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Natural Reproduction of Pactific Salmon
In A Southern Michigan Stream

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# NATURAL REPRODUCTION OF PACIFIC SALMON

# IN A SOUTHERN MICHIGAN STREAM

By

Holly Elizabeth Jennings

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

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# ABSTRACT

## NATURAL REPRODUCTION OF PACIFIC SALMON IN A SOUTHERN MICHIGAN STREAM

by

Holly Elizabeth Jennings

During 1989 and 1990 in Prairie Creek, fall spawning by Pacific salmon was monitored by counting and measuring redds at predetermined sites. Water velocity, depth and temperature were measured; substrate type was estimated; and redd locations were noted. With the use of fyke nets, the number and timing of outmigrating smolts was observed in spring 1990. Thirty-two redds were counted in 16 100-m sites (7% of the stream) during Oct. 3 through Nov. 7, 1989; the number of redds in the stream was estimated to be 366. A dam on the creek may inhibit spawner migration. The mean size redd was 2.3 m in length and 1.4 m in width. No redds were found in fall 1990. Outmigration of smolts occurred from 5/28 through 6/30. A total of 66 smolts were captured. Water temperatures at night during outmigration were mainly 16°C and above.

## ACKNOWLEDGMENTS

There are many people to whom I extend my deepest gratitude for all the advice and support they've given me over the course of my graduate studies. First of all, I thank the Michigan Agricultural Experiment Station for financing my research. I would like to thank my advisor, Dr. Niles Kevern for taking an interest in furthering my education and for persuading me to enter the masters program in fisheries. His positive attitude and words of encouragement always kept me working toward my goal, even when problems arose and my frustration with my studies became intense. I also appreciate all the help and suggestions I received from the other members of my committee, Dr. Tom Coon and Dr. Scott Witter. They gave me a new perspective on my research and thesis, and I found this very refreshing. A special thanks goes to Dr. Scott Winterstein for helping me design my sampling method and assisting me with the statistical analysis of my data. He has no idea how much I appreciate his input.

In addition, I wish to thank my work study students, Mike Morgan and Joe Patterson for all the help they provided setting nets and collecting samples. I hope they learned something from the experience, but also enjoyed it. I also thank other graduate students who assisted me with data collection: Glenn Barner, Tim Watkins, Dave Zafft and Rob Elliot, among others. And to all the graduate students who participated with me in TGIF's and SAS meetings, thanks for helping me adjust my attitude and keep my sanity. Former employers Pam Tyning and Tony Groves have kept me laughing and prevented me from taking myself too seriously; thanks to the both of you. Of course, I thank my parents who always supported my decisions and taught me to be my own person. I thank Paul Hamelin for his friendship, love and deep understanding. But most of all I wish to thank Brian Peceny for his incredible support and consideration these past three years. He helped me through some very difficult times and always reassured me when I was filled with doubt about my ability to succeed in school and in the professional world. His friendship and caring will stay with me forever.

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## INTRODUCTION

The first successful introduction of coho salmon (Oncorhynchus kisutch) into Lake Michigan occurred in 1966 and that of chinook (O. tshawytscha) in 1967 (Westers et al. 1990). Since then, yearly stocking of these species has been conducted by the Michigan Department of Natural Resources (MDNR), along with other agencies in Indiana, Illinois and Wisconsin (Westers et al. 1990). In 1988, 2.45 million juvenile chinook and 1.7 million coho smolts were stocked into the Michigan waters of Lake Michigan. Originally, the salmon were introduced to help control the abundant alewife (Alosa pseudoharengus) population and to provide further sport fishing opportunity. The alewife is a marine species that had invaded the Great Lakes probably via the St. Lawrence River (Christie 1974). The alewife was first observed in Lake Michigan in 1949 and by 1954, had been found in all the Great Lakes (Brown 1968; Christie 1974). Also during this time, the sea lamprey (Petromyzon marinus), a parasite of large piscivores such as lake trout and burbot, appeared in the Great Lakes and was observed in Lake Michigan as early as 1936 (Christie 1974). Christie (1974) suggests that because the lamprey prefer larger prey, they were non-lethal parasites until harvesting pressure on the larger fish caused the lamprey to attack smaller, less-resistant fish. Consequently, lake trout populations in the Great Lakes collapsed due to overharvesting, low reproduction and predation by the lamprey (Christie 1974). Additionally, as the larger lake trout disappeared, the lamprey utilized other fish as prey, namely burbot and lake whitefish (Christie 1974). With the demise of these large predators, the alewife population increased to great proportions, peaking in Lake Michigan in 1966 (Brown 1968). A massive die-off occurred in the spring of 1967 , and alewife carcasses littered the lakeshores (Brown 1968). Heavy mortalities of alewife in the Great Lakes during spawning runs in the spring is not unusual; these deaths have been attributed in part to the inability of the fish to adjust to severe temperature changes as they travel from their deep-water winter habitat to shallow spawning areas (Brown 1968; Christie 1974). However, the sheer numbers of alewife present in Lake Michigan created a nuisance, producing the extensive fishkills and clogging intake pipes during spawning runs (Christie 1974). The addition of predator species, such as the Pacific salmon, reduced the alewife populations and alleviated these problems.

Besides controlling forage fish populations, the Pacific salmon in Lake Michigan have become a valuable fishery. Between 1843 and 1966, the commercial fishery (for species such as lake whitefish, perch, walleye, lake trout and chubs) had a greater impact biologically and economically than the sport fishery (Keller and Smith 1990a). In fact, Keller and Smith (1990a) assert that many of the changes in fish composition within the Great Lakes and the associated decline or extinction of certain populations were mainly due to poor management and overharvesting by commercial fleets. In 1966, the MDNR decided to improve its fisheries resources and to shift its management focus from commercial to sport fishing; the coho and the chinook salmon were to become the base of this new fishery (Keller and Smith 1990a). By 1986, the number of Michigan charterboats, the majority of which are on Lake Michigan, had increased to approximately 1,000 (Jamsen 1990). About $850 million are spent by anglers each year while pursuing recreational fishing opportunities in Michigan (Robertson 1990). The MDNR has estimated that the sport fishery contributes $1.4 billion annually to Michigan's economy (Robertson 1990). Throughout the 25 years since its inception, this fishery has generated tremendous response from anglers.

After the initial introduction of coho salmon into Lake Michigan, 17,000 adults were planted by the MDNR in fall 1967 into tributaries of lakes Michigan and Huron (Rybicki et al. 1990). Since then any natural reproduction that occurred was thought of as a bonus but was not managed (A. Hilt, MDNR, personal communication). The MDNR has inhibited spawning of chinook on certain streams where they were thought to compete with native salmonids (Rakoczy and Nelson 1990). Otherwise, natural reproduction of chinook was neither encouraged nor discouraged and has been documented to have occurred in Michigan streams as early as 1973 (Rybicki 1973 and Taube 1974). However, few studies quantifying actual production have been conducted. Therefore, agencies are repeatedly stocking salmon into the Great Lakes with little knowledge of natural recruitment. Continuous hatchery-rearing and stocking of fish can be a very expensive endeavor and may not provide the diversity within populations that natural reproduction can. But the ability of Michigan streams to support extensive salmon natural reproduction is questionable.

