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ECOLOGY AND LIFE HISTORY
OF
PINK SALMON (Oncorhynchus gorbuscha) IN SELECTED
MICHIGAN TRIBUTARIES TO LAKE SUPERIOR

By

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A THESIS

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TABLE OF CONTENTS

	Page
List of Tables	v
List of Figures	vi
List of Appendices	vii
Introduction	1
Study Sites	5
Methods	8
Fall Sampling of Adults	8
Winter Sampling	12
Spring Sampling	13
Results	17
Fall	17
Fecundity, Egg Retention and Deposition.....	21
Winter	23
Spring	27
Hourly Migration	27
Emergence	29
Daily Migration	29
Rate of Migration	32
Horizontal Distribution - 1983	35
Stomach Analysis	37
Length and Weight	37
Harlow Creek	38

Discussion	40
Fall Sampling	40
Vital Statistics	44
Three-year-old pink salmon	45
Overwinter survival	47
Spring outmigration	48
Emergence	48
Hourly Migration	50
Stream Residency	50
Daily Migration	52
Summary	54
References	56

LIST OF TABLES

	Page
Table 1. Mean length and weight, numbers and percentages of adult pink salmon by age and sex from Lake Superior tributaries in the upper peninsula of Michigan - 1982 and 1983.....	18
Table 2. Average stream velocity and numbers of pink salmon fry captured from the Laughing Whitefish River - 1983 and 1984.....	33
Table 3. Streamflow and numbers of pink salmon fry taken in May 1983 on the Laughing Whitefish River using wire fry traps.....	36
Table 4. Mean length and weight of pink salmon fry from Lake Superior tributaries in the upper peninsula of Michigan - 1982, 1983 and 1984.....	39

LIST OF FIGURES

	Page
Figure 1. Location of the Carp River, Harlow Creek, and the Laughing Whitefish River along the south shore of Lake Superior in Michigan's upper peninsula.....	7
Figure 2. Diel pattern of downstream migration of pink salmon fry in the Laughing Whitefish River - 1983 and 1984.....	28
Figure 3. Numbers of pink salmon fry caught in emergent fry traps on the Laughing Whitefish River - 1984.....	30
Figure 4. Daily numbers of pink salmon fry migrating downstream in the Laughing Whitefish River - 1983 and 1984.....	31
Figure 5. Relationship between day of migration and cumulative percent of outmigrating pink salmon fry from the Laughing Whitefish River - 1983 and 1984.....	34

LIST OF APPENDICES

	Page
Appendix 1. Wire fry trap used to determine down-stream migration of pink salmon fry - 1983 and 1984	61
Appendix 2. A list of the non-target species caught in the wier/trap nets in the fall of 1982 and 1983 on the Laughing Whitefish River	62
Appendix 3. Data from redd sampling conducted in winter 1982-1983 and 1983-1984	63

ABSTRACT

ECOLOGY AND LIFE HISTORY OF PINK SALMON (Oncorhynchus gorbuscha) IN SEVERAL TRIBUTARIES TO LAKE SUPERIOR

By

Mark Steven Bagdovitz

Adult and juvenile pink salmon (Oncorhynchus gorbuscha) were studied in 3 Michigan tributaries to Lake Superior to determine relative abundance, vital statistics, overwinter survival and patterns of fry outmigration. Numbers of pink salmon spawning during odd-years in tributaries to Lake Superior have declined precipitously since 1979. The odd-year run is slightly dominant as compared to the even-year run but greatly reduced from levels seen in 1979. Approximately 90% of the adults mature as 2-year olds while the remaining 10% mature as 3-year olds. Two-year-old pink salmon average 390 mm in length which is about 30% smaller than 2-year olds in their native range. Overwinter survival of eggs and alevins indicates higher survival during the 1982-1983 winter than the 1983-1984 winter. Fry outmigration starts in the first week of May and was completed by the third week. Pink salmon fry move downstream during the first 4 hours of darkness immediately after emergence. Percent survival of fry from egg deposition to outmigration is 3.5% for the 1982 year class and 0.8% for the 1983 year class.

INTRODUCTION

Pink salmon (Oncorhynchus gorbuscha) are one of 5 species of salmon that inhabit the eastern Pacific Ocean. In North America, pink salmon range from the Sacramento River north to the Mackenzie River delta (Scott and Crossman 1979). They are the smallest of the Pacific salmon, usually reaching 3 to 5 pounds at maturity. Mature adults ascend coastal streams from July to September to spawn. Throughout this region they have a strict 2-year life cycle resulting in predictable and highly segregated even-numbered year and odd-numbered year spawning runs.

Pink salmon were accidentally stocked into Lake Superior in 1956 (Shumacher and Eddy 1960) and became the first species of Pacific salmon to be successfully introduced into the Great Lakes. Survival and proliferation of this species in freshwater has been something of an enigma. No self-sustaining populations of freshwater pink salmon have been reported from the west coast. Rounsefell (1958) termed it an "obligatory anadromous" species requiring some period of time in a marine environment in order to mature. Thus, completion of the pink salmon life cycle in freshwater was unexpected and is unique to the Great Lakes. Since the original stocking, from Thunder Bay, Ontario, abundance and range of pink salmon has increased throughout

Lake Superior (Shumacher and Hale 1962, Lawrie and Rahrer 1972) and the other Great Lakes (Collins 1975, Kwain and Lawrie 1981, Wagner and Stauffer 1982).

The accidental stocking of 21,000 fry into Lake Superior was very small as compared to the deliberate attempts to introduce pink salmon into the Atlantic Ocean off the coast of Maine (30 million fry) (Bigelow and Schroder 1953), in Newfoundland (12 million fry) (Lear 1975) and in Hudson Bay (738,000 fry) (Ricker and Loftus 1968). None of these intentional introductions produced a self-sustaining population of pink salmon. Currently, pink salmon are not stocked by any state or federal management agency in the Great Lakes basin and are a totally self-sustaining species.

Pink salmon were first noticed in Michigan tributaries in 1967 (Wagner and Stauffer 1982). Two years later, less than 100 were seen in 3 Michigan tributaries to Lake Superior. In 1971, they were common (100-999) in 4 of 10 tributaries in which they were observed. The numbers of streams in which pink salmon were seen doubled in 1973 and redoubled in 1975. There was an overall increase in numbers along with the increase in distribution. It was during this time of increasing abundance (1976) that an even-year run of pink salmon was observed in eastern Lake Superior (Kwain and Chappel 1978). Since there are no known introductions of even-year pink salmon in the Great Lakes, the question of how this run may have started was

answered by Wagner (1978) who reported a 3-year-old female taken from the Carp River, a tributary to Lake Superior in Marquette County, Michigan. The presence of 3-year-old pink salmon in Lake Superior is thought to be a result of the cold, oligotrophic nature of the lake delaying maturity until the third year (Wagner and Stauffer 1980). These late maturing fish probably provided the initial even-year spawning stock present in the Great Lakes.

By 1978, there were adult pink salmon spawning in both even and odd-years, with the odd-year run showing extreme dominance (Wagner and Stauffer 1982). By 1979, the number of streams used for spawning again increased and the increase in abundance was phenomenal. Observers from the Michigan Department of Natural Resources estimated the 1979 population to be 10 to 20 times that of previous years. It was during this year several Lake Superior tributaries were estimated to have more than 10,000 adult pink salmon during the spawning run.

Pink salmon have become a permanent part of the fish community in Lake Superior. Despite being present in the Great Lakes for the last 28 years, the potential of this species to become a component of the sport or commercial fisheries is unknown. As a prerequisite to the management of any fish population, information on its ecology and life history are essential. While there exists voluminous data on west coast pink salmon stocks, very little is available

for the Great Lakes.

This research was undertaken to provide information on the ecology and life history of pink salmon in the Michigan tributaries to Lake Superior. Data on the population structure of adults, overwinter survival of eggs and alevins and fry outmigration will provide baseline information for future management and research on pink salmon in the Great Lakes. In addition, the results of this research may provide new insights into the ecology of pink salmon stocks of the North Pacific.

The specific objectives for this research were to:

- 1). Estimate relative abundance of adult pink salmon in selected Lake Superior tributaries in the upper peninsula of Michigan.
- 2). Determine adult age, length, weight, growth, fecundity and sex ratio.
- 3). Estimate egg deposition and survival.
- 4). Monitor larval development, survival, and outmigration.
- 5). Estimate relative year-class strength of successive generations of fry.

STUDY SITES

The principal study site was the Laughing Whitefish River ($46^{\circ} 38' \text{N}$, $87^{\circ} 02' \text{W}$) located on the south shore of Lake Superior in Alger County, Michigan (Figure 1). This river was chosen because of location and it has been a Michigan Department of Natural Resources study site and data on pink salmon populations is available since 1973.

The river has 18 km of mainstream, 37 km of tributaries and drains approximately 60 km of forested upland (Brown 1944). The lower 400 meters of the river is primarily marsh and wetland and is characterized by abundant emergent and submergent vegetation and terrestrial woody debris. From the end of the marsh upstream for approximately 0.8 km, the substrate is exposed bedrock with intermittent gravel bars that provide limited spawning habitat for salmonids. At about 0.8 km and extending for 2.8 km upstream, the stream gradient decreases and the substrate is predominately sand and silt. Very little gravel is present and no salmonids have been observed spawning in this section (Paul Hannuksela, Michigan Department of Natural Resources, Marquette Fisheries Research Station, personal communication). At 4 km upstream the gradient and velocity increase and the substrate changes to rock and gravel throughout much of the remaining river.

The principal spawning area is located approximately 4 km from the mouth and directly upstream from the wooden bridge on Point Road in Alger County. Previous observations indicate in the past 10 years, approximately 80 % or more of the spawning adults utilize this section (Paul Hannuksela, Michigan Department of Natural Resources, Marquette Fisheries Research Station, personal communication). As a result, this section (225 meters) was designated as the primary study site. Other sections of the Laughing Whitefish River were monitored during the fall for spawning adults to evaluate the extent of reproductive activity outside this area.

