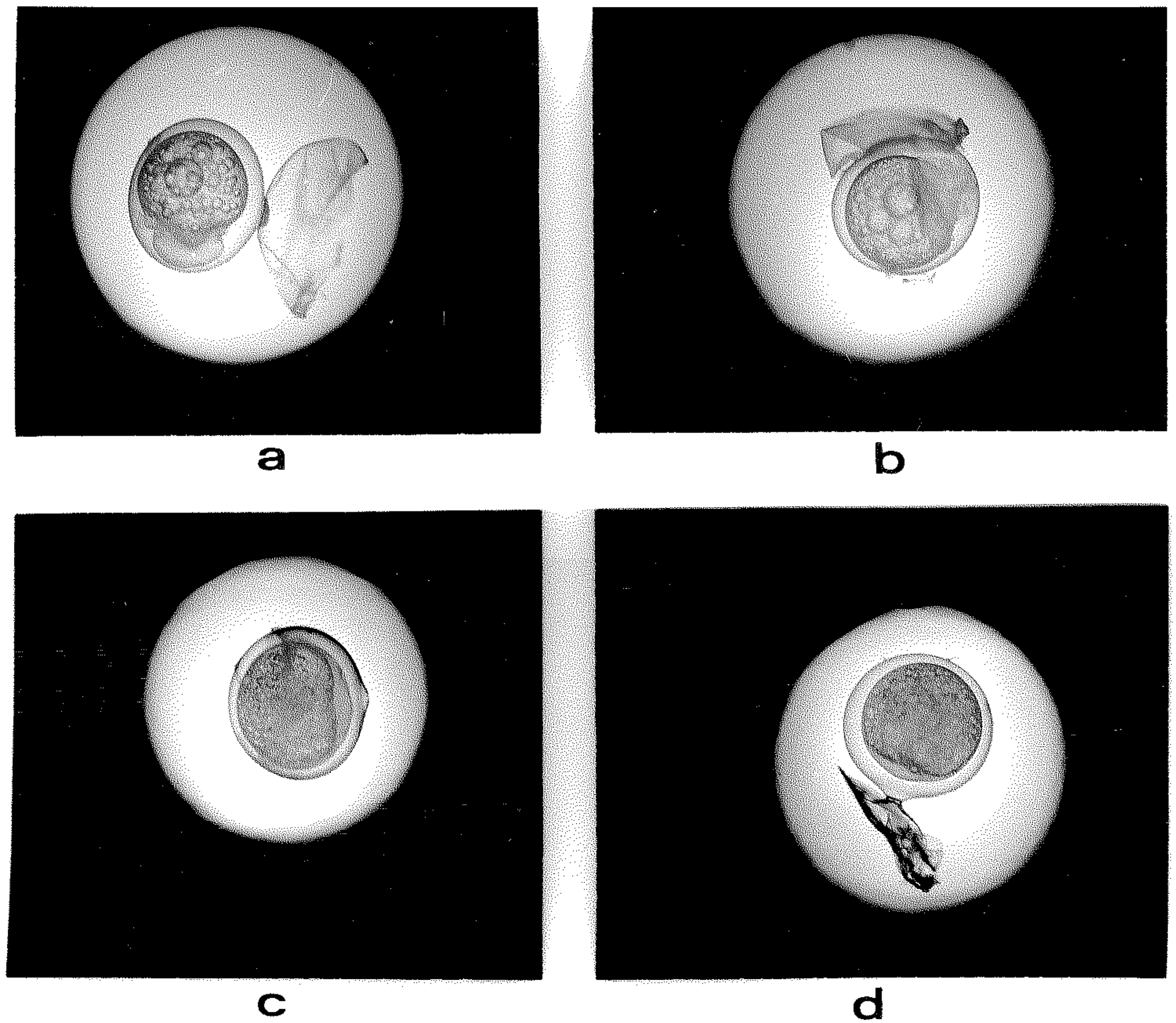

a
b
c
d

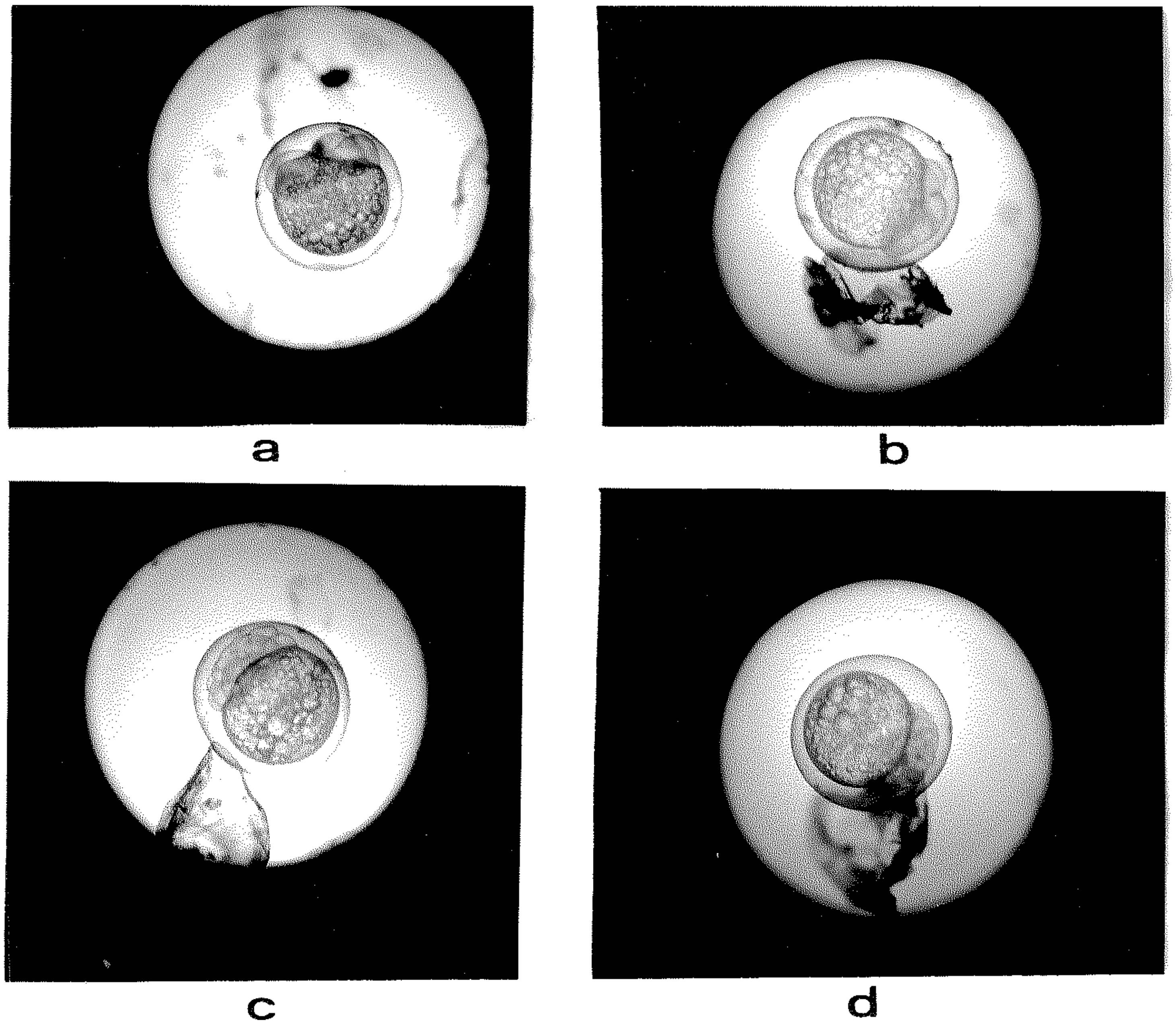
Figure 17. Early developmental stages of eggs. 22.5X