Studies of Pacific salmon in northern lower Michigan conducted by Carl (1982) in Baldwin Creek and by Seelbach (1985) in the Little Manistee River report the occurrence of successful spawning. Natural reproduction data for southern lower Michigan streams, though, is severely lacking.

According to Rakoczy and Nelson (1990), the average size of coho and chinook harvested and the number returning to spawn have declined in recent years. These lower returns can be seen in recent data from the Platte River, Michigan (Table 1). Patriarche (1980) reported a significant decrease in mean lengths and weights of adult coho during his two-year study (1978 and 1979). Female Lake Michigan coho seen

Table 1. Adult coho and chinook returning to the Platte River weir, Michigan, 1979-1990 (Pecor 1991).

| YEAR | COHO | CHINOOK |
|---|---|---|
| 1979 | 36,404 | 4,702 |
| 1980 | 123,113 | 4,435 |
| 1981 | 168,049 | 3,563 |
| 1982 | 129,363 | 2,999 |
| 1983 | 156,358 | 6,114 |
| 1984 | 142,102 | 5,924 |
| 1985 | 80,354 | 4,865 |
| 1986 | 52,770 | 5,147 |
| 1987 | 55,144 | 7,787 |
| 1988 | 26,118 | 4,646 |
| 1989 | 49,793 | 1,899 |
| 1990 | 32,821 | 1,761 |

in fall 1979 had an average size smaller than female Pacific Coast coho (Patriarche 1980). The MDNR hypothesized that this drop in size and numbers returning was due to a dwindling forage base, and it has decreased stocking efforts in order to restore the prey populations and promote better utilization of prey by individual fish (Rakoczy and Nelson 1990). Apparently, this reduction in stocking has worked. The year class of 1984, the year of peak stocking, has produced below average returns, whereas the 1985 and 1986 year classes, stocked in much lower numbers, have produced above average returns (Rakoczy and Nelson 1990).

As stated previously, the Pacific salmon returns in the Great Lakes have been fluctuating recently, as well as the forage base on which they depend. Also, few studies of natural reproduction of these salmon have been conducted in southern lower Michigan. Therefore, the goal of this study was to quantify this production in a particular southern Michigan stream and provide these data as further evidence of the present condition of these salmon populations.

The Grand River, located in southern lower Michigan, is among those tributaries of Lake Michigan that are consistently stocked with chinook and coho salmon. Natural reproduction probably occurs in this river but has not been described or quantified to any great extent. To study reproduction throughout the entire Grand River system seemed impractical; therefore, this study concentrated on one tributary of the Grand where salmon have spawned. Prairie Creek was selected for this study for four main reasons: early visual observations indicated potential spawning habitat; anglers have observed salmon spawning in the creek for years past; the creek is assumed to be fairly representative of 10 to 20 other Grand River tributaries that have good water quality and suitable gravel and that support similar fish assemblages; and the creek is easily accessible.

The proposed objectives for this study included: estimating the number of Pacific salmon nests, or redds, produced in Prairie Creek during fall 1989 and 1990; describing spawning habitat characteristics associated with each redd; and estimating the recruitment of juvenile salmon from Prairie Creek to the Grand River during spring 1990. By accomplishing these objectives, I hoped to measure the extent of Pacific salmon natural reproduction in this creek and compare the measured habitat variables to data from other studies conducted in Michigan and on the Pacific coast.

# DESCRIPTION OF STUDY SITE AND METHODS USED

Prairie Creek is located in Ionia County, in central lower Michigan (Figure 1). It is approximately 25 km long and no more than 23 m at its widest point during low water. It flows south, entering the Grand River just southeast of the town of Ionia. The watershed of Prairie Creek consists of gently to steeply sloped hills with well-drained loamy soils overlaying sand and gravel, where agriculture is the main land use (Threlkeld 1967). The creek is fairly well-buffered by a strip of upland forest containing hardwoods such as oak, maple and beech; some reaches of the creek, though, are immediately adjacent to residential and industrial property in the downstream section, and to some cropland and pastures farther upstream.

Prairie Creek is a marginal trout stream because it retains fairly high temperatures throughout the summer in some sections (C. Bay, MDNR, unpublished data; R. Moore, National Oceanic and Atmosperic Administration, unpublished data; Trimberger 1988; A. Hilt, MDNR, personal communication). However, it does have better water quality than many of the other marginal trout streams tributary to the Grand River (Seelbach, 1991, MDNR, interoffice communication). The river contains resident populations of brown trout and juvenile steelhead (A. Hilt, MDNR, personal communication). Rotenone treatments have been administered