Four other Lake Superior tributaries served as additional sites for data collection. These included Harlow Creek (46° 38'N, 87° 28'W), Carp River (46° 38'N, 87° 20'W), and the Little Garlic River (46° 38'N, 87° 30'W) located in Marquette County and the Huron River (46° 54'N, 88° 02'W) located in Baraga County.

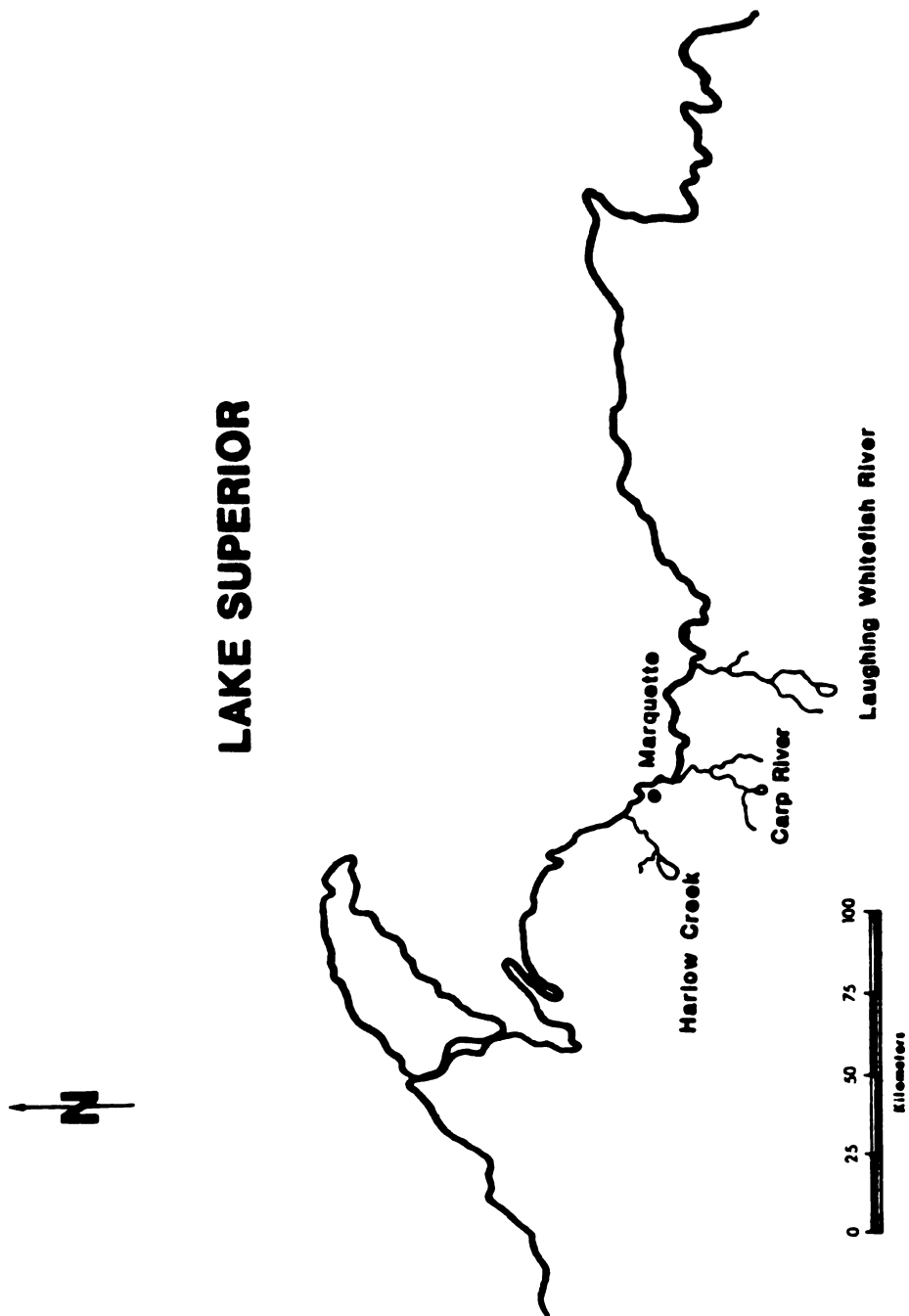


Figure 1. Location of the Carp River, Harlow Creek, and the Laughing Whitefish River along the south shore of Lake Superior in Michigan's upper peninsula.

METHODS

Fall Sampling of Adults

Relative abundance of adult pink salmon entering the Laughing Whitefish River was determined in the fall of 1982 and 1983.

In fall 1982, a weir consisting of a wire holding box, 3.05 m x 0.76 m x 1m (10'x 2.5'x 3'), and a mesh net lead, 30.5 m x 1 m x 38 mm (100' x 3' x 1.5"), was used to collect adult pink salmon. The weir was placed near the mouth of the river and directly upstream from the public boat launch located at the Laughing Whitefish River State Campground. The holding box was placed along the right bank with the lead line running to the opposite shore. With this system, migrating fish would encounter the net and follow the lead into the box. Fish captured at the first weir were marked and released to continue their upstream migration. A second weir, identical to the one described above, was placed 4 km upstream and directly below the spawning grounds. This weir was used to provide recapture data for a population estimate. Both weirs were checked daily for migrating fish. This system was in operation from 8 September to 25 September.

Periodic flooding and debris accumulation made operation of the weirs ineffective and difficult. On 18

September the 38 mm mesh lead was replaced on the downstream weir with a 64 mm (2.5") lead to reduce debris accumulation. Observations of the spawning grounds on 21 September indicated pink salmon to be actively spawning. Migrating pink salmon had obviously avoided or eluded the net, so on 25 September both weirs were removed.

To obtain a point estimate of the numbers of pink salmon present on the spawning grounds, a modified Petersen single census estimate (Ricker 1975) was employed. Capture of adult pink salmon was conducted 22 September with electro-fishing gear. All captured fish were marked (adipose clip) and released. Recapture data was obtained 23 September by electro-fishing on the spawning grounds.

Vital statistics recorded for each fish captured included length (mm), and sex. The weight of the adult pink salmon was not taken in 1982. Other tributaries were visually surveyed to approximate the size of the run throughout Michigan's upper peninsula.

All pink salmon caught were aged by their scales. Scales samples were taken from an area above the lateral line and below the first ray of the dorsal fin. Scales were mounted on a micro-fiche reader (Bell and Howell ABR 1020) and magnified at 67X. The magnified distances in the anterior field, from the focus to the first annulus, were measured and the number of circuli in the first year were counted. Scale measurements or circuli counts from any point along the scale to the edge are not valid due to

erosion of the scale margin. Scale erosion was evident in all fish but enough scale material remained for aging. A pink salmon that follows the normal 2-year life cycle lives through one winter after emergence from the redd; consequently one annular ring is formed. Likewise a 3-year-old pink salmon lives through two winters and forms two annuli.

Fecundity samples were taken from ripe females. Only eggs still encased in the ovarian sac were used to exclude egg counts from partially spawned fish. Egg retention estimates were taken from spent females collected on the spawning grounds. The number of eggs retained and total length of each female were noted. Egg retention was calculated by summing the number of eggs retained, dividing by the sum of the estimated fecundities and multiplying by 100.

Due to the ineffectiveness of the weir system used in 1982, 2 trap nets (51 mm stretch) were used in 1983. It was thought this would be more efficient in capturing pink salmon and better suited to the effects of high water. The first trap was placed in the same position as the weir in 1982 with the leads extending to each bank. The second trap was placed approximately 25 meters upstream from the first. The second trap was used to capture fish that may have avoided the first trap. Both traps were checked once in the morning and evening for migrating fish.

This system was in operation from 7 September to 19 September. During this time only 1 pink salmon entered the

first trap while no pink salmon were caught in the second. While the traps were in operation, 6 to 10 pink salmon were seen congregating near the opening of the first trap. On 19 September, when it was apparent pink salmon were not going to enter the traps, they were removed and adults allowed to migrate upstream.

A population estimate using a modified Petersen single census estimate was again used to determine relative numbers of adults present within the spawning area. All pink salmon were caught with electro-fishing gear. The marking run was conducted on 22 September with the recapture run occurring on 23 September. All fish captured 22 September were marked (adipose clip) and released. An additional collection of adults was made 27 September. Vital statistics recorded for each fish captured 23 and 27 September included length (mm), weight (g), sex, spawning condition, and a scale sample for aging. Other tributaries were visually surveyed to estimate the size of the run throughout Michigan's upper peninsula.

To facilitate sampling of eggs and alevins during winter months, pink salmon redds were marked in the Huron, Carp and Laughing Whitefish Rivers and Harlow Creek in the fall of 1982 and 1983. Completed redds were marked with an iron stake placed in the stream bottom near the center of the redd. In addition, a piece of marking ribbon was placed on the nearest tree and the distance to the stake measured to the nearest centimeter.

Winter Sampling

Larval survival and development from fertilization to migration was determined by sampling redds from Harlow Creek, Huron, Carp and Laughing Whitefish Rivers in the winter of 1982-1983; and Harlow Creek, Carp, Little Garlic and Laughing Whitefish Rivers in the winter of 1983-1984.

In 1982, 2 methods were used to sample eggs and alevins. Redds were manually excavated using a shovel with eggs and alevins being swept from the gravel into a 3.05 m x 1 m x 3.1 mm (10' x 3' x 1/8") seine placed directly downstream from the redd. A depletion sampler (.5 m x .5 m x .7 m) was used in conjunction with a water pump to remove eggs and alevins from the gravel. The depletion sampler consisted of a rectangular screened box with a 3.1 mm (1/8") mesh catch bag attached to the side. Sampling was initiated by placing the depletion sampler over the redd, with the catch bag facing upstream, and forcing water from the pump into the gravel. Eggs and alevins were dislodged from the gravel and floated downstream into the catch bag.