A. 4-cell stage, 9 hour.

B. 8-cell stage, 11 hour.

C. 16-cell stage, 13 hour.

D. 32-cell stage, 15 hour.


a
b
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d

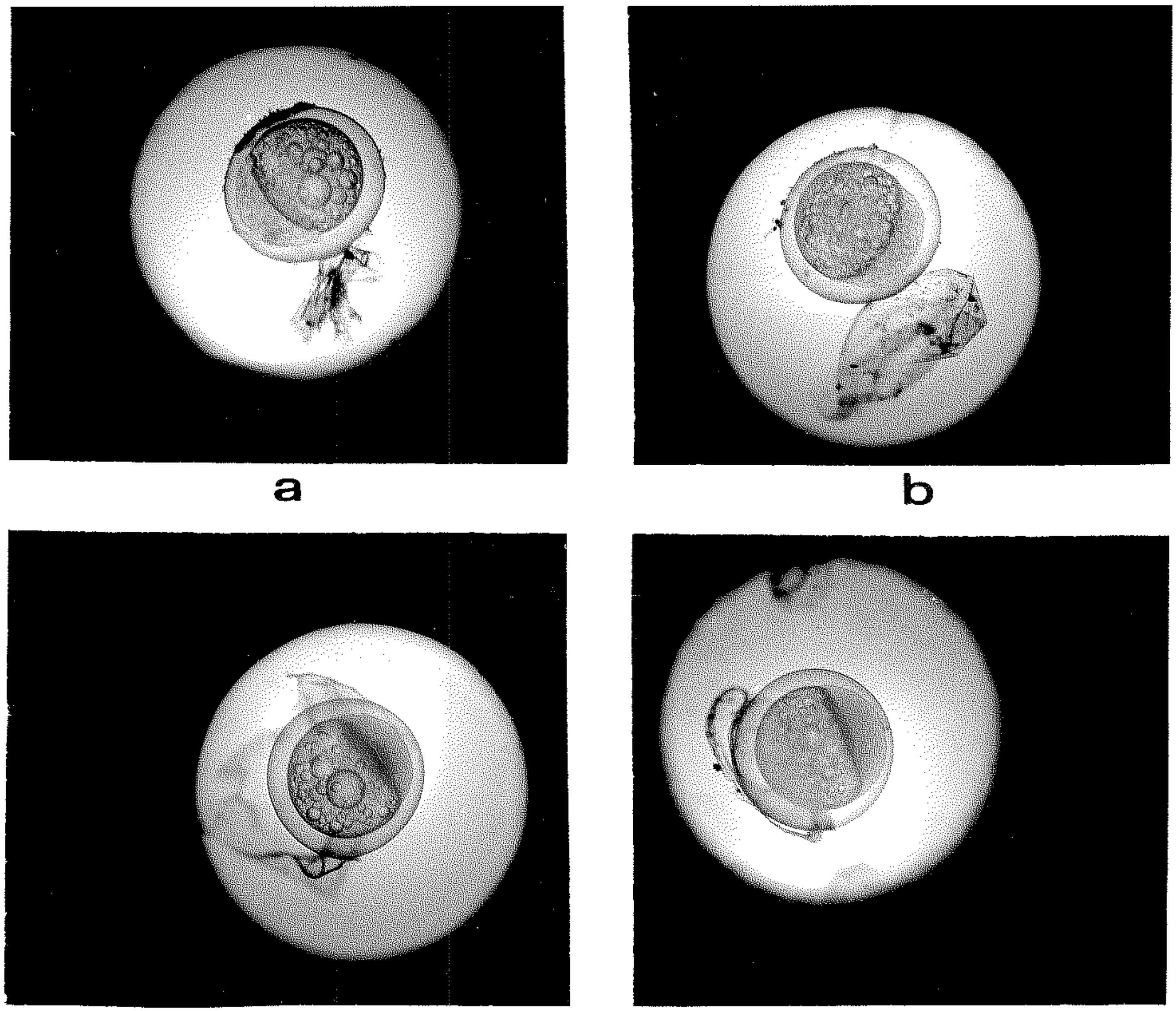
Figure 18. Early developmental stages of eggs. 22.5X

A. 64-cell stage, 17 hour.

B. Early blastoderm stage, 25 hour.

C. Mid-blastoderm stage, 35 hour.

D. Late blastoderm stage, 48 hour.



a b c d

Figure 19. Pre-blastopore closure stages of eggs. 22.5X

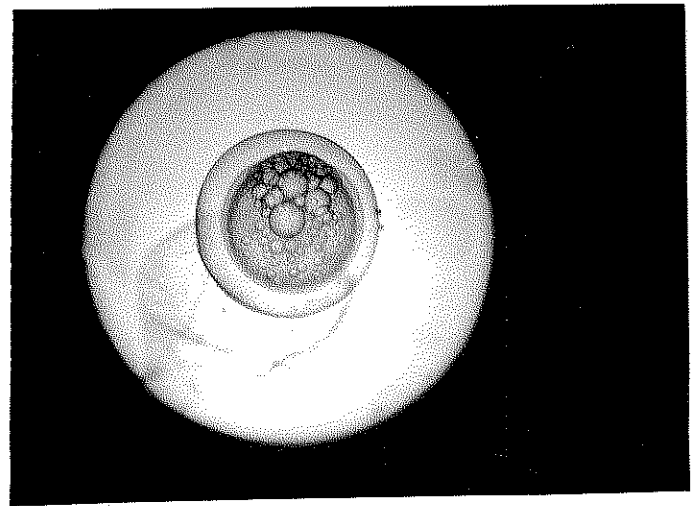
A. 63-hour stage.

B. 72-hour stage.

C. 85-hour stage, blastopore closing.

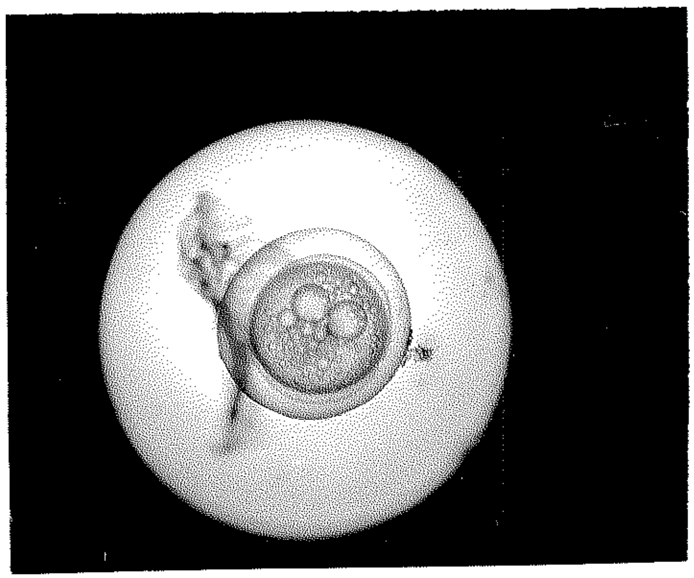
D. 96-hour stage, blastopore closed.

a



b

c



d

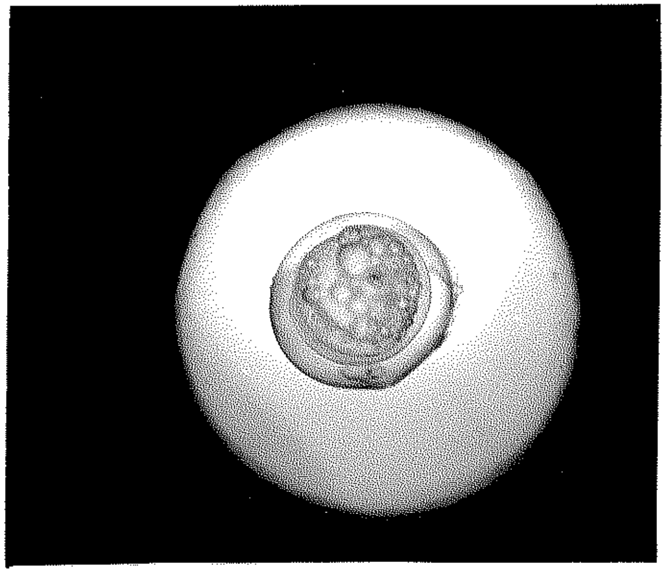
Figure 20. Early embryonic stages of eggs. 22.5X

A. 108 hours.

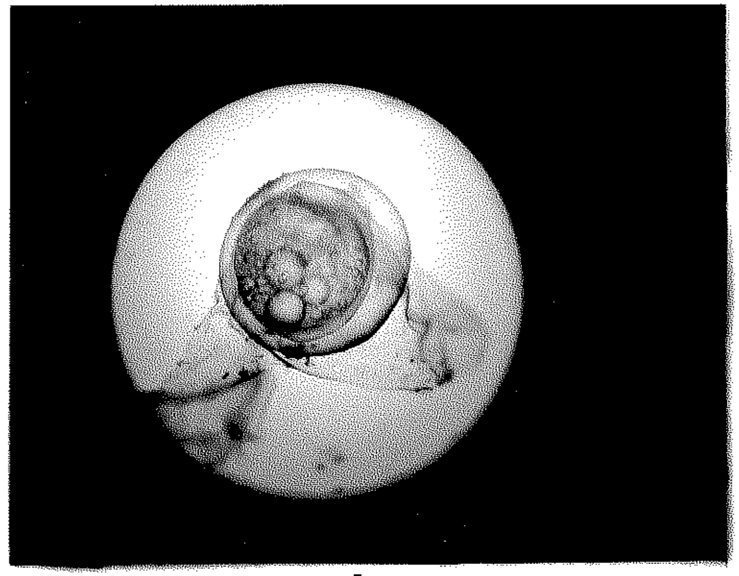
B. 5 days.