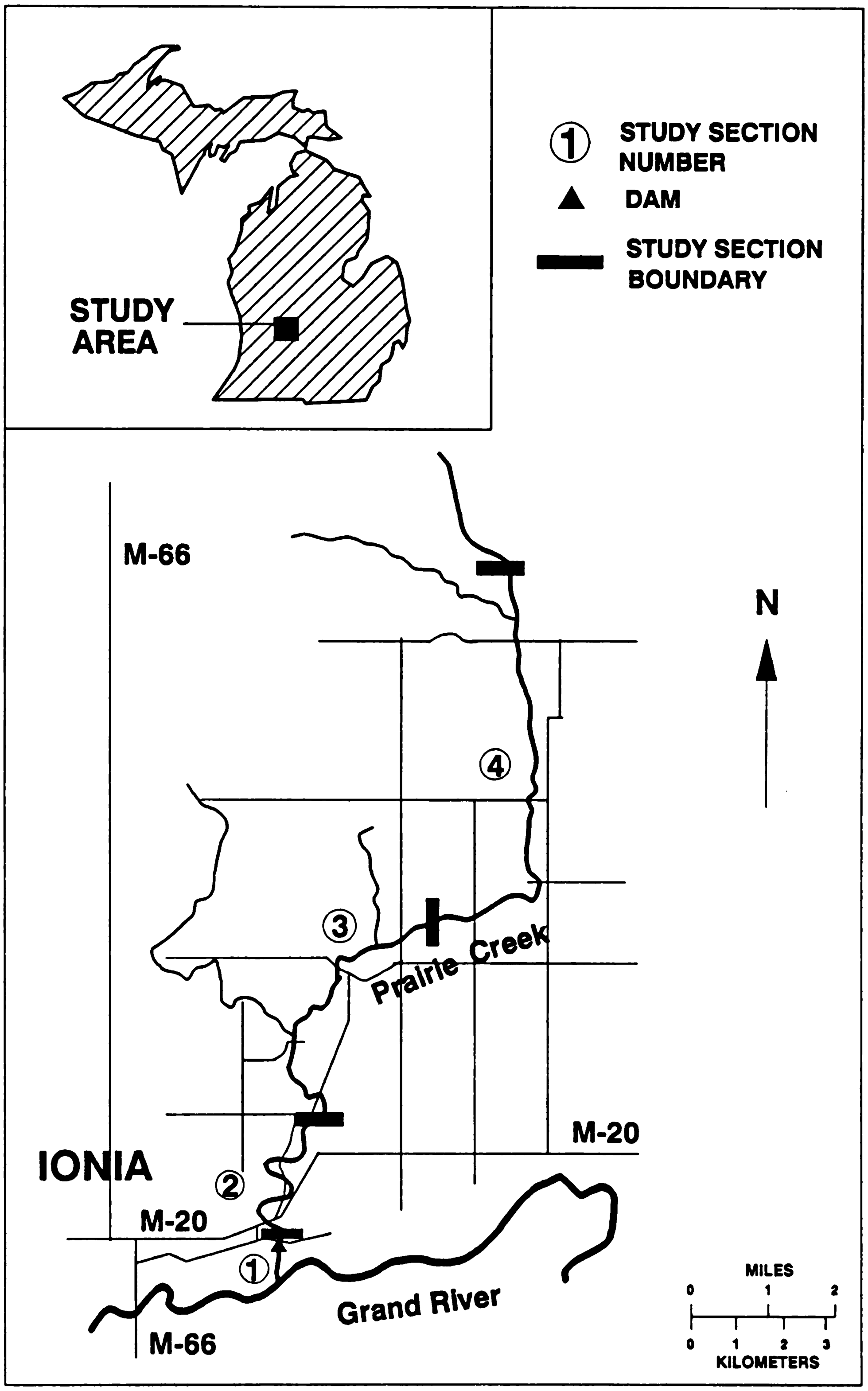


Figure 1. Location of study area: Prairie Creek, Michigan.

in Prairie Creek on three separate occasions: once in 1966, again in 1975 and recently in 1991 (A. Hilt, MDNR, personal communication). The brown trout and steelhead have been stocked into the creek periodically since 1966, especially after each chemical treatment (A. Hilt, MDNR, personal communication).

A dam with a fish ladder is located less than a mile upstream from the mouth. The dam, located at its present site for many years past, was refurbished and elevated in 1972 to prevent the passage of "rough fish" (i.e. non-game species thought to compete with the salmonids) from the Grand River (Weaver, 1981, MDNR, interoffice communication). In this way, the MDNR hoped to reduce the number of chemical treatments needed to control these unwanted species (Weaver, 1981, MDNR, interoffice communication). Spawning chinook and coho salmon have been observed upstream of this site; therefore, they have been able to utilize the fish ladder or swim over the dam.

To choose sites for fall sampling, I divided the river into four sections (Figure 1). The smaller tributaries of Prairie Creek were not included in this study because often they were very narrow, intermittent or had a high proportion of silt. I assumed spawning would not occur in these due to insufficient habitat.

The southernmost section is situated between a dam and the mouth of the stream (Figure 2). The first 50 m

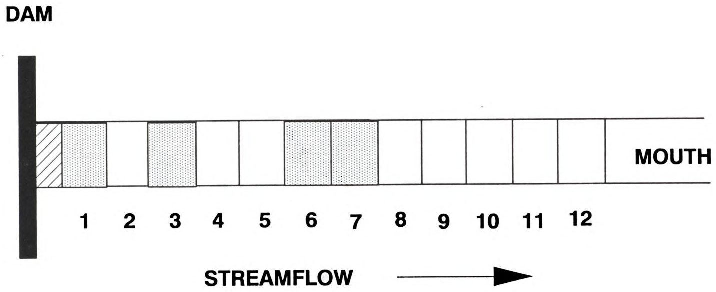


Figure 2. Sites selected for study in Section 1 (shaded areas). Prairie Creek, Michigan, 1989-1990.

downstream of the dam were ignored in case the bridge or angling activity may somehow affect spawning habitat or behavior. The remaining 1200-m stretch was divided into twelve 100-m sites. Four of these sites were then chosen randomly.

Each of the other three sections contained four bridges (Figure 3). Sampling occurred near bridges because of ease of access. The first 50 m on each side of each bridge were ignored for the same reason as with the first section, to avoid any influence of the bridges on spawning behavior or habitat (Figure 4). The 300 m beyond that on each side were divided into 100-m sites, six in all. One site was then randomly selected. Therefore, each of the four sections contained four sites, sixteen sites in all, and these 1600 m sampled totaled approximately 7% of the entire study area.

I investigated each site by wading in the stream, and the sites were observed many times over the spawning period in the fall of 1989 and 1990. All redds were located and counted. Usually coho and chinook redds could not be differentiated from one another. An estimate of total number of redds was made assuming a normal distribution. Total redds in each section were calculated by multiplying the mean density of sampled redds in a section (per 100 m) by the total length of that section. The totals within all sections were then summed. The variance of the estimate of