Due to difficulties in operation of the depletion sampler and the water pump, especially in winter, all but 4 redd samples were taken by excavating the redd with a shovel. For each method, pink salmon eggs and alevins were sorted from the debris and stored in 5% formalin. Numbers of live and dead eggs and alevins were determined by direct observation. Dead eggs appeared white or milky while live eggs were usually orange or red.

Spring Sampling

Data on outmigrating pink salmon fry from stream spawning areas into Lake Superior were collected in spring 1983 and 1984.

In the spring of 1983, sampling of pink salmon fry took place on the Laughing Whitefish River and Harlow Creek.

Sampling methods on the Laughing Whitefish River included a single drift net and 3 wire fry traps (.45 m x .91 m) (Tait and Kirkwood 1962, Appendix 1). The drift net was used to examine hourly and daily migration patterns and wire fry traps were used to evaluate horizontal distribution of migrating fry.

The drift net used on the Laughing Whitefish River consisted of a 3.1 mm (1/8") mesh bag net mounted on a 61 mm x 76 mm (24" x 30") rectangular frame. The net and frame was suspended in the water column by two pieces of steel conduit. The drift net was supported by placing it against a bridge located downstream from the spawning grounds. The frame was lowered down the conduit to sample the top 61 mm of the water column for migrating pink salmon. This 61 mm represented approximately 40 to 80% of the water column depending on water level. Organisms moving downstream, including pink salmon, entered the bag net and were prevented from escape by the force of the current. The net was emptied by sliding it up the conduit and untying the cod end of the bag. The contents were removed

and the bag was tied off and returned to the water. The entire emptying process took about 30 seconds to perform.

The drift net was placed in the Laughing Whitefish River 10 meters downstream from the end of the study section. The bridge spanning the river on Point Road was used to support the net. On each sampling date, a random sample of pink salmon fry were collected and preserved in 5% formalin for examination of length, weight and stomach contents. Remaining fry were returned to the stream.

Results of sampling conducted on the Laughing Whitefish River during spring 1982 indicated pink salmon fry moved out of the stream during evening and night time hours exclusively (Taylor and Bagdovitz 1983). Therefore, sampling in 1983 and 1984 was conducted between 20:00 and 08:00 hours.

From 17 to 23 May 1983, 3 wire fry traps was used, in the same downstream location as the drift net, to determine horizontal distribution of migrating pink salmon fry.

In order to sample 3 current velocities, the traps were placed in parallel fashion across the river to reduce interference from an adjacent trap. Traps were checked twice a day, once in the morning and once again in the evening. The amount of water sampled, in cubic meters, was determined from the area (m) sampled by each trap and daily flow (m/sec) measurements. From this, the volume of water sampled to collect 1 pink salmon was estimated. Stream

flow measurements were taken with a current meter, immediately upstream from the opening of each trap. All traps were removed 23 May when no more pink salmon were caught.

A series of 3 wire fry traps were used on Harlow Creek to evaluate numbers of downstream migrating pink salmon fry. One of the 3 traps was identical to the wire traps used on the Laughing Whitefish River (Appendix 1) while the other 2 were the same design but about 50% smaller (.32 m x .61 m). The traps were located 50 meters downstream from the Route 550 bridge where it crosses the creek. Traps were checked once daily at varying times from 20 April to 24 April and from 4 May to 23 May. The traps were not run from 25 April to 3 May because of high water.

In order to follow the migration pattern of pink salmon fry from gravel emergence downstream to the marsh and into Lake Superior, 3 types of nets were used in the spring of 1984 on the Laughing Whitefish River. No other rivers were sampled in the spring of 1984.

Six emergent fry traps (Phillips and Koski 1969) were placed over redds marked the previous fall to estimate timing of fry emergence from the gravel. Traps were checked 3 times a day, once at 20:00, 01:00 and 08:00 hours. Data was collected from only 5 of 6 redds due to vandalism to one of the nets.

A series of 3 drift nets, identical to the one used in 1983, were used to examine hourly and daily migration

patterns. These nets were set in the same location as in 1983 and were checked hourly from 20:00 to 08:00 starting 2 May and ending 23 May.

Wire fry traps were placed between the marsh and Lake Superior to collect fry that might be moving from the marsh directly into open water. These traps were checked twice a day at various times.

To determine if pink salmon fry reside in the stream, marsh or near shore areas of the lake after emergence, a 10.7 m x 3.1 mm (35' x 1/8") seine and a fine mesh dip net were used in these areas to collect pink salmon fry. Seining and dip netting was conducted both at night and during daylight hours in the marsh and along the shoreline. Seining in the stream was conducted during daylight hours. In the laboratory, fry were measured to the nearest millimeter and weighed to the nearest thousandth (.001) of a gram using an Ohaus balance (Brainweigh B300D).

In order to determine the extent of feeding by pink salmon prior to and during outmigration, a random sample of 100 fry captured in emergent fry traps and drift nets were used to examine gut contents. Length and date of capture of each fish was taken prior to dissection. Gastro-intestinal contents from the esophagel opening to the anal opening were examined using a binocular microscope.

RESULTS

Fall

The population estimate for the Laughing Whitefish River indicated the abundance of pink salmon in 1982 was similar to previous even-year runs. A total of 34 fish were caught and marked 22 September during the first electro-fishing run while 25 were caught during the second run conducted 23 September. Thirteen fish caught 23 September were marked. Using a modified Petersen estimate, 65 (95% CF, 44 - 86) adult pink salmon were spawning in the study area on the Laughing Whitefish River during the third week of September 1982. Visual estimates indicated approximately 80% of the spawning activity was concentrated in the 225-meter study section. An additional 17 pink salmon were collected 5 October with electro-fishing gear and by picking up dead salmon. A list of the non-target species captured is listed in Appendix 2.

A total of 42 pink salmon were collected in 1982 (Table 1). Of these fish, 25 were males and 17 were females resulting in a sex ratio of 1.47 males : 1 female, which is not significantly different from a 1 : 1 ratio (Chi-square value = 1.5, $P > 0.05$). Eighty-one percent of the fish taken during the 1982 spawning run were 2-year

Table 1.-- Mean length and weight, numbers and percentages of adult pink salmon by age and sex from Lake Superior tributaries in the upper peninsula of Michigan - 1982 and 1983.

1982

<u>Sex</u>	<u>Age</u>	<u>Mean Length (mm)</u> (+/- 95% C.I.)	<u>Range</u>	<u>Mean Weight (g)</u> (+/- 95% C.I.)	<u>N</u>	<u>%</u>
Female	2	367 (+/- 33)	344-390	-----	13	31
Male	2	370 (+/- 41)	325-414	-----	21	50
Female	3	429 (+/- 68)	410-457	-----	4	10
Male	3	493 (+/- 118)	440-525	-----	4	10

1983

Female	2	395 (+/- 8)	335-486	501 (+/- 307)	84	50
Male	2	407 (+/- 8)	330-484	563 (+/- 320)	70	42
Female	3	477 (+/- 40)	460-496	862 (+/- 484)	5	3
Male	3	499 (+/- 84)	453-554	962 (+/- 380)	9	5

* Percentages do not equal 100 due to rounding

olds with the remainder being 3-years old. Mean length of 2-year olds was 367 mm (+/- 38) and the lengths ranged from 325 to 414 mm. Differences in length between males and females were not significant (Student's T-value = 1.4, d.f. = 32, $P > 0.05$). Three-year-old pink salmon, which averaged 461 mm (+/- 105), were significantly larger than 2-year olds (Student's T-value = 29, d.f. = 40, $P < 0.05$). Three-year-old males were significantly larger than females of the same age (Student's T-value = 11, d.f. = 6, $P < 0.05$). Lengths of 3-year olds ranged from 410 to 525 mm.

The population estimate of the spawning grounds on the Laughing Whitefish River in the fall of 1983 indicated the numbers of adult pink salmon were slightly higher than those found in 1982. A total of 45 fish were caught and marked on 22 September during the first electro-fishing run while 45 were caught during the second run conducted on 23 September. Eighteen fish caught 23 September were marked. Using a modified Petersen estimate, 111 (95% CF, 79 - 143) adult pink salmon were spawning in the study area on 22 and 23 September 1983. Surveys of other areas throughout the river indicate approximately 90% of the fish to be actively spawning in the 225 meters of prime spawning habitat. An additional 35 pink salmon were collected on 27 September. A total of 80 fish were collected from the Laughing Whitefish River in the fall of 1983.

Additional adults were collected on 15, 17, 23 September in the Carp River (N = 51) and 21 September on Harlow

Creek (N = 37). The total number of adult pink salmon examined from all 3 tributaries was 168. All data collected in 1983 was pooled across rivers and the results are shown in Table 1.

Of 168 fish collected, 79 were males and 89 were females resulting in a sex ratio of 0.89 males to 1 female which is not significantly different from a 1 : 1 ratio (Chi-square value = 0.6, $P > 0.05$). Approximately 92% of the fish sampled in 1983 were 2-year olds and 8% were 3-year olds. Lengths ranged from 330 to 486 mm for 2-year olds and 453 to 554 mm for 3-year olds. The mean length of a 3-year-old pink salmon was 491 mm (+/- 67) and is significantly larger than 2-year olds (Student's T-value = 59.7, d.f. = 163, $P < 0.05$) which averaged 398 mm (+/- 66). Males were significantly larger than females for both 2- (Student's T-value = 11.7, d.f. = 146, $P < 0.05$) and 3-year-old pink salmon (Student's T-value = 7.8, d.f. = 12, $P < 0.05$).

Mean weight of pink salmon by age and sex is shown in Table 1. The mean weight of 2-year olds was 533 g (+/- 308), while the mean weight of 3-year olds was 920 g (+/- 396). Three-year olds are significantly larger than 2-year olds at the 95% level (Student's T-value = 107, d.f. = 166, $P < 0.05$).

Since pink salmon did not enter the weir/trap nets in either 1982 or 1983, correlations of migrations to stream

flow or temperature cannot be made. The date on which adults were observed on the spawning grounds is considered an artifact of our attempted sampling procedure and inferences on the timing of migration based on this data should not be made.