C. 6 days.

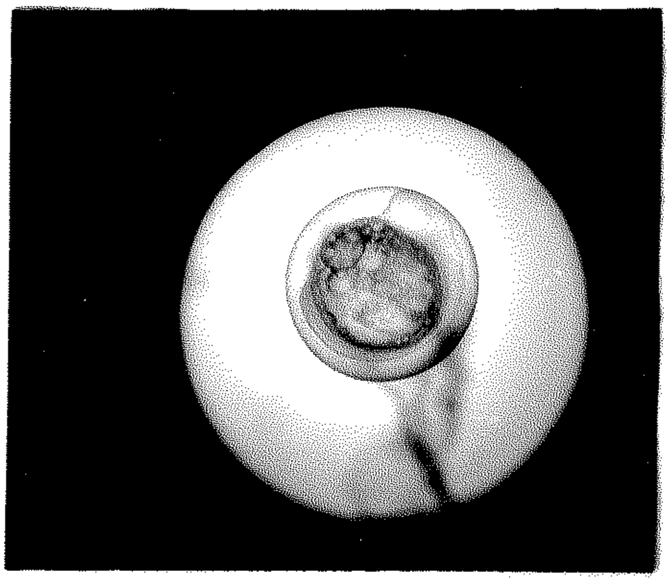
D. 8 days.



a



b



c

d

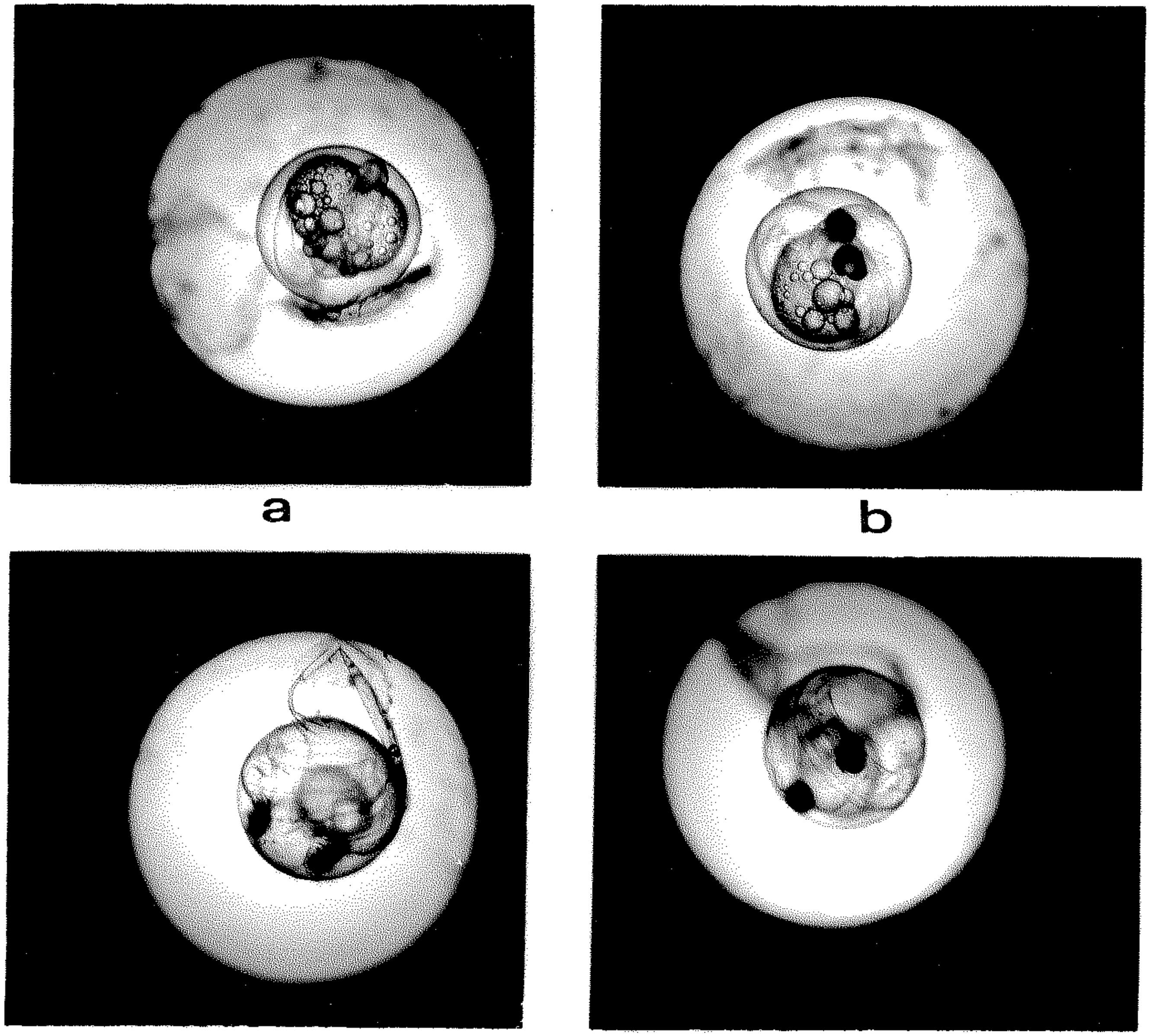
Figure 21. Late embryonic stages of eggs. 22.5X