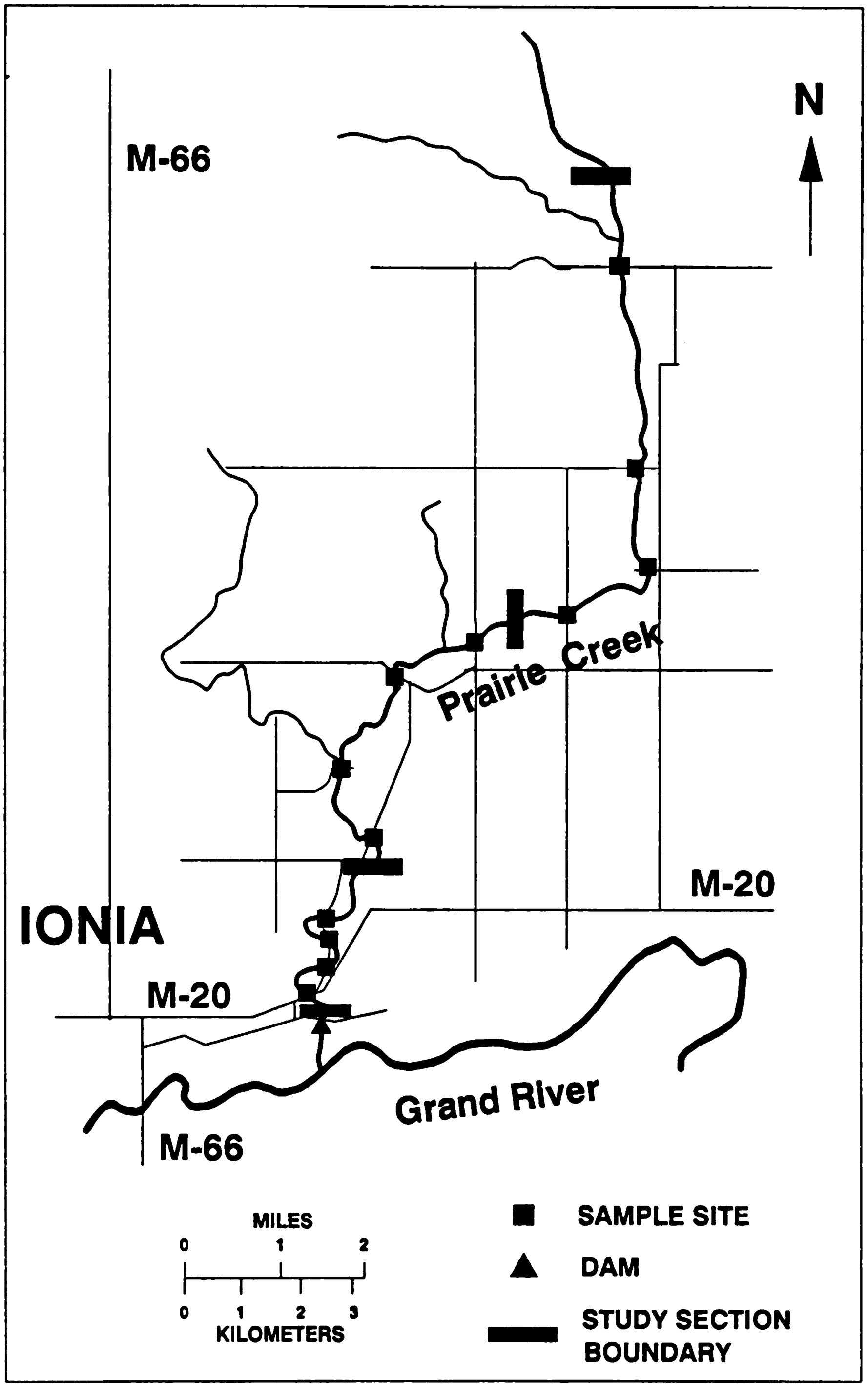


Figure 3. Location of sample sites in Sections 2,3, and 4. Prairie Creek, Michigan, 1989-1990.

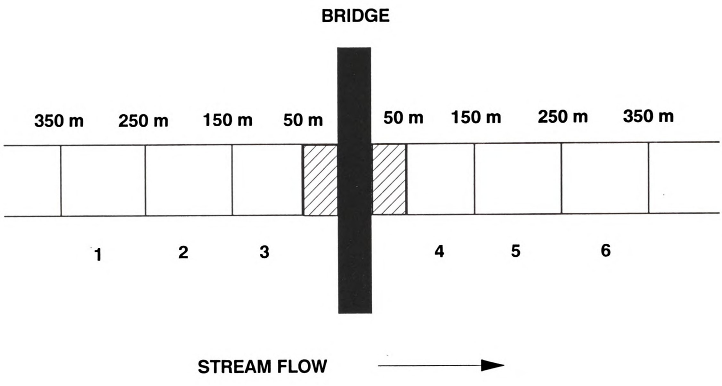


Figure 4. Selection of sites in Sections 2, 3, and 4. Prairie Creek, Michigan, 1989-1990.

total redds within each section was calculated using the following equation:

$$[(\text{length of section})^2/(\text{length of site})^2] * \text{var } u$$

where var u = the variance of the mean density of redds in a section (based on sums of squares). These variances of total redds in each section were summed to produce a variance of the total redds in the stream. The standard deviation calculated from this variance was then multiplied by the appropriate Student's t value to produce a 90% confidence interval with 15 degrees of freedom.

A chi-square test was performed to determine if any significant differences existed between number of redds above the dam and number below the dam (the data from the sections above the dam were pooled). The maximum length and the width across the depression of each redd were measured and averages were calculated. In addition, measurements of streamflow and water depth were taken over the streambed just upstream of each redd and over the ridge and depression of each redd. The streamflow in m/s was measured at the streambed and at 0.6 of the depth from the bottom using a Marsh-McBirney digital meter. The actual depth of each depression within the existing streambed was found by calculating the difference between the water depth over the streambed and the water depth over the depression; these depths were averaged for all redds. Air and water temperatures in degrees Celsius were measured with a

hand-held thermometer at the time of observations. The proportion of each substrate size within each redd was estimated using four main size classes: sand, which is .25 to 3 mm in diameter; fine gravel, 4 mm to 4 cm; coarse gravel, 4.1 cm to 8 cm; and cobble, 8.1 cm to 30 cm.

Seven redds were excavated in winter 1990 to determine egg presence and viability. The method was similar to those described by Hobbs (1937) and by Braum (1978). The device used to sample the eggs consisted of a 1 m x 1.3 m rectangular frame of PVC pipe to which fine-meshed netting was attached, and this was held perpendicular to the current downstream of the redd. Starting at the downstream edge of the redd and moving towards the ridge of the tailspill, I shovelled the sediment to a depth of approximately 0.5 to 1 m and deposited it about 0.5 m upstream of the net. The larger particles were allowed to settle back down to the streambed while the finer particles were carried by the current into the net. Disturbed eggs caught in the current were also trapped in the net. The live eggs were identified by their translucent, orange appearance; the dead eggs were opaque and white.

During spring 1990, two fyke nets were used to block the river and catch smolts moving downstream. Fyke nets were used because they were inexpensive, easy to handle and readily available. And other investigators (Davis et al. 1980; Milner and Smith 1985) have found that fyke nets are effective for capturing smolts. The two nets in this study were installed about 300 m upstream of the dam. The net openings were 1.2 m x 1.5 m oblong frames made of wood and were straight on one side so that they would rest flush with the streambed when set (Figure 5). Attached to each frame was a funnel approximately 3 m in length with three inner funnels. Only one net was set between April 27 and June 5, 1990 in the area of greatest flow (Figure 6). Because the net had only one long lead that could extend to the streambank, a seine was used to block the other side of the river. From June 6 through July 2, the funnels of the two nets were situated next to each other perpendicular to the current and again in the water of highest velocity (Figure 7). The lead-nets were attached to these and ran upstream toward each shore at a 45° angle from the streambank, blocking off the entire stream. Mesh size of all netting used was 1.25 cm. Steel reinforcing rods with diameters of 0.6 cm and 1.25 cm were used to anchor all parts of these nets.