Scale measurements showed 3-year-old pink salmon grew significantly more slowly during the first year than did salmon maturing in 2 years. The mean distance from the focus to the first annulus (magnified) for 2-year olds was 52.7 mm (+/- 19) and for 3-year olds was 43.3 mm (+/- 29). The mean number of circuli for 2-year olds was 21 (+/- 7) and 17 (+/- 9) for 3-year olds. Both distance measurements and circuli counts are significantly larger for 2-year olds (Student's T-values = 8.27 and 3.48, d.f. = 57, $P < 0.05$).

Fecundity, Egg Retention and Deposition

Eggs from 4 females were collected for a fecundity estimate (2 from the Laughing Whitefish River and 2 from the Carp River). Because sampling was done on the spawning grounds, most females collected were either spent or partially spawned and could not be used in the fecundity analysis. Mean length and fecundity was 384 mm (+/- 36) and 1155 (+/- 139) eggs respectively. All fish examined were 2-year olds. Because of the small sample size, a regression of egg numbers on length or weight was not done.

Forty-eight spent females collected from the Carp and Laughing Whitefish Rivers in 1982 and 1983 were used to

estimate egg retention.

Egg retention (ER)

$$ER = \text{sum of eggs retained} / \text{sum of eggs carried}$$

$$ER = 942 / 44529$$

$$ER = .02115 = 2.1\%$$

Fecundities were estimated from the least squares regression of number of eggs versus total length from Wagner (unpublished data). The number of eggs retained ranged from 0 to 113 with the average being 21 (+/- 45). In addition, the mean number of eggs retained was 2.1% of fecundity.

Potential egg deposition for the 225 meter study area on the Laughing Whitefish River was calculated by multiplying the estimated number of females (from the population estimate and sex ratio) by 1002, the estimated fecundity given by Wagner (unpublished data) for 2-year-old pink salmon (N = 64). Since the estimated fecundity for 3-year-old pink salmon is similar (1003) (N = 9), no adjustments were made for the number of 3-year-old females present. In 1982, potential egg deposition was 26,362, while in 1983 potential egg deposition was 62,562.

Fifty-six percent of the adults captured 23 and 27 September 1983 were spent, 32% were partially spawned and 13% had not spawned.

Winter

Sampling of redds for eggs and alevins was conducted in December 1982, January, February, April, September, October and December 1983, and April 1984. A mild winter facilitated sampling during January and February 1983. Sampling during January, February and March 1984 was not conducted due to severe weather conditions. A total of 32 and 29 redds were marked in the fall of 1982 and 1983 respectively.

In the winter of 1982-1983, 29 of the 32 redds marked were sampled, 15 contained pink salmon eggs, 9 "redds" had no eggs and 5 were superimposed by other salmonid species, principally coho salmon (Oncorhynchus kistutch). Superimposition occurs when a fish builds a redd where another fish had previously deposited eggs.

In the winter of 1983-1984, 15 of the 29 redds marked in the fall of 1983 were sampled, 10 of these redds contained pink salmon eggs. Three "redds" contained no eggs and 2 had only coho salmon eggs present. The lower number of redds sampled in 1983-1984 reflects the severe weather conditions that made sampling difficult. The higher percent of redds containing eggs probably reflects the improved ability of the author to recognize a redd from random diggings by female pink salmon.

Live eggs and alevins were readily sampled by either the depletion sampler or the shovel and seine but dead eggs and alevins could not be easily sampled because of

decomposition. Samples taken within 2 weeks of deposition were utilized to estimate the number of live and dead eggs. After that, I felt only live eggs and alevins could be representatively sampled.

To provide an estimate of the number of eggs deposited and percent survival of the eggs within the first week, one redd on the Little Garlic River, Laughing Whitefish River, and Harlow Creek were sampled soon after egg deposition in September 1983. Exact time of egg deposition is not known, but for 2 of 3 samples a spent female was guarding the redd. From this, I assumed the redd had been constructed within the past 2 weeks. Percent fertilization could not be determined from this data because dead eggs had already started to decompose.

A total of 466 eggs were collected from the redd sampled in the Little Garlic River, all of these eggs were dead. On the Laughing Whitefish River, 350 eggs were taken from the sampled redd, of which 19% (65 eggs) were alive. The redd sampled in Harlow creek contained 304 eggs, of which only 11% (35 eggs) were still alive.

Overwinter survival of eggs and alevins was determined for each sampling date. Since samples were taken at various rivers and data on any one river was insufficient, the data was pooled (across rivers) for each month.

In order to estimate survival, the number of eggs deposited must be known. Average number of eggs taken from

3 redds sampled in September 1983 (373) was used to estimate the number of eggs deposited. Percent survival at each sampling date was determined by dividing the average number of live eggs collected by the estimated number deposited (373) and multiplying by 100. The mean number of eggs and/or alevins collected for that particular month is given along with the 95% confidence interval. The data is presented in Appendix 3.

A total of 648 eyed eggs were taken from 6 redds in December 1982 for an average of 108 ($\pm$ 285) eggs per redd. All live eggs were in the eyed stage but none had hatched. If it is assumed 373 eggs were deposited per redd then 29% survived until 2 December.

By January 1983, all fish sampled from the 1982 year class had hatched. A total of 603 live alevins were collected from 5 redds for an average of 121 ($\pm$ 600) eggs per redd. Only 6 of the 609 alevins sampled were dead. This may reflect difficulties in sampling dead alevins rather than a high survival rate. Assuming 373 eggs were deposited, 32% survived by January.

Two redd samples taken in February 1983 contained 147 alevins for an average of 74 eggs ($\pm$ 382) per redd. Percent survival was approximately 20% by February.

Three redd samples taken just prior to outmigration in April produced 197 alevins for an average of 66 ($\pm$ 94) fish per redd. Survival was approximately 18%.

A total of 96 ($\pm$ 55) eggs were taken from 2 redds on

29 October, 1983. Assuming 373 were deposited, survival to the end of October was approximately 13%.

All pink salmon collected December 1983 were hatched. A total of 111 fish were taken from 4 redds for an average of 28 (+/- 102) fish per redd. Survival to 2 December 1983 was approximately 7.4%.

The last redd sample, taken 29 April 1984 contained 32 live alevins. These fish were slightly smaller in length than those migrating in May (Student's T-value = 3.81, d.f. = 329, $P < 0.05$), but no significant differences were found in weight (Student's T-value = .15, d.f. = 329, $P > 0.05$). Survival to April was estimated at 8.6%.

Seven of the 44 redd samples had some evidence of superimposition. This represents 16 % of the redds sampled. Majority of redd superimposition was from spawning coho salmon but eggs and alevins from chinook salmon (Oncorhynchus tshawytscha) and rainbow trout (Salmo gairdneri) were also observed in redd samples. Harlow Creek showed the highest incidence of superimposition.

Twelve "redds" sampled (27%) did not contain pink salmon eggs. This may have resulted from a female digging and then abandoning the redd before eggs were deposited or from random digging by female pink salmon being mistaken for a redd. In addition, 7 redds sampled during winter contained only coho salmon eggs. It is not known if these redds ever contained pink salmon eggs or if the eggs were completely removed by superimposition.

Spring

Since methods and results of the spring outmigration were similar for 1983 and 1984, the data was pooled and analyzed together.

Hourly Migration

Nightly migration of juvenile pink salmon was obtained from drift nets on the Laughing Whitefish River during the spring of 1983 and 1984. Nets were set at 20:00 hours and checked hourly until 08:00. All fish were removed at the end of each hour. Results for 1983 and 1984 are shown in Figure 2.

In both years, migration began at about the same time in the evening and ended at about the same time in the morning. No fish were caught before 21:00 hours or after 06:00 hours. Sunset during the migration period was approximately 20:15 and sunrise was about 06:15. Fifty percent of the night's catch was reached during the same interval in both years, 23:00 to 24:00 hours. In 1983 the nightly peak was between 23:00 and 24:00 hours when 41% of the fish were caught. In 1984, migration peaked between 22:00 and 23:00 hours when 33% were caught. After 01:00 the number of fish decreased gradually until sunrise. No pink salmon were observed during random checks of the traps throughout the day.