A. 11 days.

B. 15 days.

C. 18 days.

D. 22 days.



a b c d

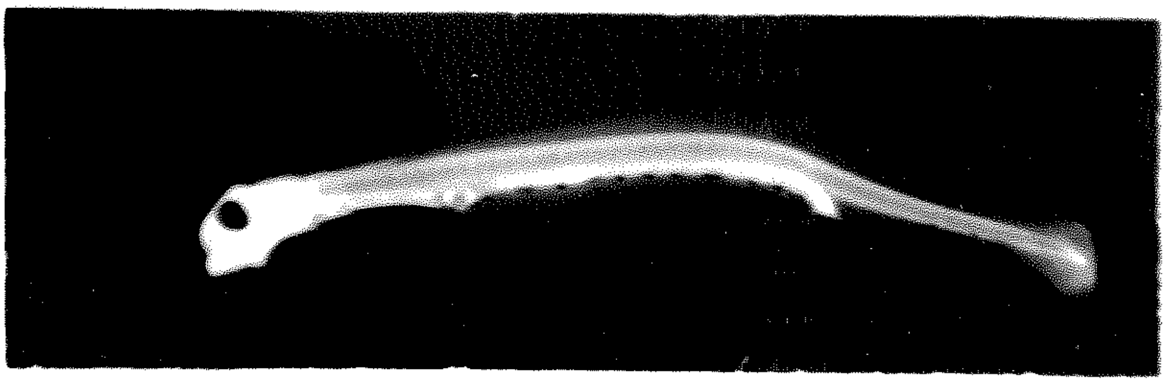
Figure 22. Larval stages. 15.4X

A. 1 day after hatching, 8.0 mm.

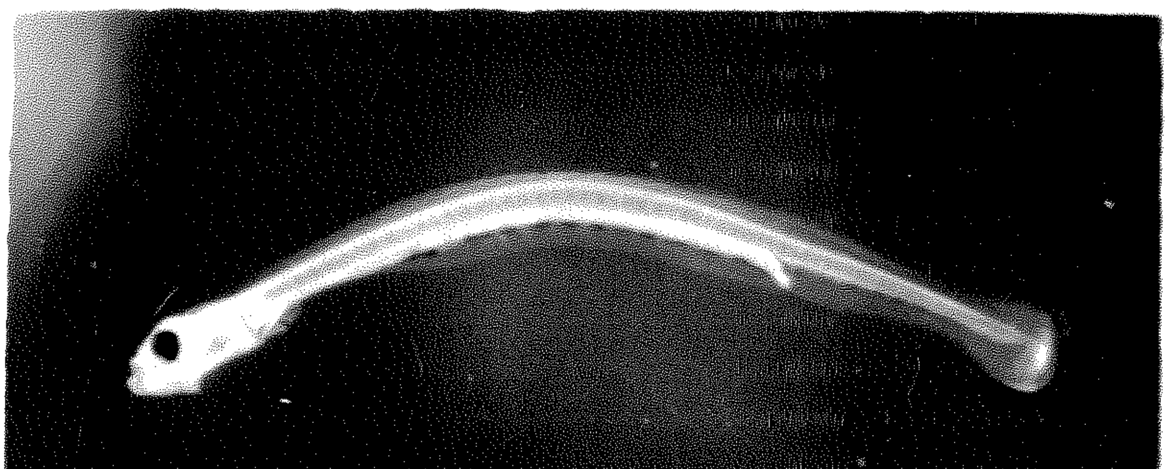
B. 5 days, 7.6 mm.

C. 10 days, 8.0 mm.

a



b



c

Changes in the Smelt Population Since 1964

Since Dryfoos' study, two major changes have occurred in the Lake Washington smelt population. The most noticeable change is in the size of the smelt. During Dryfoos' study, the 1961 year class non-deformed 21 month smelt averaged 125 mm. standard length. These fish were caught in the lake proper with a 6' Isaacs-Kidd midwater trawl. The 1968 year class spawners (24 month), taken with the fyke net at the mouth of the Cedar River, averaged 107.3 mm. for males and 102.3 mm. for females, a reduction in the average length of approximately 20 mm. Table 9 shows the average lengths of 1961-63 year classes and 1966-68 year classes between 18 and 23 months. The reduction in size from 1961-63 year classes to the 1966-68 year classes is readily apparent. The length-weight relationship of the 1968 year class spawners also shows a change from Dryfoos' findings as shown in Fig. 23. Dryfoos' length-weight relationship is based on 469 smelt greater than 70 mm.

The other major change which has occurred is in the abundance of smelt. Since 1965, the smelt population in even-numbered years has increased markedly, while the odd-numbered year classes have remained at approximately the pre-1965 levels. The odd-year/even-year cycle was evident in Dryfoos' data, but has become even more noticeable since his study. The data to measure relative smelt abundance are taken from Dryfoos' data, other data collected sporadically in 1965 and 1966, and data collected incidental to the study of young sockeye salmon from 1967 to 1970. The primary units of gear were 6 foot and 10 foot

TABLE 9

Average Lengths of Adult Smelt by Year Class

between ages 18-23 months

	Average Length (mm.)													
	1961 y.c.		1962 y.c.		1963 y.c.		1966 y.c.		1967 y.c.		1968 y.c.		1969 y.c.	
age in months	n	$\bar{X}$	n	$\bar{X}$	n	$\bar{X}$	n	$\bar{X}$	n	$\bar{X}$	n	$\bar{X}$	n	$\bar{X}$
18		-	33	100.8		-	137	84.8	32	94.8		-		-
19	10	114.6	25	108.0	13	115.3		-	34	101.5	82	85.4	20	106.8
20		-	28	112.5		-	121	92.8		-	102	91.6		
21	8	123.3	13	112.4		-		-	14	102.0	69	95.6		
22	10	111.7	22	121.7		-		-	13	106.9	58	101.8		
23		-		-		-	106	96.8	15	105.3	58	104.1		

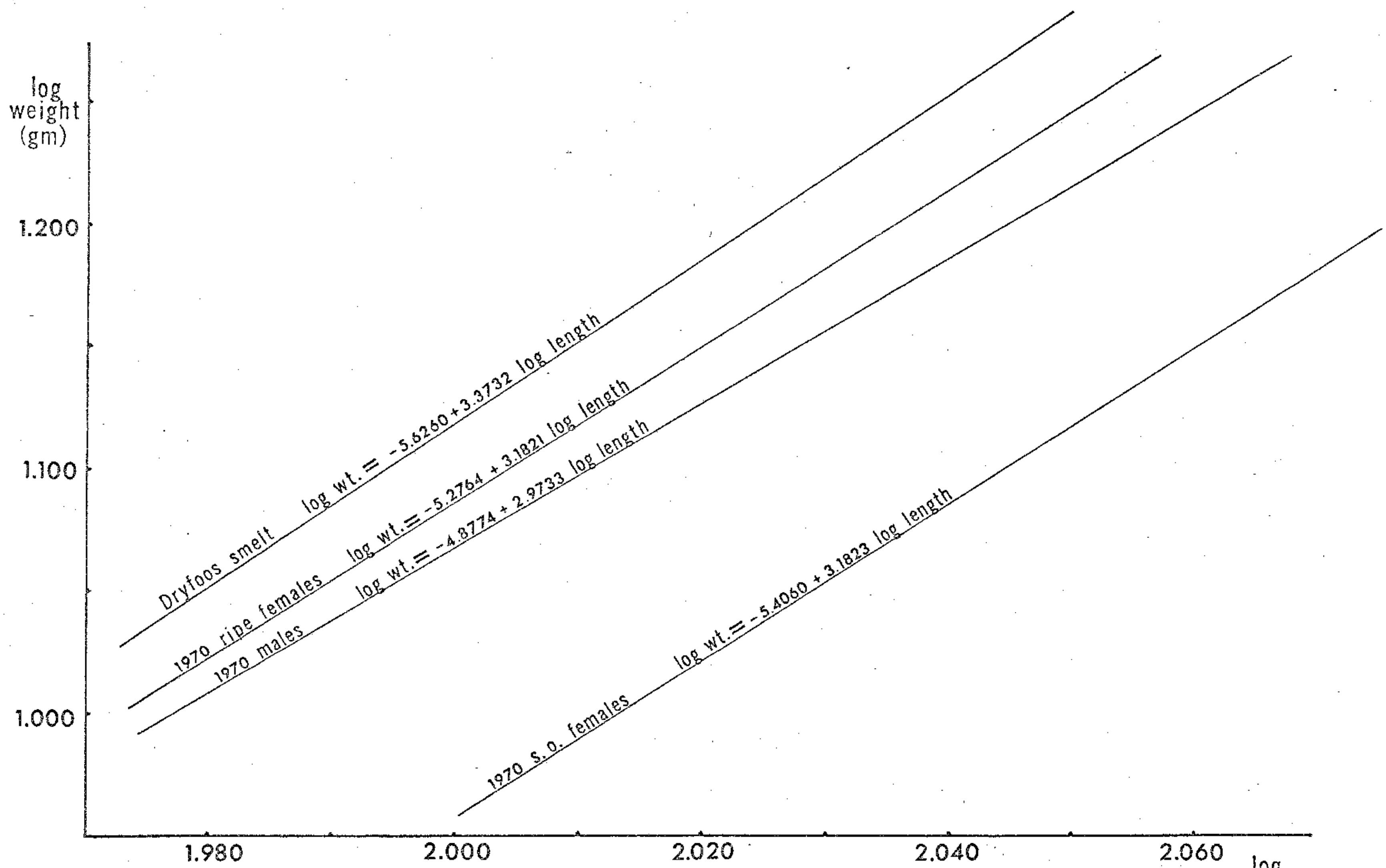


Figure 23. Length-weight relationships for 1970 spawners and 1962-64 smelt (Dryfoos smelt).