The nets were set from four to six times a week, mainly at night between 9:00 pm and 9:00 am because no smolts were found when they were set during the day. Each morning during sampling, the nets were checked for smolts. Any smolts found were counted and measured for length. Stream temperatures were measured on a Ryan thermograph and on a

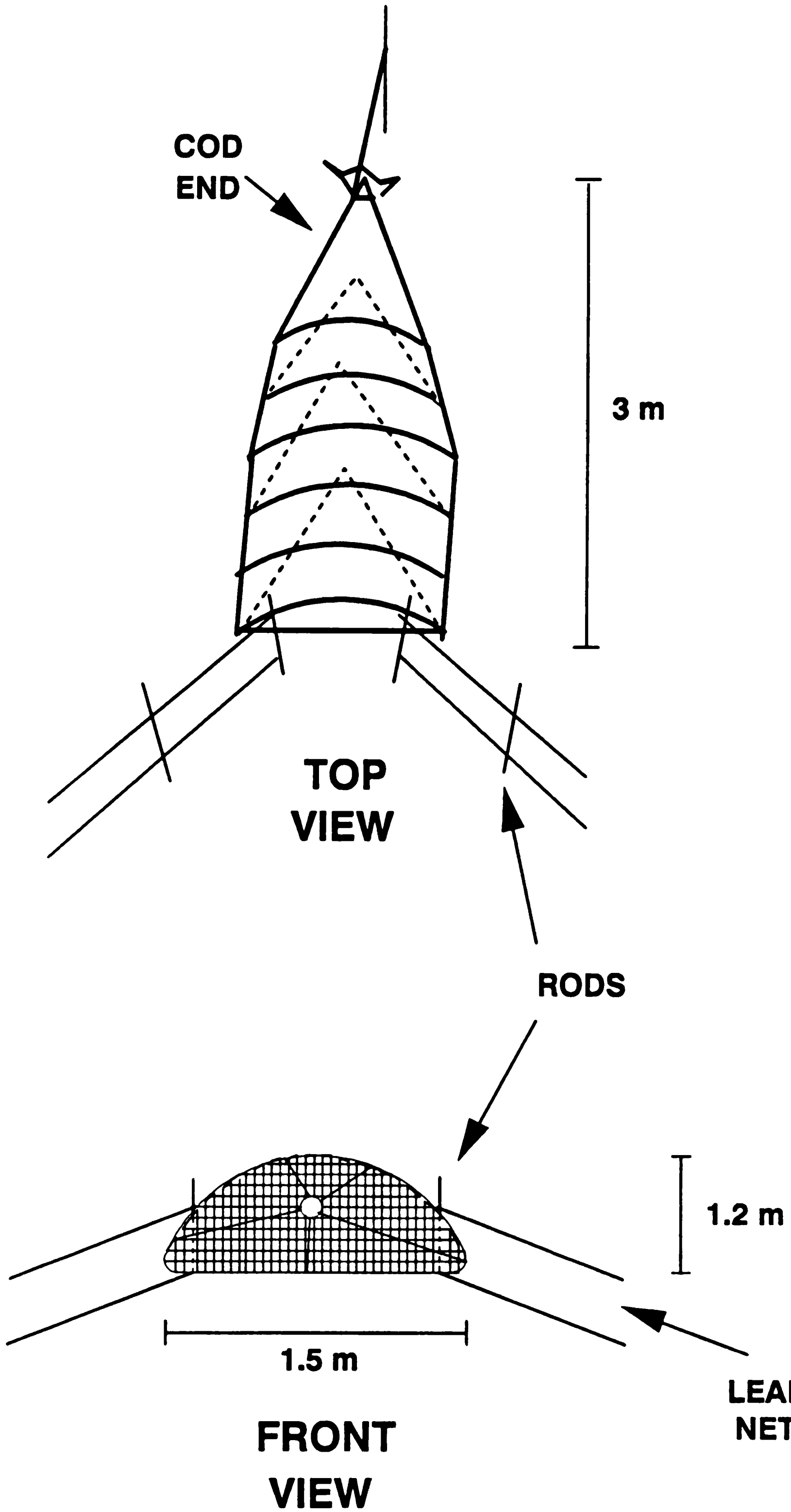


Figure 5. Design of fyke net used to capture salmon smolts in Prairie Creek, Michigan, spring 1990.

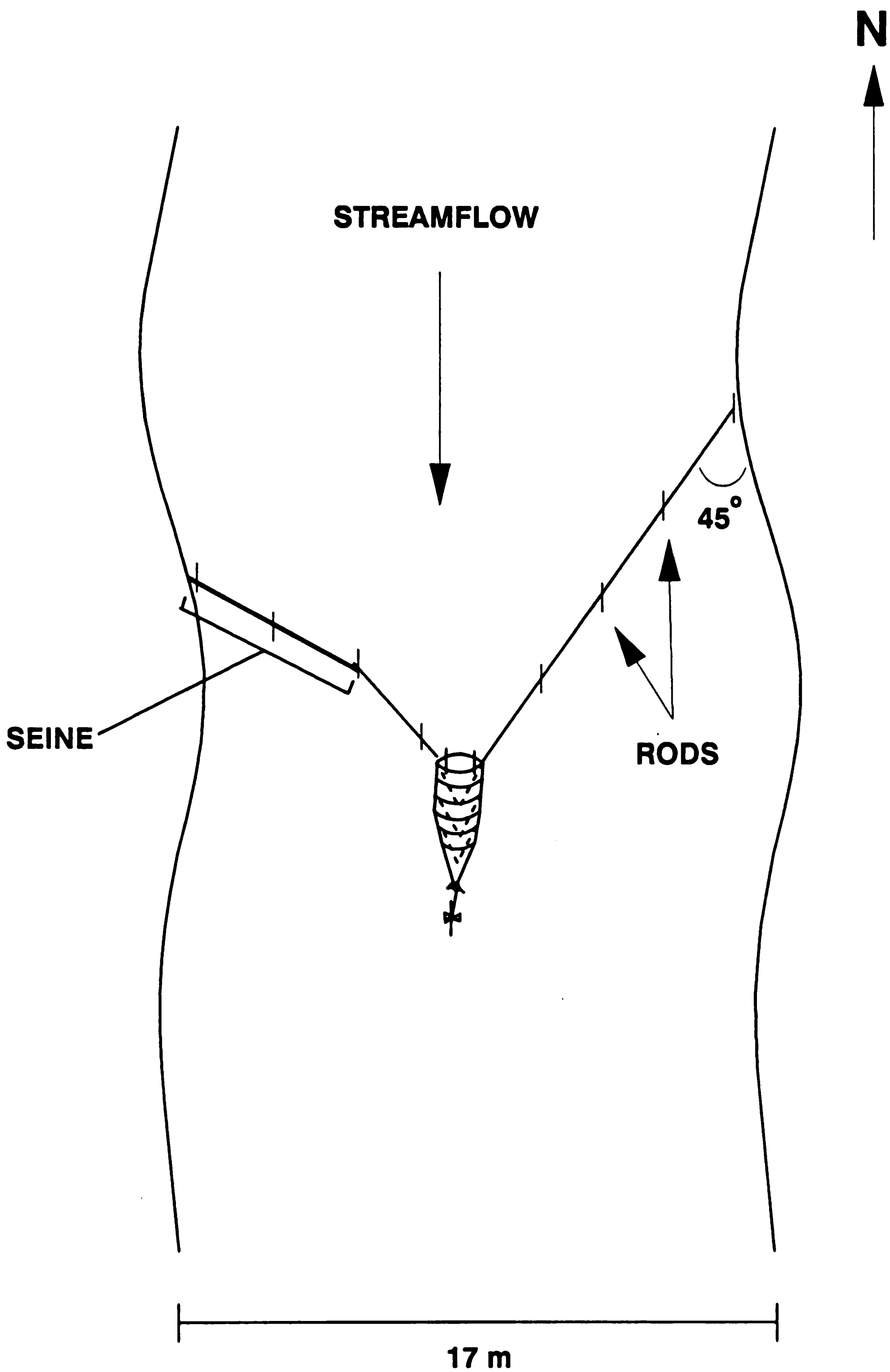


Figure 6. Placement of single fyke net to capture salmon smolts in Prairie Creek, Michigan, late April - early June, 1990.