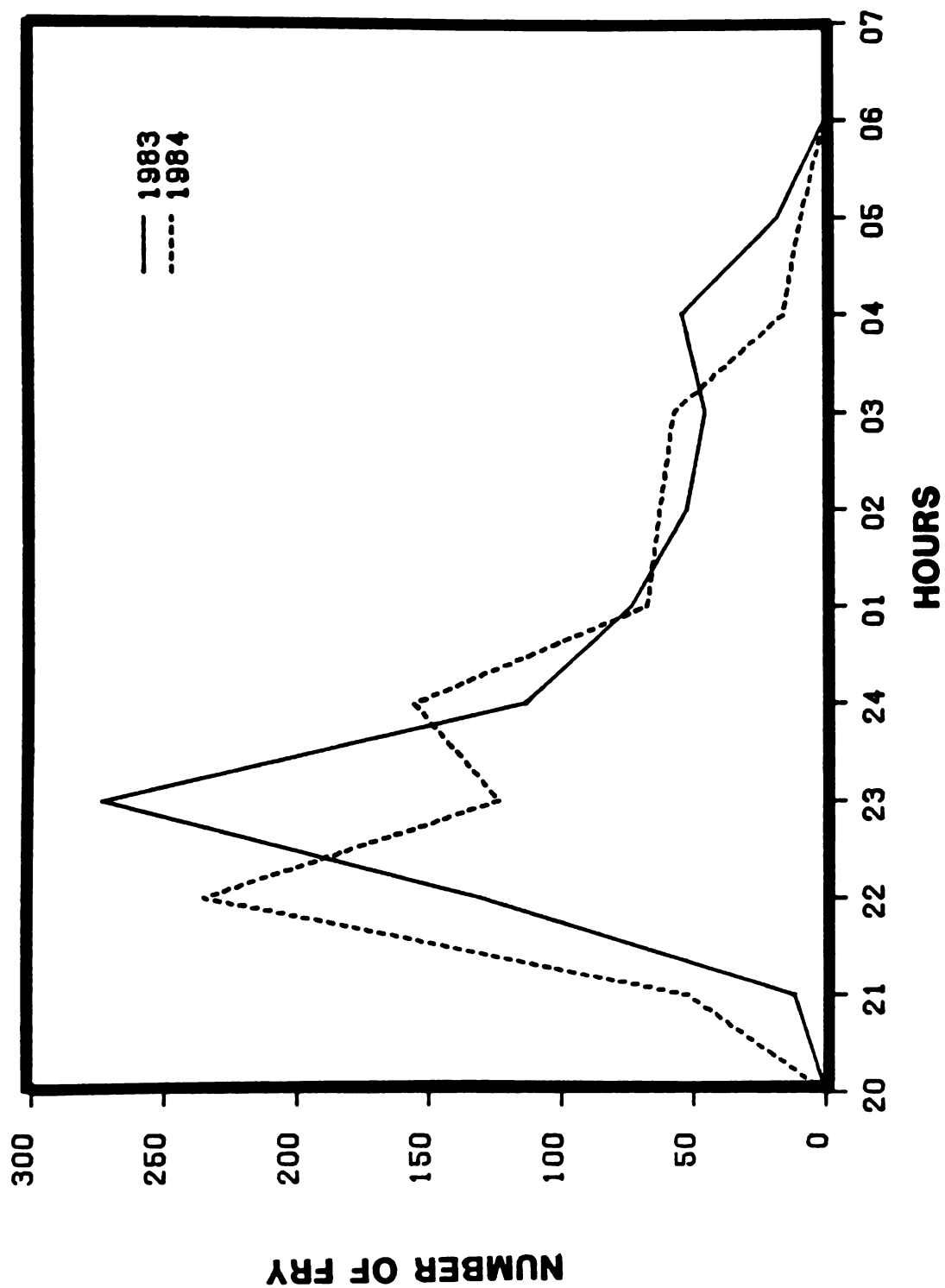


Figure 2. Diel pattern of downstream migration of pink salmon fry in the Laughing Whitefish River - 1983 and 1984.

Emergence

Emergent fry traps were run only in 1984. Data from all redds were pooled and are shown in Figure 3. Pink salmon fry began to emerge on 8 May. Emergence peaked 16 May and no fish were caught after 18 May. A total of 42 fish were caught over the 10 day sampling period. Emergence was restricted to the night time hours exclusively as 81% of the fish were caught between 20:00 and 01:00 hours, and 19% were caught between 01:00 and 08:00. Sampling was finished 23 May when the traps were removed. All redds were excavated to check for remaining pink salmon fry. A total of 12 fish were recovered from 5 redds. Only one of the 12 was alive, the remaining 11 had died prior to excavation.

Daily Migration

Daily pattern of fry migration for 1983 and 1984 is shown in Figure 4. In 1983, the first pink salmon fry was caught 7 May and no fish were caught after 21 May, a total of 14 days. Peak of migration was well defined on 11-12 May. In 1984, the first fish was caught 2 May and the last on 20 May, a total of 18 days. The peak was not well defined in 1984 as migration was spread out over a longer period.

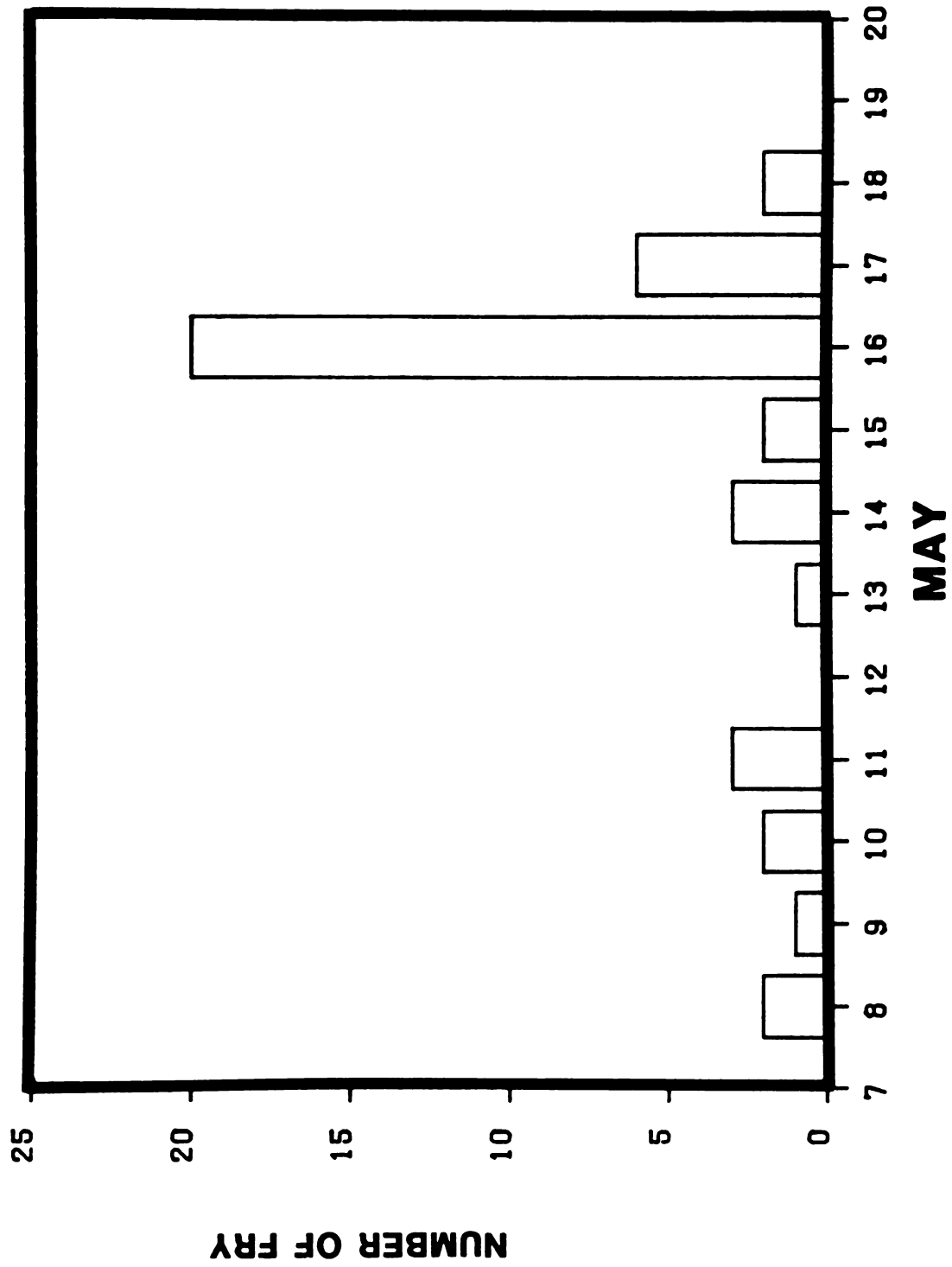


Figure 3. Numbers of pink salmon fry caught in emergent fry traps on the Laughing Whitefish River - 1984.

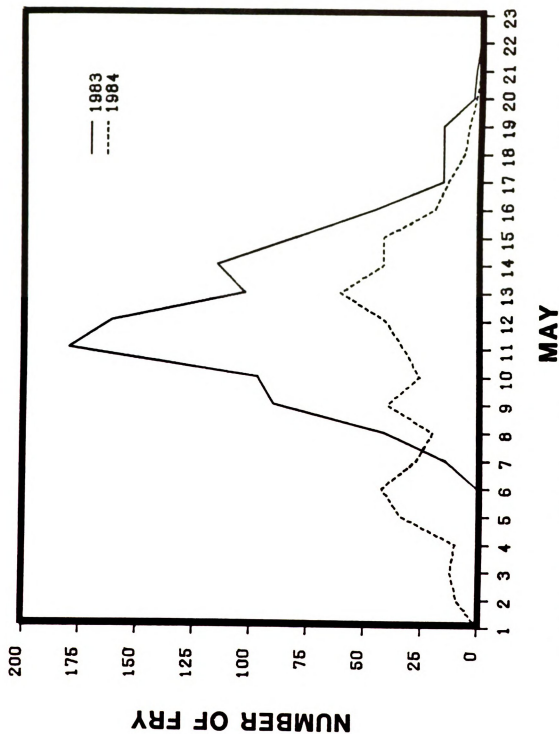


Figure 4. Daily numbers of pink salmon fry migrating downstream in the Laughing Whitefish River - 1983 and 1984.

Total number of pink salmon fry and average stream velocity for each of the 3 drift nets is shown in Table 2. The total number caught for 1983 was 900 fish while in 1984, 842 were captured. Since the effort in 1984 was 3 times that of the previous year, the totals should not be compared. Net #2 is the same net set in the same position in the Laughing Whitefish River as in 1983. Using this net for comparison, the number captured is 900 for 1983, which is approximately twice as many as captured by the same net in 1984 ($N = 487$). Using the number of fry caught from net #2 and potential egg deposition for each year, survival from spawning to outmigration is 3.5% for the 1982 year class and 0.8% for the 1983 year class.

Rate of Migration

Differences in rate of migration from the Laughing Whitefish River between 1983 and 1984 can be shown by plotting days of migration against cumulative percent of the total number of fry caught (Figure 5). The slope of the curve is an index of the rate of fry migration from the river. The slope of the 1983 curve is 13.6 (± 1.6) while the slope of the 1984 curve is 7.2 (± 0.5). Both curves are sigmoid and the slopes differ significantly from each other (Student's t -value = 32.3, d.f. = 20, $P < 0.05$). Thus, rate of outmigration is different for each year.

During both years few fish were observed during the initial few days of migration. In 1983, a large portion of

Table 2. --Average stream velocity and numbers
of pink salmon fry captured from the
Laughing Whitefish River - 1983 and 1984.