Isaacs-Kidd midwater trawls towed at 6 and 5.4 knots, respectively. The 6' IKMWT was used in Dryfoos' study and the 1965-1966 sampling. The 10' IKMWT has been used since 1967. The catch per unit effort values (1 C/E unit = # smelt caught per 10 min. tow with 6' or 10' IKMWT) are shown in Fig. 24 for the 6' net and in Fig. 25 for the 10' net. The age in months is based on March as month 0, following Dryfoos' convention. Unfortunately, few samples were taken of the 1964 and 1965 year classes. Enough samples of the 1966 year class were taken to know that in that year the smelt population showed a significant increase. The odd-numbered year classes, the 1967 and 1969 year classes, have not shown an increase but remain at approximately the same level. The 1968 year class was at a high level and the 1970 year class appears as though it, too, will be strong. The cyclic nature of the smelt population is reflected in the average lengths of the adults as shown in Table 9. The adults of odd-numbered year classes (low abundance) are larger than adults of corresponding ages from adjacent even-numbered year classes (high abundance).

During Dryfoos' study, while the smelt population was low, the population of the primary smelt food item, the mysid *Neomysis awatchensis*, was at a high level. In 1968, the mysid population had dropped to a low level while the smelt population was high (Fig. 26). The 1962-64 mysid catches are based on Dryfoos' catches with the 6' IKMWT while the 1968-70 mysid catches are based on catches with the 10' IKMWT. To calculate mysids/100m^3, the area of the opening of the 1/2" mesh liner was multiplied by the distance traveled by the net in a 10 minute tow and divided

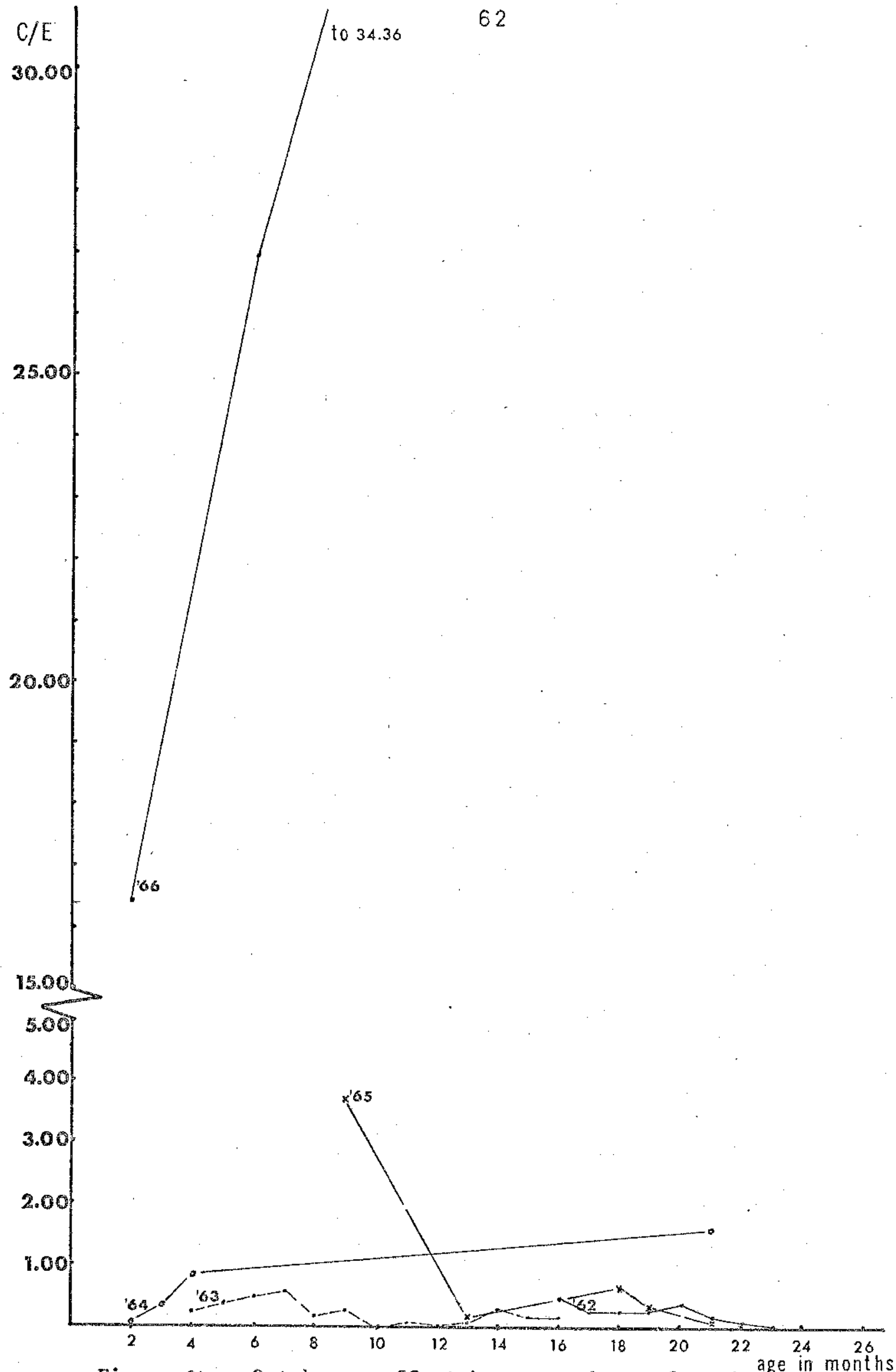


Figure 24. Catch per effort by year class of smelt according to age in months (6' IKMWT).

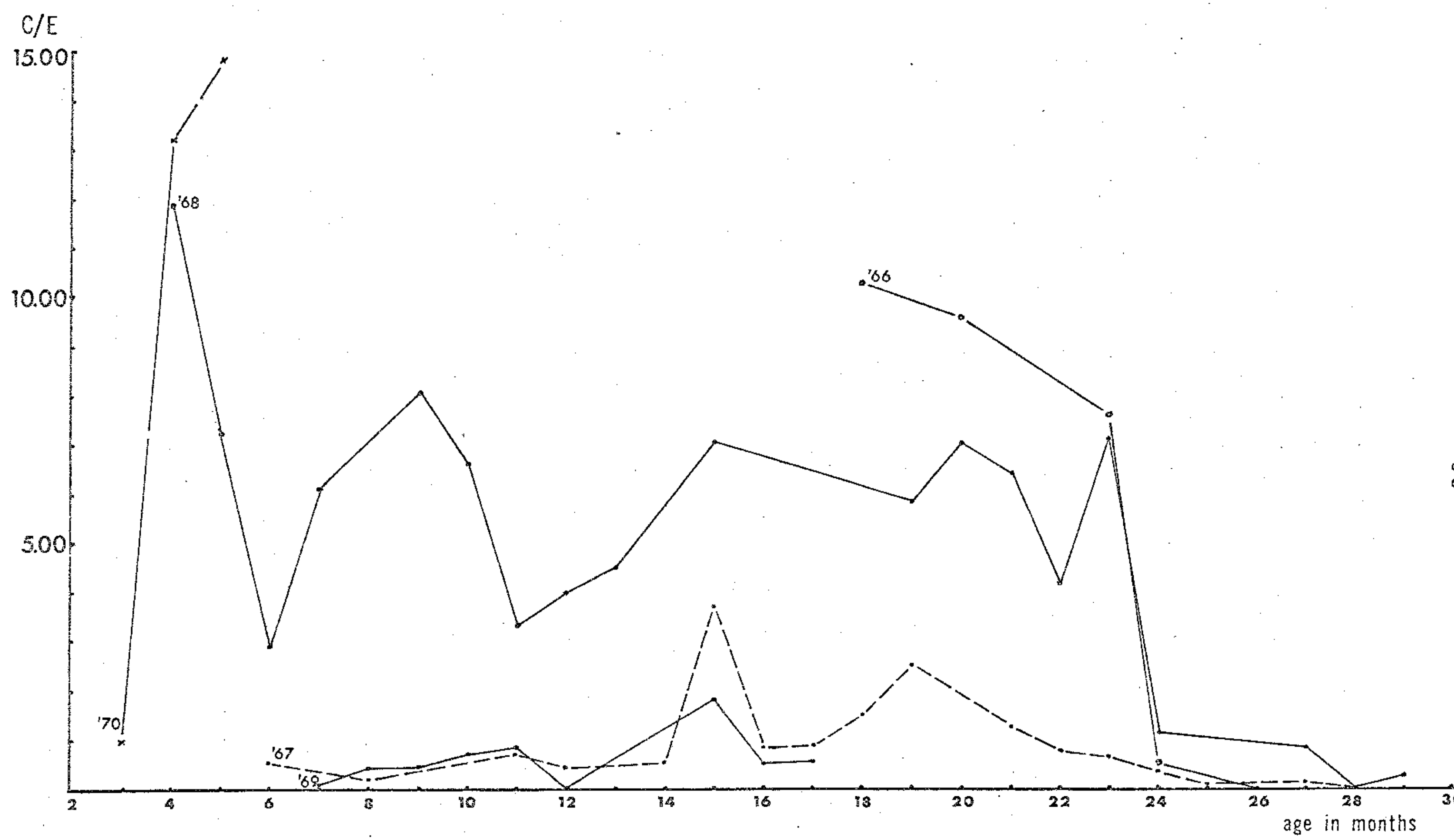


Figure 25. Catch per effort by year class of smelt according to age in months (10' IKMWT).