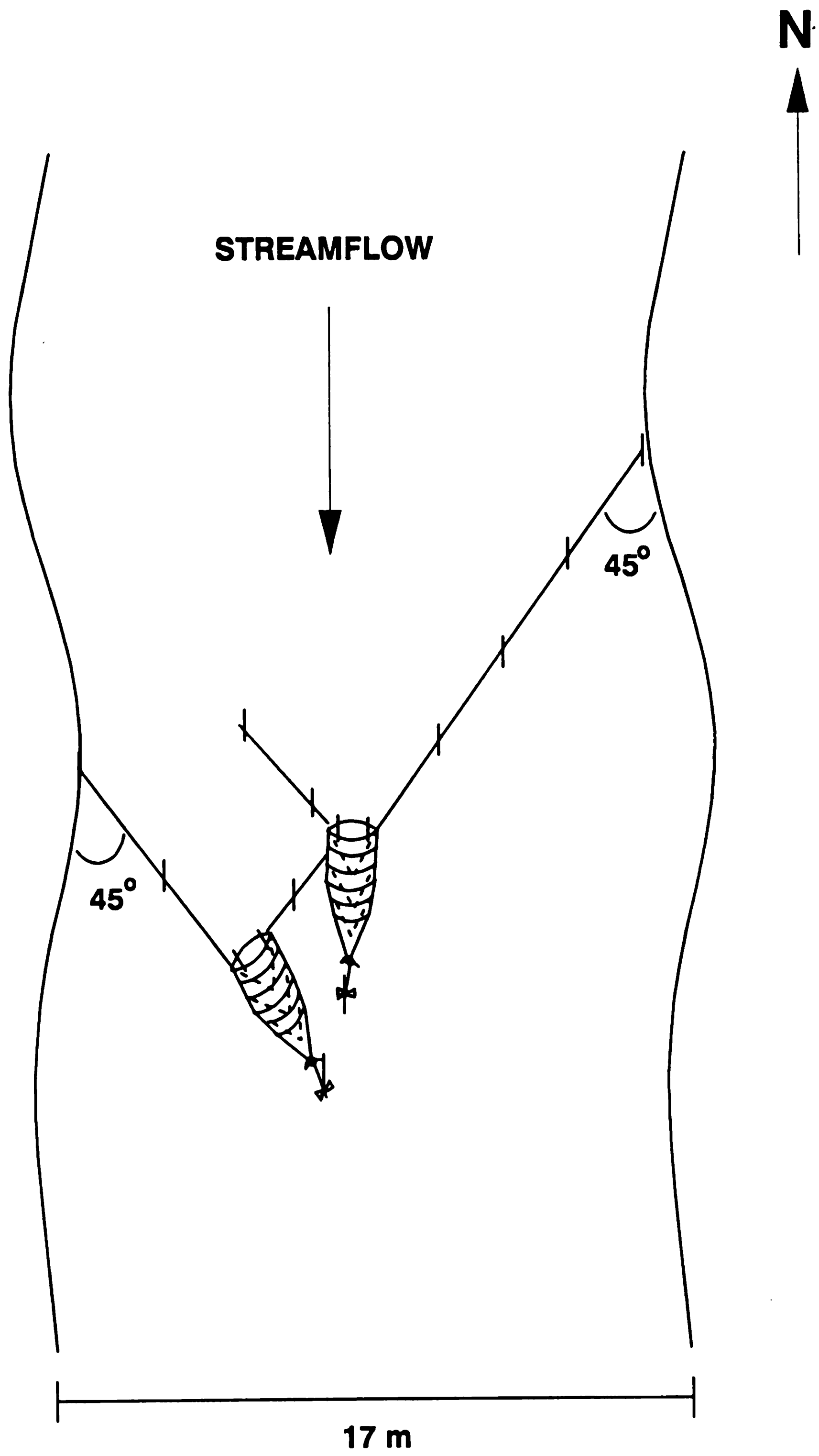


Figure 7. Placement of two fyke nets to capture salmon smolts in Prairie Creek, Michigan, early June - early July, 1990.

hand-held thermometer. The time of migration was noted. A weighted mean migration date (weighted by the number of smolts migrating per day) was calculated by assigning a consecutive number for each date during the migration period; for example, the number 614 corresponded with June 14, the number 615 with June 15, etc. Multiplying each number by the number of smolts caught on that particular day, summing over all the days, and dividing this result by the total number of smolts gave the weighted mean migration date. A normal distribution was assumed.

# RESULTS

Between October 3 and November 7, 1989, a total of 32 redds were counted (Table 2). After this date, no new redds were created. All fish seen associated with the redds were positively identified as coho and chinook. The total number of redds in Prairie Creek with a 90% confidence interval was estimated to be 366.65 ± 398.75. This confidence interval may seem very wide and is mainly due to the small sample size, which produced a very high variance. The estimate of total redds produced a density of approximately 14 redds per km. The number of redds above the dam significantly differed from the number below the dam ($p < 0.05$), based on densities of 1.5 redds per 100-m site above and 3.5 per 100-m site below. Many anglers were present, especially below the dam, during this sampling.

The lengths of all redds measured ranged from 0.9 to 6.5 m with a mean length of 2.3 m ± 0.49. Widths ranged from 0.5 to 4.7 m with a mean width of 1.5 m ± 0.36. And redd depths ranged from 0.04 to 0.20 m with a mean depth of 0.1 m ± 0.02. The mean depth of the streambed just upstream of the redds was 0.375 m. The stream velocities at redd locations ranged from 0.19 to 0.88 m/s. The mean velocity

Table 2. Redd frequency in all sites, Prairie Creek, Michigan, fall 1989.

| SITE | SECTION 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| A | 0 | 0 | 3 | 0 |
| B | 2 | 3 | 3 | 0 |
| C | 9 | 1 | 0 | 0 |
| D | 3 | 2 | 2 | 4 |
| TOTAL | 14 | 6 | 8 | 4 |
| MEAN | 3.5 | 1.5 | 2 | 1 |

was 0.57 m/s $\pm$ 0.064. The above estimates all include 95% confidence intervals. The water temperature ranged from 6.5°C to 12°C during the spawning interval. Seventy percent of redds sampled had fine gravel as the main substrate. Almost 17% had equal amounts of fine gravel and coarse gravel. Sand was abundant in only five redds and comprised from 20 to 35% of the observed substrate.

Of the redds sampled for eggs, three of the seven had live eggs, one contained only dead eggs and the remaining three were apparently devoid of eggs. The diameter of 40 eggs was measured; egg sizes ranged from 6 to 7 mm. Anchor ice was common over many of these redds. Two fry incubated and hatched from eggs collected in Prairie Creek were identified as chinook.