<u>Net#</u>	<u>Average Flow*</u> (m/sec)	<u># Fish</u>	
		1983	1984
Net #1	.385	---	157
Net #2	.467	900	487
Net #3	.315	---	197
* 1983 data			

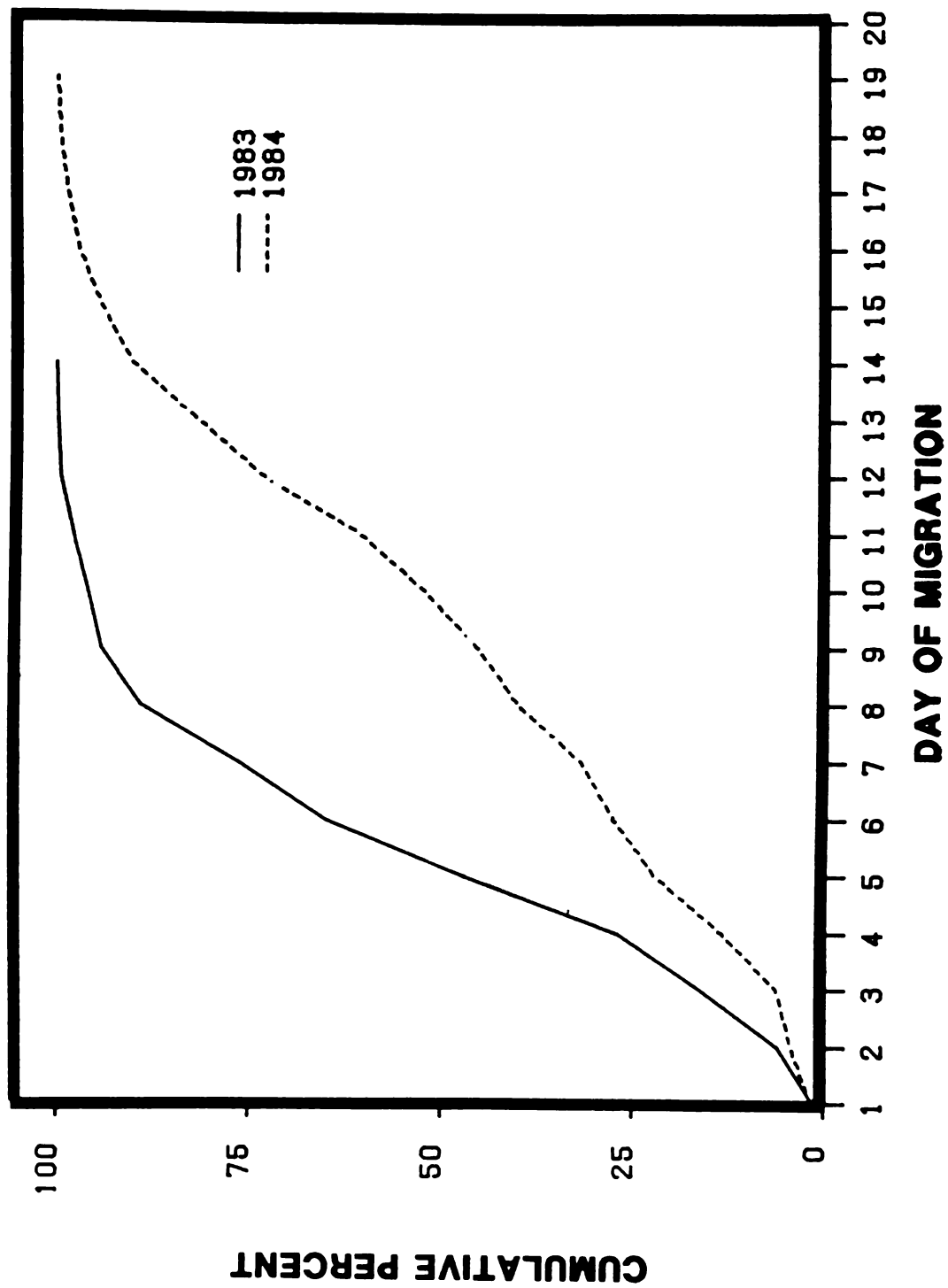


Figure 5. Relationship between day of migration and cumulative percent of outmigrating pink salmon fry from the Laughing Whitefish River - 1983 and 1984.

fish moved out of the stream between the 4th and 9th day. After the 10th day, migration declined rapidly. In 1984, rate of migration stayed fairly constant from the 4th day through the 16th day. After that, migration slowed and was over by the 18th day. Despite differences in migration pattern, the date at which 50 % of the run was completed occurred on 11 May, in both years. Temperature and flow patterns for both years were similar. No major freshets occurred at any time during migration in either year and water temperature did not appear to affect migration.

Horizontal Distribution - 1983

Using 3 wire fry traps in the same location as the drift nets, horizontal distribution of migrating pink salmon fry was determined in the spring of 1983 (Table 3). The drift net set in the center of the river (net #2) was always located in the highest stream velocity over the 6 day period. To determine differences in horizontal distribution of migration, volume of water sampled and number of fish captured for each net was compared.

On 3 of 6 sampling dates, the net sampling the greatest volume of water (#2) caught the greatest number of fish. However, on 19, 20, 21, and 22 May, net #1 sampled less water but caught more fish, per cubic meter, than net #2. From this, it appears pink salmon fry migrating in this part of the river may not always move through the fastest current.

Table 3. --Streamflow and numbers of pink salmon fry taken on the Laughing Whitefish River in spring 1983 using wire fry traps.

<u>Date</u>	<u>Net</u>	<u>Flow</u> (m/sec)	<u>Depth</u> (cm)	<u>M³/12 hr.</u>	<u>#Fish</u>	<u>M³/Fish</u>
5/17	1	.40	51	4053.5	11	368.5
5/17	2	.45	61	5453.7	21	259.7
5/17	3	.40	57	4530.4	14	323.6
5/18	1	.44	51	4459.2	4	1114.8
5/18	2	.50	60	5961.6	12	496.8
5/18	3	.28	57	3171.6	0	---
5/19	1	.38	54	4077.6	8	509.7
5/19	2	.48	61	5818.2	6	969.7
5/19	3	.28	59	3282.8	2	1641.4
5/20	1	.37	53	3897.0	5	779.4
5/20	2	.50	60	5961.2	7	851.6
5/20	3	.31	59	3634.4	4	908.6
5/21	1	.37	52	3823.4	2	1911.7
5/21	2	.45	60	5365.4	0	---
5/21	3	.32	58	3688.2	1	3688.2
5/22	1	.35	52	3616.0	2	1801.3
5/22	2	.42	60	5007.0	0	---
5/22	3	.30	56	3338.0	0	---

Five pink salmon fry were captured in fry traps set between the marsh and Lake Superior. These fish were not significantly different in length or weight from those caught in drift nets on the same day (Student's T-value = 1.5 and .97, d.f. = 24, $P > 0.05$). No pink salmon were caught by seining or dip netting in the stream, marsh or shoreline areas.

Stomach Analysis

Of the 100 fry examined for gastro-intestinal contents, only 3 had identifiable organisms present. These organisms were identified as insects of the family Chironomidae. I was unable to determine the particular genus and species of Chironomidae because of the extent of digestion. In all 3 cases the food organism was found in the intestine. Sixty-eight percent of the fry were found to have ingested sand and plant material. I believe this material was probably incidentally ingested during their development in the gravel. In addition, 32% of the fry had some unidentifiable organic material present in their intestine. I do not know if the presence of this material is a result of active feeding or incidental ingestion.

Length and Weight

Average length and weight of pink salmon fry caught in 1982, 1983 and 1984 are shown in Table 4. Mean length of fry from the Carp River in 1982 (Taylor and Bagdovitz 1983) is significantly larger than fry sampled in either 1983 or

1984 from the Laughing Whitefish River (Student's T-value = 2.3, d.f. = 354, $P < 0.05$). Weight was not significantly different between rivers for either year (Student's T-value = 1.16, d.f. = 354, $P > 0.05$).

Daily variations in length and weight of fry caught on the Laughing Whitefish River during outmigration in 1983 and 1984 were not significantly different on all but one sampling date. On 3 May 1984, mean length and weight of migrating fry were 33.6 mm (+/- 2.6) and 0.225 g (+/- .04) respectively. Both mean length and weight for this date are significantly larger than the population mean (Student's T-value = 11.74 and 2.07, d.f. = 498, $P < 0.05$). This is the only date in either year this occurred.

Harlow Creek

A total of 13 pink salmon fry were captured on Harlow Creek in 1983. Eleven fry were caught 11 May, the same day as peak migration on the Laughing Whitefish River. The remaining 2 were caught 13 May. Mean length and weight are 29 mm (+/- 1.5) and .147 g (+/- .021) respectively (Table 4). Mean length is significantly smaller than fry captured on the Laughing Whitefish River in 1983 (Student's T-value = 3.26, d.f. = 333, $P < 0.05$). There is no significant difference in weight (Student's T-value = .23, d.f. = 333, $P > 0.05$).

Table 4. --Mean length and weight of pink salmon fry
from Lake Superior tributaries in the upper
peninsula of Michigan - 1982, 1983 and 1984.

<u>Date/Location</u>	<u>N</u>	<u>Mean Length (mm)</u> <u>(+/- 95% C.I.)</u>	<u>Mean Weight (g)</u> <u>(+/- 95% C.I.)</u>
1982 Carp	36	31.1 (+/- 2.2)	0.196 (+/- .06)
1983 LWR	320	30.5 (+/- 4.4)	0.150 (+/- .07)
1983 Harlow	13	29.0 (+/- 1.5)	0.147 (+/- .02)
1984 LWR	420	30.4 (+/- 3.0)	0.150 (+/- .08)

* LWR stands for Laughing Whitefish River

DISCUSSION

Fall Sampling

Observations by the Michigan Department of Natural Resources of spawning tributaries throughout the upper peninsula of Michigan in 1981 indicate a precipitous decline in the number of adult pink salmon.