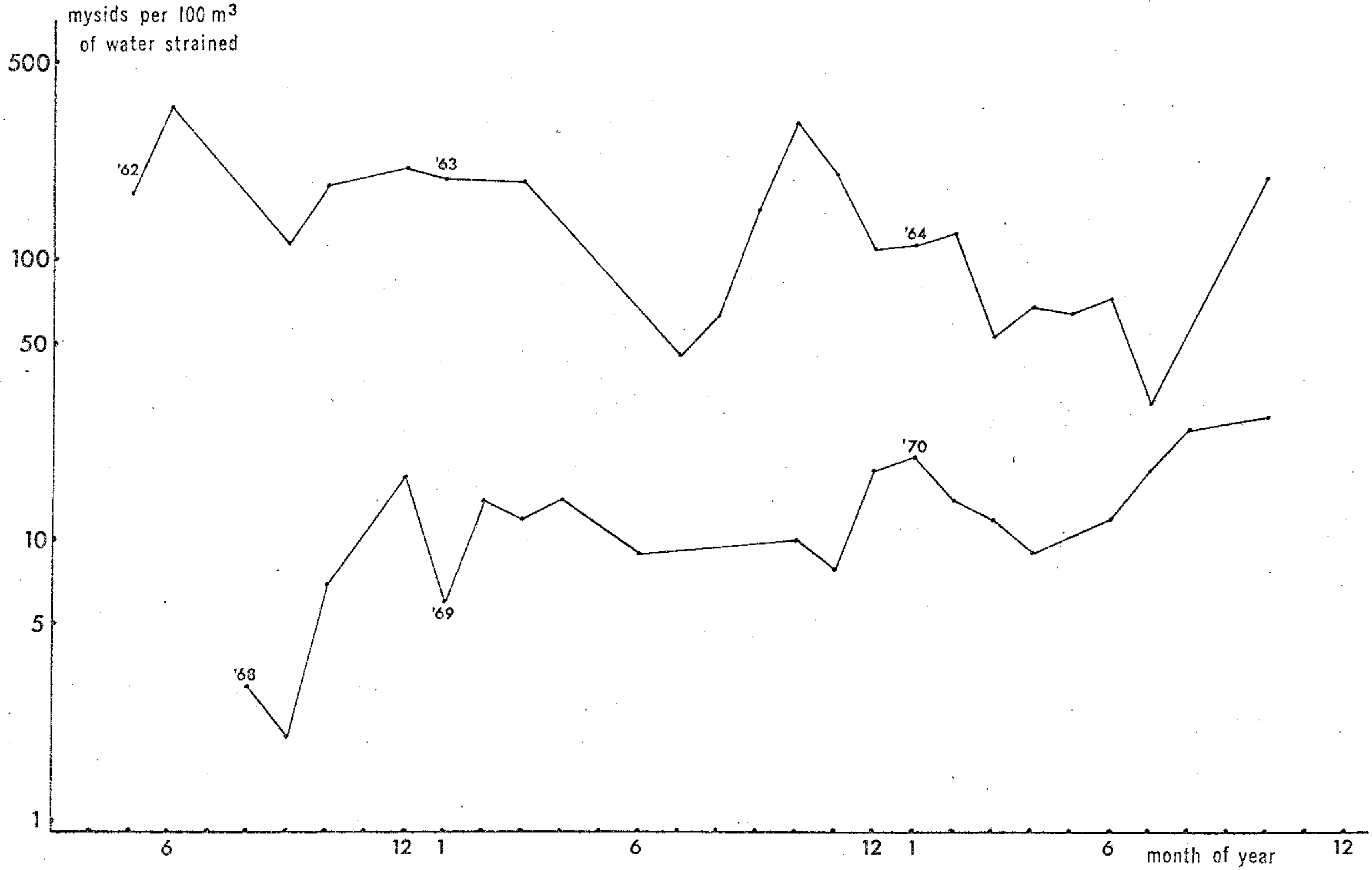


Figure 26. Monthly Neomysis catches by year based on the number of mysids caught per 100 m^3 of water strained by net.

into the number of mysids caught in the haul. The 1962-64 mysid catches were recorded as milliliters of mysids caught per tow and later converted to mysids per tow by multiplying by the number of mysids per ml. The 1968-70 mysid catches were estimated visually for each tow. Only tows in which mysids were caught were used in estimating the population levels.

The decrease in the mysid population from 1964 to 1968 forced the smelt into competition with the young sockeye salmon for smaller food organisms, such as Epishura and Diaphanosoma (J. C. Woodey, personal communication). This interspecific competition for the smaller food organisms and the intraspecific competition for the remaining mysids probably led to the size reduction and decreasing length-weight relationship of the smelt. In 1970, with the adult smelt population at a low level (Fig. 25, 1969 year class) the mysid abundance appears to be increasing. The adult smelt present are much larger than smelt of a comparable age from recent year-classes (Table 9).

The vertebral anomalies described by Dryfoos also appear to have declined during the period of increasing abundance. Only one smelt with a noticeable vertebral anomaly was taken in a total of 2011 smelt in the 1970 spawners. Dryfoos found a 21.6% occurrence in 999 smelt. No smelt were X-rayed for a thorough examination for the two types of anomalies described by Dryfoos, but the frequency of the more severe defects apparent to the eye was considerably reduced.

SUMMARY AND DISCUSSION

The longfin smelt in Lake Washington spawned in at least four tributaries to the lake in 1970. These tributaries were Juanita Creek, May Creek, Coal Creek and the Cedar River. Of these four spawning areas, the Cedar River is the most important, the others being relatively minor and possibly the result of straying by individuals from the Cedar River population. The northern spawning area, Juanita Creek, may be of greater importance than the other two creeks. In the creeks, spawning was confined to the lower quarter mile while in the Cedar River spawning occurred in the lower 1.25 mile. Egg fertilization in the Cedar River was high, 87.8%.

The 1970 spawning run extended from at least mid-January through mid-April with the major spawning period between late February and late March. The peak of the run was around March 17. The major run occurred as the river temperature increased from 4.4 to 7.2°C, similar to the range reported for *Osmerus mordax* (McKenzie, 1964) and *Thaleichthys pacificus* (Smith and Saalfeld, 1955). The 1969 smelt catches were also taken in this temperature range. The rising temperature could determine the timing of the spawning run with daily fluctuations of spawning intensity determined by the water flow.

Early in the run, smelt ascended the river within three hours after darkness; later the main migration was between four and six hours after darkness. The males ascended first, between 1800 and 2400 with the females running later, between 2100 and

0300. Spawning appeared to occur between about 2200 and 0500. The females dropped out of the river after spawning while the males remained on the spawning grounds until dawn. One exception to this was reported in 1969 when Mr. Robert Brown of Renton reported seeing smelt in the river about three miles upstream during the middle of the day. In 1970 there was no evidence of smelt in the river during the day and no evidence of smelt above 1.25 mile despite repeated attempts to detect such occurrences.