Eight fry were caught between April 30 and May 31, 1990. Their lengths ranged from 35 to 55 mm. Outmigration of chinook smolts occurred from May 28 to July 1, 1990, with peak migration occurring in mid-June (Figure 8). Data for days not sampled were estimated based on data from several days before and after those dates. No coho smolts were caught. The weighted mean migration date was June 14. A total of 66 smolts was captured. They were identified by the loss of parr marks, a silvery appearance and a streamlined body shape (Hoar 1976). With one exception, water temperatures at night during smolt outmigration were 16°C or above (Figure 9). Lengths of smolts were 48-95 mm, with a mean of 76.2 mm $\pm$ 3.11. More smolts were in the 80-89 mm size class than in any other particular size class (Figure 10). No pattern was found linking lengths and timing of migration; smolts of all sizes were present throughout the migration period.

During high flows in spring 1990, drift would rapidly collect on the lead nets, creating greater force on the nets. This in turn bent the rods to the point that the current was flowing over the float line of the leads. Many fry may have escaped in this current. By the time the smolts began migration, water levels were quite low, and this was not a problem.

Only two redds were seen during fall 1990, one in Section 1 and one in Section 4. Two fish carcasses were

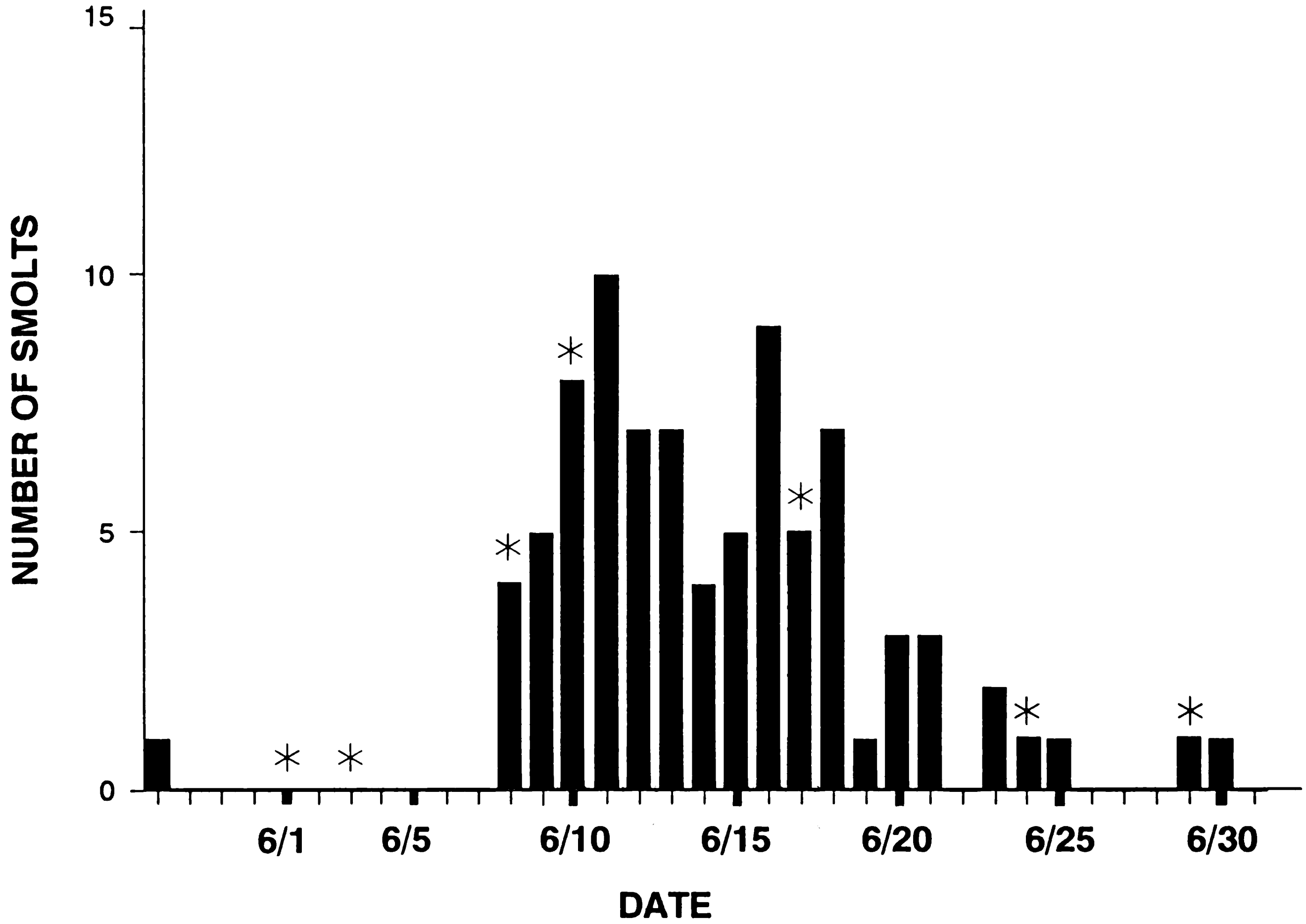


Figure 8. Migration of chinook smolts, Prairie Creek, Michigan, spring 1990. (* No sampling on these dates; data estimated from previous and subsequent data points.)