The pink salmon spawning run of 1981 was the smallest odd-year run since the early 1970's. Based on the size of the 1979 spawning stock, the 1981 run was expected to reach 10,000 or more fish in the Laughing Whitefish River. A trapping weir operated on this river in fall 1981 caught only 173 pink salmon (Taylor and Bagdovitz 1983). Observations throughout the river indicated no adult pink salmon reached the upstream spawning grounds. Surveys of other upper peninsula tributaries also indicated very low numbers of pink salmon. This is in sharp contrast to the large numbers of adults seen 2 years earlier (Wagner and Stauffer 1982). A similar decline was also seen in Minnesota tributaries to Lake Superior (Nicolette 1983).

Population estimates for the Laughing Whitefish River in 1982 and 1983 and visual observations of several tributaries in the upper peninsula of Michigan indicate the odd-year run of adult pink salmon is slightly dominant even though greatly reduced from levels seen in the late 1970's.

The reason for this sudden decline is not know but several explanations may be possible.

Low water levels during spawning and incubation may have brought about high mortality of eggs and alevins within the stream prior to outmigration. Mortality might have occurred from oxygen deprivation, accumulation of toxic substances (e.g. ammonia), and freezing. This would have resulted in few outmigrants and very low numbers of adults returning to the stream 2 years later.

If large numbers of pink salmon from the 1979 year class survived incubation and migrated into the lake, immature pink salmon may have died sometime after leaving the stream and before they reached maturity. High mortality may have been caused by large numbers of juveniles competing for limited food resources in Lake Superior. The decline of rainbow smelt (Osmerus mordax), a known food source of pink salmon (Kwain 1982), in Lake Superior came about in the late 1970's and may have contributed to the decline of pink salmon (James Peck, Michigan Department of Natural Resources, Marquette Fisheries Research Station personal communication).

It was also postulated that large numbers of pink salmon might experience delayed maturity and would return in 1982 as 3-year olds. But since the size and age composition of the 1982 spawning run was similar to other even-year runs, large numbers of pink salmon from the 1979

year class apparently did not experience delayed maturity.

The cause of this sudden decline is unknown at this time and I feel that none of the above hypotheses completely explains the collapse of the 1979 year class.

Streamflows in many of the Michigan tributaries to Lake Superior were quite low in the fall of 1981 and the density of spawners at this time was quite high (Wilbert Wagner, Michigan Department of Natural Resources, Marquette Fisheries Research Station, personal communication). Considering the high density of spawners, low water levels and possible reduction in the amount of available spawning habitat, overseeding of the spawning gravel resulting in high egg and alevin mortality might have taken place. If overwinter survival was low, a collapse of the odd-year run would have been the result.

Research on west coast Pacific salmon stocks has shown that overwinter survival of eggs and alevins is a key factor in determining year-class strength. In a study of egg survival in pink salmon redds in Alaska, McNeil (1964) has shown the capacity of a spawning bed to produce fry may be impaired by excessive numbers of spawning females. Egg loss during spawning increases as the density of female spawners increases. This mortality was caused, for the most part, by redd superimposition. Ricker (1962), Neave (1966) and Wickett (1958) all reported the average yield of fry approaches an upper limit as the density of spawners reaches optimum levels as determined by environmental cond-

itions. Heard (1978) noted that the local climate and its resulting effects in the stream are extremely variable and have a marked influence on what constitutes an overseeded spawning bed at any specific time. Overseeding is defined as an egg density in the spawning gravel that leads to a significantly greater mortality than would be found with a lesser density. Climate influences overwinter survival of the eggs through variations in streamflow and temperature. Thus, overseeding does not occur at a fixed number of spawners but varies with climatic conditions.

During periods of low streamflow, low levels of dissolved oxygen in the intra-gravel water and high egg mortality are known to occur (McNeil 1966). Wickett (1958) reported a positive correlation between the amount of rainfall or stream discharge during spawning and incubation and survival of a pink salmon stock to returning adults. He concluded that survival of eggs and alevins is improved by favorable discharge during incubation.

It is also possible high streamflow during spawning may reduce survival of pink salmon eggs. Ellis (1969) hypothesized that egg losses during spawning may be a result of inefficient deposition of eggs by females during periods of high streamflow.

Based on the limited observations in 1979 and 1981 and information from the west coast, I hypothesize that overwinter survival and year class strength of Lake

Superior pink salmon is improved by high, but not excessive, streamflow during spawning and incubation. Quantitative measurements of streamflow, available spawning habitat and overwinter survival of pink salmon fry are needed to validate this hypothesis. Further work on controlling mechanisms of year class strength is needed to adequately understand and predict fluctuations in abundance experienced by Great Lakes pink salmon.

Vital Statistics

Neave (1966) found in Pacific stocks of pink salmon that differences in length or weight may be evident between years and/or rivers. With the exception of 3-year-old males, pink salmon captured in 1982 from Michigan tributaries were significantly smaller, in length, than pink salmon captured during the same year in Minnesota (Nicolette 1983). Pink salmon taken in 1981 Minnesota were significantly smaller than pink salmon taken in Michigan in 1983. In Canadian tributaries of Lake Superior, Kwain and Lawrie (1981) reported even-year pink salmon were larger than odd-year fish, regardless of age. With the exception of 3-year old males, odd-year spawners in Michigan were significantly larger than even-year fish. Mean length of the males was significantly larger than females with the exception of 2-year olds in 1982. This is similar to that reported by Ricker (1964) who found male pink salmon from British Columbia are usually larger than females maturing in the

same year.

In McClinton Creek, British Columbia, Pritchard (1937) reported that male pink salmon averaged between 536 and 573 mm (fork length) while females were between 510 and 543 mm for even-year runs between 1930 and 1936. These fish were all 2-year olds. Adult pink salmon from McClinton Creek were approximately 30% larger than 2-year olds found in Lake Superior and 10% larger than 3-year olds. This is probably a result of the infertile nature of the lake producing the smaller size of maturity of 2-year olds and the delayed maturity (3-year olds) seen in about 10% of the spawning adults.

Differences in weight between 2- and 3-year olds and between males and females in 1983 were significant even though variability was quite high. It is possible the variability in weight is a result of the varying condition of the fish at time of capture (ripe, partially spawned, spent) and if so, these measurements may not adequately reflect differences in weight between males and females or year classes before they enter the river.

Three-year-old pink salmon

Three-year-old pink salmon are thought to arise from delayed maturity of the adults caused by slow growth in the cold, oligotrophic environment of Lake Superior (Kwain and Chappell 1978, Wagner and Stauffer 1980). Abundance of 3-year-old pink salmon in even-years in Lake Superior may be

related to the large numbers of odd-year spawners from which these 3-year olds arise. On the eastern Pacific coast 3-year old spawners are exceedingly rare (Anas 1959, Turner and Bilton 1968) and thus there is virtually no shifting of individuals between adjacent year classes. Three-year-old pink salmon allow for a shifting of genetic information between stocks, therefore, genetic divergence based on spawning stock is less likely to occur in Lake Superior than in the Pacific northwest stocks.

While 3-year-old pink salmon were present in Michigan tributaries in both 1982 and 1983, they are nearly absent in Minnesota tributaries during odd-years. The single individual recorded by Nicolette (1984) in Minnesota in 1981 was the first 3-year-old pink salmon observed in that area during an odd-year run.

It is interesting to note the eggs used to establish Great Lakes pink salmon were taken from the Skeena River, British Columbia in 1955 (Scumacher and Eddy 1960) and the only 3-year-old pink salmon ever reported from a west coast tributary came from the Skeena River in 1956 (Anas 1959). Thus, the 3-year-old reported by Anas (1959) and Great Lakes pink salmon are direct descendants from the same river and year class. This raises the possibility, although remote, that delayed maturity in pink salmon may be partially genetically determined.

Overwinter Survival

Estimates of overwinter survival of pink salmon eggs and alevins indicates approximately twice as many fish survived the 1982-1983 winter as did the 1983-1984 winter. This agrees with data from the drift net catches on the Laughing Whitefish River since twice as many fry were caught in 1983 than in 1984.

Survival estimates are based on the number of eggs deposited in one redd by a female pink salmon and a sample size of 3 redds is considered by the author to be very inadequate. Two redd samples taken in September 1984 (Kocik, unpublished data) from Harlow Creek and the Laughing Whitefish River contained 619 and 625 eggs respectively. The data from 1984, along with the large variability in the number of eggs recovered from each redd, indicates my original estimate of 373 eggs per redd may be inaccurate and many more samples should be taken before further inferences are made.

In each of 3 redd samples taken soon after deposition, the average number of eggs (373) recovered is approximately a third of the total estimated fecundity (minus egg retention) of a female pink salmon as determined by Wagner (unpublished data). Since female pink salmon are known to build more than one redd, remaining eggs may have been deposited elsewhere. Heard (1978) estimated that for female pink salmon spawning in Sashin Creek, 55% of the

potential egg deposition disappeared during spawning. Predators, scavengers and turbulent streamflow were listed as possible causes of egg disappearance.

Based on redd samples from Harlow Creek, frequency of redd superimposition appears to be inversely related to the amount of spawning habitat present in the river. This tributary has very little spawning area and is used by several salmonid species for reproduction. Five of 13 pink salmon redds sampled on Harlow Creek contained either coho salmon, chinook salmon, or rainbow trout eggs and alevins.

Spring Outmigration

Emergence

Temporal aspects of fry emergence from identified individual redds in nature have generally not been studied directly. Such information has been obtained with simulated redds (Godin 1980) or from trap catches of fry migrating downstream (Neave 1955). Fry trap or drift net catches of fry may not accurately represent temporal patterns of fry emergence. This is because newly emerged fry may not move downstream immediately after emergence owing to their possible re-entry into the gravel or holding of position in the water current (Neave 1955, Hoar 1956).