The females appear to spawn completely on their first migration to the spawning grounds. The males may return to the river several times in the season, thus weighting the sex ratio in favor of the males on a given night. A few spawn-out females may return. The sex ratio approached 1:1 at the peak of the run indicating the females may show a greater specificity for spawning conditions, such as temperature and water flow, than the males. The average lengths of both males and females decreased as the run progressed, a phenomenon described for *Osmerus mordax* as well. The males are larger than the females, unlike *Osmerus mordax* where the reverse is true. The ripe females show a higher condition factor than the males, a reflection of the ripe ovaries. Virtually all smelt appeared to die after spawning. A few sterile individuals may remain in the lake until early summer when they also disappear from the catches. A small percentage may mature in their third year in some year classes. These fish show no indication of having spawned previously. The smelt in Lake Washington is essentially a two year fish. There had been no indication of survival to three years until several age II fish were taken in August and October, 1970. It is possible that the odd-numbered and even-numbered year classes are reproductively isolated thus forming two distinct populations. This could be determined through further studies of the spawning populations.

There is some evidence to suggest that numbers of smelt eggs are eaten by small stream-dwelling cottids. The congregating adult smelt are preyed upon primarily by northern squawfish off the mouth of the Cedar River. Large numbers of sockeye fry are entering the lake from the Cedar River during the smelt spawning run so predators feeding on sockeye fry may also take smelt.

Egg development was recorded photographically. The artificially fertilized eggs showed a high percentage of abnormal development, possibly the result of polyspermy. The abnormal development was not found in naturally spawned eggs. Development took 25 days at a temperature range of 9.6-10.6°C. This is equivalent ot 253 Centigrade temperature units as compared to 280 C.t.u. in Dryfoos' study. A mild agitation is required to initiate hatching, but in the natural environment of the stream bed, this presents no problem. In the natural environment, the larvae are minutes away from the lake at hatching, thus they are potentially in a feeding situation shortly after emerging. The captive larvae were quite active during the first six days after hatching while the yolk was being absorbed. After this time the larvae weakened and died by the tenth or eleventh days.

The 1966 year class of smelt showed a remarkable increase in abundance. At this time, the mysid population, principal food organism of the smelt, went through a significant decrease in abundance. Dryfoos found in his food analysis that a smelt in its second summer and fall contained an average of 5 mysids on any given day of fishing. During the peak smelt abundance, an average of 34 smelt were caught per tow with the 6' IKMWT. This is equivalent to 0.55 smelt per 100 m^3 of water strained by the net. If this is assumed to represent the populaton level of the smelt in 1966-67, then in one night 2.75 mysids per 100 m^3 of water could be taken and in one month 82.5 mysids per 100 m^3 could be taken. From Fig. 26, it can be seen that a mortality of this magnitude could reduce the mysid population significantly during the summer months. The greatest abundance was less than 500 mysids per 100 m^3. There was an apparent decline from 1962 to 1963 and 1964 to a level around 75 mysids per 100 m^3. Data are lacking between 1964 and 1968, but considering the predation estimates just presented, it is possible the smelt have been responsible for the reduction in the mysid abundance. In 1970, with the adult smelt at a low level of abundance, the mysids appear to be increasing in numbers. Nothing is known about other mortalities affecting the mysid population or the reproductive rate of the mysids in Lake Washington, so these factors have not been considered.

The indication is that the large smelt population in 1966-68 reduced the mysid population. The smelt were then forced to compete intraspecifically for the remaining mysids or switch to smaller food organisms, which increased the interspecific competition with the sockeye salmon. The average size of the smelt decreased during this period of increased competition. This increased competition could have led to the reduction in the frequency of vertebral anomalies found by Dryfoos as the deformed individuals were probably unable to compete successfully for food and were more vulnerable to predation.

All sewage was diverted from the southern region of the lake in 1963 (W. T. Edmondson, personal communication). The occurrence of the vertebral deformities was 27% in 1961, 31% in 1962, 14% in 1963 and 3% in 1964 (Dryfoos, 1965). If the deformities were environmentally determined, it is possible that whatever had been affecting the development of the vertebrae may have been eliminated with the sewage diversion. If the deformities were genetically determined, they should still be detectable in the population, though the more severe deformities would have been eliminated.

The increase in abundance in the 1966 year class widened the difference between the odd-numbered year classes and even-numbered year classes. The even-numbered year classes have remained at a high level while the odd-numbered year classes have not shown an increase. The 1968 year class was about 5 times as abundant as the 1967 and 1969 year classes while the 1966 year class was almost twice as abundant as the 1968 year class. The reason for the sudden increase in abundance is not readily apparent. At the time, the lake was undergoing changes in productivity as a result of the diversion of treated sewage from the lake. A combination of ideal spawning and incubating conditions with an improving nursery area may have led to the increase. Later year classes did not show this response, so it is possible that (1) these later year classes reached the new carrying capacity of the lake and have not been able to increase or (2) the increase may not have been caused by some permanent change but a combination of conditions leading to abnormally high survival of eggs and larvae.

The Lake Washington smelt could prove to be a useful indicator species (Larkin and Northcote, 1969), as it has already responded to some of the changes in the lake environment. Unfortunately, the lack of samples from the 1964 and 1965 year classes has caused an important gap in the data. For the past few years the smelt data have been a by-product of sockeye salmon research. Now that the smelt can be readily caught during their spawning run, the dependency on the previous source of data has been reduced. By monitoring the smelt spawning run each year, one can detect fluctuations in abundance, condition, size of the fish, and other changes in the population which may occur.

This study has uncovered many questions suggesting further studies related to the Lake Washington smelt. A more detailed study of the minor spawning areas would be desirable to see how much each one contributes to the smelt population. There is the possibility that each one supports a separate population. A more rigorous study of the relationship between the smelt spawning run and water flow could indicate if there really is a relationship between the two. The movements of the larval smelt after they have hatched and entered the lake are not known; there is no information on the larvae between the ages of 0 and 3 months. The horizontal migration patterns in the lake have not been described. The sockeye salmon show a typical migration pattern every year (J. C. Woodey, personal communication) and it is possible the smelt also respond in a similar manner. Little can be said about smelt migratory behavior without knowing something about the mysid movements and life history. At present there is no information on mysid reproductive rates, feeding habits, growth rates, or mortality factors other than those due to smelt. With the increase in abundance of both smelt and sockeye, one would also expect the predator populations to show a marked increase; studies of the predatory populations are thus desirable. Another possible study would be to examine more closely the smelt collected from 1967-70, using X-ray techniques for example, to see if the type I and II vertebral anomalies described by Dryfoos are still present in the population. It is possible that the more severely deformed, more noticeable individuals have been eliminated while less severely deformed individuals are able to survive.

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APPENDIX I

Record of 1969 Cedar River Smelt Hauls by Net fished from Boeing Bridge

Date	Time	# Smelt	# Salmon Fry	Other
15/2/69	1525-1545	-	1	-
	1848-1905	-	31	-
	1910-1926	-	30	-
	1929-1944	-	35	1 cottid 1 brook lamprey 1 6" rb. trout
	1946-2001	-	32	1 brook lamprey 1 3" rb. trout
	2003-2018	-	48	-
	2020-2035	1 male	53	1 brook lamprey
	2040-2055	-	67	-
	2057-2112	1 male	70	-
	2115-2130	-	109	1 cottid
	2132-2147	-	97	-
	2150-2205	-	113	-
20/2/69	2148-2202	-	163	1 cottid
	2205-2220	1 male	200	1 brook lamprey
	2222-2237	-	150	-
	2240-2255	-	175	1 yrlng coho
	2300-2315	1 female	224	1 yrlng coho 1 stickleback
	2320-2335	1 male	200	-
	2338-2353	-	250	-
	2356-0011	2 males	200	-

APPENDIX I (cont.)

Date	Time	# Smelt	# Salmon Fry	Other
20/2/69 (cont.)	0015-0030	1 female	164	-
	0035-0050	1 female	200	-
	0053-0108	-	150	-
	0111-0126	-	150	-
	0129-0144	-	117	-
	0145-0200	-	100	-
23/2/69	0207-0222	-	107	-
	0225-0240	-	76	1 2.5 lb. trout
	0242-0257	-	101	-
	0300-0315	-	78	1 yrlng coho
	0320-0335	-	56	-
	0338-0348	-	73	-
	0350-0405	-	78	-
	0408-0423	-	-	1 beaver
	0428-0443	-	63	-
	0447-0502	-	78	-
	0505-0520	-	61	-
	0522-0537	-	58	-
7/3/69	2040-2055	1 male	225	-
	2100-2115	-	225	-
	2118-2133	-	225	-
	2136-2151	1 male	150	-
	2154-2209	1 male	200	-
	2212-2227	3 males	300	-

APPENDIX I (cont.)