Emergence data from the Laughing Whitefish River indicates pink salmon fry to be actively moving out of the gravel with the onset of darkness. With the emergent fry nets used on the Laughing Whitefish River, holding of

position in the water column above the redd or re-entry into the gravel by the fry, as suggested by Neave (1955) and Hoar (1956), is possible without detection. Seining conducted within the stream during the day failed to catch any pink salmon fry.

Godin (1980) found, in a study of pink salmon emergence from artificial redds, that 80% of the fry emerged at night (12 h L : 12 h D) for all redds at all temperatures except 15 C. In addition, the proportion of fry emerging during the day increased significantly over the emergence period. This was most pronounced at higher temperatures. Pink salmon emergence on the Laughing Whitefish River was strictly nocturnal over the temperature range observed (4-11 C).

The peak of emergence seen on 15-16 May (Figure 4) is the result of 20 pink salmon fry leaving the redd between 20:00 and 01:00 hours. This is the only date in which I found relatively large numbers of pink salmon leaving a single redd during a short period of time. This synchrony of emergence is common for Pacific salmon on the west coast and is considered an adaptation to reducing risk of predation (Godin 1981).

Use of emergent fry traps may have contributed to mortality of pink salmon before they left the redd. After migration had ceased, the emergent traps were removed and the redds excavated. Twelve pink salmon were found, 11 of

which were dead. All dead fry had come from the same redd. Observations of this trap when it was in use indicated that sand was accumulating inside the trap. Gravel around the outside of the trap did not appear to be accumulating sand. It is possible this "sand trap" effect might have reduced intergravel water flow and contributed to mortality not seen in other traps.

Hourly Migration

Downstream dispersal of salmonid fry from the redds to their initial feeding areas is typically nocturnal, at least during the early and middle portions of the migration period (Roppel 1956, Hartman et al. 1962, Northcote 1969). Data I collected on hourly migration coincides with emergence data as the majority of movement takes place within the first hours of darkness. This agrees with Pritchard (1944) and Neave (1955) who found pink salmon to be leaving the stream in large numbers within a few hours after sunset. This nocturnal movement pattern is considered an anti-predator adaptation as capture efficiency of predators decreases with decreasing light intensities (Brett and Groot 1963).

Stream Residency

Pink salmon fry were not caught at any time by seining or dip netting in the stream or marsh and only 3% of the fry were found to be ingesting food organisms. These observations, along with emergence and migration data,

suggest that pink salmon use the stream ecosystem for only a very short time after emergence and before outmigration. These results agree with Kwain (1982) who did not find any pink salmon fry in the near shore areas of Lake Superior and assumed young pink salmon move away from the shoreline areas soon after leaving the streams. Levy and Northcote (1982) reported that pink salmon fry were transient in the estuary of the Fraser River and migrate quickly into the Pacific ocean. Pink salmon fry in Lake Superior exhibit similar behavior as they appear to be going directly into open water.

Observations on stream residency of pink salmon fry are not supported by data collected by the Michigan Department of Natural Resources. On 3 May 1980, 8 pink salmon fry were collected from the Laughing Whitefish River during the day and were reported to be schooling in the shallow areas of the river (Paul Hannuksela, Michigan Department of Natural Resources, Marquette Fisheries Research Station, personal communication). Similar behavior has been reported by Kamyshnaya (1967) who reported that under arctic daylight conditions, pink salmon fry migrated from the Muchka River, a tributary of the Teriberka River which enters the Barents Sea, around the clock. Large numbers of pink salmon schooling and migrating during daylight hours from eastern Pacific rivers has not been reported.

Daily Migration

Data from the west coast has shown that daily variations in stream temperature do not appear to have a marked effect on the daily timing of downstream fry movements (Northcote 1969, Healey 1980). Similar observations were noted on the Laughing Whitefish River. Often when temperature differences between days are small, very large differences in the number of pink salmon caught in the drift nets occurred. This does not discount the possibility of temperature affecting the rate of development of the fry and initiating outmigration in the spring.

Drift net catches and percent survival from spawning to outmigration indicate major differences in overwinter survival of pink salmon between the 1982 and 1983 year classes on the Laughing Whitefish River. A total of 900 fry were caught in the spring of 1983 while only about half as many were caught in 1984 (487). Survival of the 1982 year class (3.5%) was 4.4 times higher than the 1983 year class (0.08%). In both years the number of spawners was below "capacity" as large areas of spawning habitat that had been utilized in previous years went unused. The mild temperatures, high streamflow and lack of snowfall during the winter of 1982-1983 may have contributed to the higher survival of eggs and alevins. The 1983-1984 winter was harsh compared to the previous year but normal for this latitude.

This difference in numbers of outmigrants indicates survival between years can be quite variable and a large number of spawning adults does not necessarily mean larger numbers of progeny leaving the stream in the spring.

SUMMARY

The number of adult pink salmon spawning during odd-years in Michigan tributaries to Lake Superior has declined precipitously since 1979. The 1981 run was the lowest run of odd-year pink salmon observed since the early 1970's. The numbers of pink salmon spawning throughout Michigan tributaries to Lake Superior in 1983 was similar to that seen in 1981. The even-year run has remained at low levels.

The reasons for the decline of the odd-year run are unknown but circumstantial evidence indicates that low water levels and high numbers of spawners in 1979 may have contributed to high mortality of eggs and alevins.

The life history of Lake Superior pink salmon is similar to that found in their native range. Differences occur in the age of maturity of about 10% of the spawning adults (3-year olds). Two-year-old adults are approximately 30% smaller than those found in the Pacific northwest while 3-year olds are approximately 10% smaller.

Redd sampling indicated differences between year classes in the overwinter survival of the eggs and alevins. A larger number of redds must be sampled before further inferences on survival are made.

Emergence and outmigration of pink salmon fry into

Lake Superior peaks during the first 4 hours after sunset. Downstream movement decreases gradually until sunrise. Pink salmon fry were not caught in the stream or marsh during daylight hours. Twice as many fry were moving downstream in the spring of 1983 than in the spring of 1984.

Survival from egg deposition to outmigration was 3.5% for the 1982 year class and 0.8% for the 1983 year class. Mild temperatures, high streamflow and lack of snowfall during the 1982-1983 winter may have contributed to higher survival.

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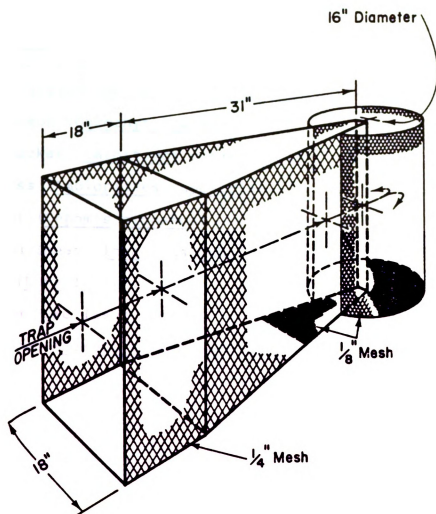
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APPENDICES

Appendix I. Wire mesh fry traps used in 1983 and 1984
to collect pink salmon fry.



Appendix 2. A list of the non-target species caught in the weir/trap nets in the fall of 1982 and 1983 on the Laughing Whitefish River.

Chinook Salmon (Oncorhynchus tshawytscha)

Coho Salmon (Oncorhynchus kisutch)

White Sucker (Catostomus commersoni)

Rock Bass (Ambloplites rupestris)

Bluegill (Lepomis gibbosus)

Brown Bullhead (Ictalurus nebulosus)

Burbot (Lota lota)

Northern Pike (Esox lucius)

Creek Chub (Semotilus atromaculatus)

Appendix 3. Data from redd sampling conducted in
winter 1982-1983 and 1983-1984.

1982-1983

<u>River/date</u>	<u>#Fish</u>	<u>Live</u>	<u>Dead</u>	<u>Eyed Eggs</u>		<u>Alevins</u>	
				<u>Live</u>	<u>Dead</u>	<u>Live</u>	<u>Dead</u>
Huron 12/82	441	182	259	182	70	0	0
Huron 12/82	15	15	0	15	0	0	0
Huron 12/82	84	52	32	52	15	0	0
Harlow 12/82	178	109	69	109	1	0	0
LWR 12/82	380	290	90	290	31	0	0
LWR 12/82	190	0	190	0	0	0	0
LWR 1/83	60	60	0	0	0	60	0
LWR 1/83	511	505	6	0	0	505	6
Carp 1/83	7	7	0	0	0	7	0
Harlow 1/83	24	24	0	0	0	24	0
Carp 1/83	7	7	0	0	0	7	0
LWR 2/83	11	11	0	0	0	11	0
Harlow 2/83	136	136	0	0	0	136	0
LWR 4/83	93	93	0	0	0	93	0
Harlow 4/83	34	34	0	0	0	34	0

Appendix 3. --Continued

1983-1984

<u>River/date</u>	<u>#Fish</u>	<u>Live</u>	<u>Dead</u>	<u>Eyed Eggs</u>		<u>Alevins</u>	
				<u>Live</u>	<u>Dead</u>	<u>Live</u>	<u>Dead</u>
LGR 9/83	466	0	466	0	0	0	0
LWR 9/83	350	65	285	0	0	0	0
Harlow 9/83	304	35	269	0	0	0	0
LWR 10/83	57	57	0	57	0	0	0
Harlow 10/83	244	39	205	39	19	0	0
Carp 12/83	51	45	6	0	0	45	1
Carp 12/83	146	0	146	0	0	0	0
Harlow 12/83	226	65	161	0	69	65	24
Harlow 12/83	148	1	147	0	52	1	0
LWR 4/84	13	13	0	0	0	13	0

<u>Summary</u>	<u>1982-1983</u>	<u>1983-1984</u>	<u>Total</u>
#redds sampled	29	15	44
#redds sampled with pink salmon	15	10	25
#empty redds	9	3	12
#Coho salmon imposed redds	5	2	7

*LWR stands for Laughing Whitefish River and LGR stands for Little Garlic River.