Date	Time	# Smelt	# Salmon Fry	Other
7/3/69 (cont.)	2230-2245	1 male	40	-
	2247-2302	-	500	-
	2305-2320	-	450	-
	2322-2337	-	450	-
	2340-2355	1 male	500	-
	2357-0012	1 male	450	-
	0015-0030	-	500	-
	0032-0047	1 male	400	-
	0050-0105	1 male	375	-

APPENDIX II

Fyke Net Catches of Smelt off the Mouth of the Cedar River, 1970

Date	Time	# Males	# ripe Females	# spawn-out Females	Total	Others
26/2/70	1800 -2100	13	11	1	25	-
2/3/70	1800 -2100	50	12	5	67	1 squawfish 1 cottid
	2100 -2400	6	1	0	7	1 coho smolt
	0000 -0300	1	13	1	15	7 coho smolts
	0300 -0600	12	0	7	19	-
3/3/70	0600 -0900	1	0	0	1	1 coho smolt
	0900 -1200	0	0	0	0	-
	1200 -1500	0	0	0	0	12 coho smolts
	1500 -1800	0	0	0	0	-
	1800 -2100	31	20	1	52	6 coho smolts
4/3/70	1800 -2100	19	10	2	31	1 coho smolt
5/3/70	1800 -2100	51	37	2	90	1 squawfish

APPENDIX II (cont.)

Date	Time	# Males	# ripe Females	# spawn-out Females	Total	Others
6/3/70	1800 -2100	52	18	1	71	-
9/3/70	1500 -1800	0	0	0	0	-
	1800 -2100	15	8	0	23	-
	2100 -2400	3	3	1	7	-
	0000 -0300	6	7	0	13	1 coho smolt
	0300 -0600	4	0	0	4	1 rb. trout 2 coho smolts
10/3/70	0700 -0900	0	0	0	0	2 coho smolts
	0900 -1200	0	0	0	0	2 coho smolts
	1200 -1500	0	0	0	0	-
	1500 -1800	0	0	0	0	-
	1800 -2100	61	15	2	79	1 cottid
	2100 -2400	59	31	3	93	-
17/3/70	1800 -2100	78	27	13	118	1 coho smolt
	2100 -2400	262	162	45	469	1 rb. trout

APPENDIX II (cont.)

Date	Time	# Males	# ripe Females	# spawn-out Females	Total	Others
17/3/70 (cont.)	0000 -0300	58	89	14	161	-
	0300 -0600	2	1	0	3	2 coho smolts
25/3/70	1800 -2100	36	6	3	45	2 cottids
	2100 -2400	227	46	16	289	-
	0000 -0600	6	11	5	22	-
1/4/70	1800 -2100	2	1	0	3	-
	2100 -2400	1	0	0	1	2 peamouth 1 sucker
	0000 -0300	3	2	0	5	1 sucker
	0300 -0600	11	1	1	13	1 squawfish 1 coho smolt
15/4/70	1800 -2100	0	0	0	0	-
	2100 -2400	8	1	0	9	2 squawfish

APPENDIX III

Catch by Fyke Net under Bridge at Mouth of

Cedar River 9/3/70-10/3/70

Haul	Time	# Males	# ripe Females	# spawn-out Females	Total
1	1800-1900	0	0	0	0
2	1900-2000	3	1	0	4
3	2000-2100	0	0	0	0
4	2100-2200	1	0	0	1
5	2200-2300	0	0	0	0
6	2300-2400	1	2	2	5
7	0000-0100	0	0	0	0
8	0100-0200	0	1	3	4
9	0200-0300	0	0	4	4
10	0300-0400	3	0	11	14
11	0400-0500	94	0	11	105
12	0500-0600	90	0	9	99
13	0600-0700	32	0	2	34
14	0700-0900	0	0	0	0
15	0900-1200	0	0	0	0
	Totals	224	4	42	270

APPENDIX IV

Average Lengths, Weights, and Condition Factor by Catch Date

Male Smelt

Date	n	Length	Weight	K[a]
26/2/70	16	108.4 mm.	14.28 gm.	1.121
2/3/70	67	107.8	14.80	1.181
3/3/70	31	107.9	14.73	1.171
4/3/70	19	108.7	15.64	1.218
5/3/70	47	108.9	15.09	1.168
6/3/70	52	107.4	14.97	1.207
9/3/70	21	106.8	14.17	1.163
10/3/70	85	107.6	15.11	1.213
17/3/70	149	106.8	14.14	1.160
25/3/70	92	106.4	14.10	1.171
15/4/70	7	103.7	13.57	1.217

Female Smelt

Date	n	Length	Weight	K[a]
26/2/70	14	104.9	13.44	1.166
2/3/70	21	103.0	14.21	1.300
3/3/70	20	102.8	13.74	1.265
4/3/70	10	104.1	14.95	1.325
5/3/70	34	102.9	13.96	1.280
6/3/70	18	101.2	13.39	1.293
9/3/70	15	103.4	13.90	1.257
10/3/70	35	102.8	13.66	1.256

APPENDIX IV (cont.)

Female Smelt (cont.)

Date	n	Length	Weight	K[a]
17/3/70	55	101.6	12.33	1.177
25/3/70	40	100.3	12.12	1.201
spawn-out females	76	103.6	10.27	0.923

[a] $K = W \times 10^5 / L^3$ W = weight in grams

L = length in millimeters

(Carlander, 1969)

APPENDIX V

Gill Net Catches off the Cedar River

Date	Time	Feet of Net	Depth of Set	# Squawfish[a]	# Largescale[b] Suckers	# Peamouth[c]	Others
28/1/70	2030-0025	100 ft.	40-50 ft.	0	2	0	0
29/1/70	1400-2100	500	10-60	22	54	20	5 rb. trout 1 yellow perch
6/2/70	0030-0330	200	25-60	2	6	2	2 rb. trout
12/2/70	0545-0900	200	40-60	9	20	0	0
9/3/70	1800-2100	200	40-60	7	29	9	1 black crappie
10/3/70	1315-1615	200	20-40	1	14	0	1 male smelt
	0940-1200	100	12	0	2	0	0
	1200-1500	100	12	0	1	0	0
15/4/70	1930-2300	200	40-60	15	13	4	0

[a] *Ptychocheilus oregonensis* (Richardson)

[b] *Catostomus macrocheilus* Girard

[c] *Mylocheilus caurinus* (Richardson)

204 Fisheries Center
University of Washington
Seattle, Washington
January 22, 1971

Mr. Donald E. Kauffman
Room 115
General Administration Bldg.
Olympia, Washington 98501

Dear Mr. Kauffman:

Regarding your letter of December 20, 1970, I have to confess that I have no additional data on sockeye aside from those listed in Appendix I in my thesis on the Lake Washington smelt. These data were submitted to your office in 1969, so they are not really a new contribution. In my 1970 study on the smelt, the gear did not catch the sockeye fry as the mesh of the trap nets used was too large to retain fish of this size. This factor was one of the criteria I used when selecting the nets as I did not wish to duplicate the large sockeye fry catches of 1969. The nets were successful in meeting this objective as no sockeye of any size were taken; the somewhat unfortunate result is that there is no additional data on the sockeye. During the study, however, several samples of approximately fifty sockeye fry each were collected with a dip net from the bridge at the mouth of the Cedar River as the fry were entering the lake. These samples were taken for or by James Woodey and his findings will undoubtedly be covered in his report.

Thank you for your kind comments on the thesis.

Very truly yours,

Lawrence L. Moulton

Lawrence L. Moulton

106 Fisheries Center
University of Washington
Seattle, Washington
December 4, 1970

Washington Dept. of Fisheries
115 Gen. Administration Bldg.
Olympia, Washington

Dear Mr. Kauffman:

Enclosed is a copy of my recently completed thesis on the Lake Washington smelt spawning run. I hope you will accept it as the report of the list of species caught as required under the terms of the scientific collector's permit. In addition, it adds considerable information on the life history of one of the fish populations under the Department's jurisdiction.

Very truly yours,

Lawrence L. Moulton

Lawrence L. Moulton