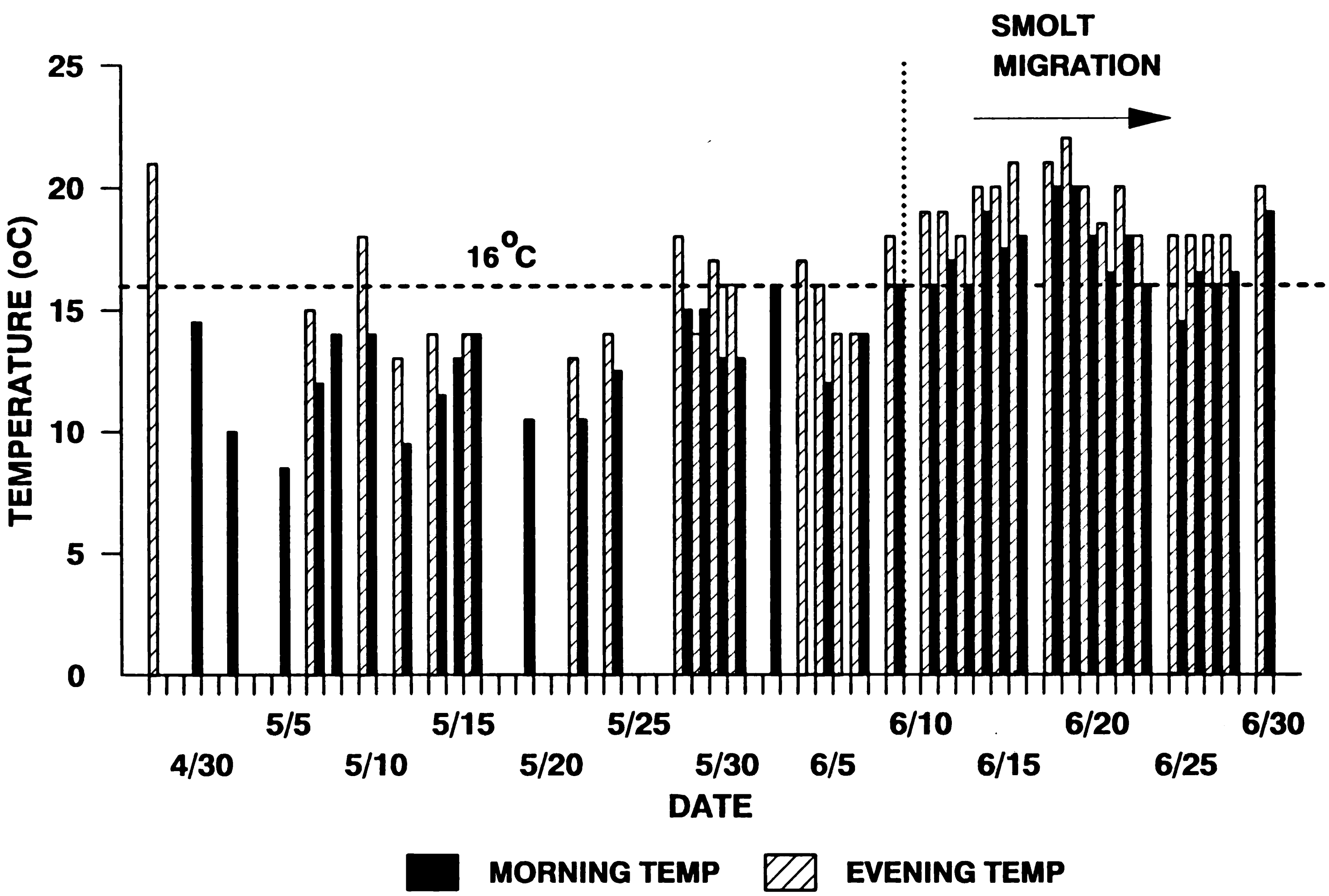


Figure 9. Morning and evening temperatures during smolt migration sampling, Prairie Creek, Michigan, spring 1990.

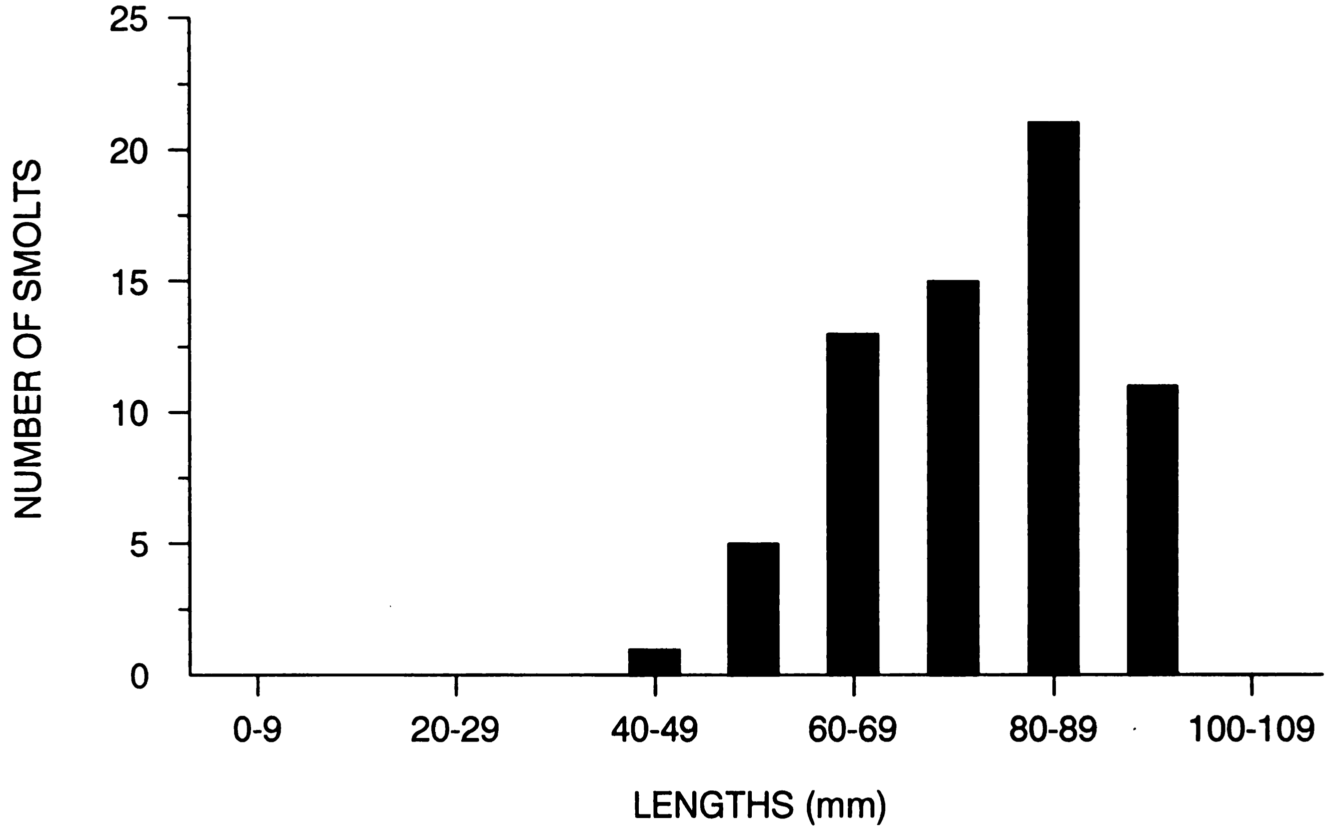


Figure 10. Length frequencies of chinook smolts, Prairie Creek, Michigan, spring 1990.

seen in Section 3, and these were identified as chinook. At the beginning of sampling, water levels were higher than the previous year, and the water was very turbid. If spawning did occur, it was difficult, if not impossible, to observe. When the water levels eventually receded and turbidity decreased, little evidence of spawning was present.

# DISCUSSION

## I) Spawning Returns: 1989.

Spawning of coho and chinook salmon was observed in Prairie Creek in 1989. The estimate of 366 total redds produces a density of approximately 14 redds per kilometer. The mean numbers of redds per 100 m site in Prairie Creek (3.5 below the dam and 1.5 above the dam) were much lower than those described by Taube (1974) who found averages of 15.26, 14.98 and 13.34 coho redds per 100 m in 1969, 1970 and 1971, respectively, in a 2279.9 m stretch of the Platte River in Michigan. However, the Platte River is considerably larger both in discharge and cross-sectional area.

Migration in Prairie Creek during 1989 began in late September. By the beginning of November, spawning had ceased. Taube (1974) noted that coho spawning on the Platte River had ended by November 18, November 19 and November 2 in 1969, 1970 and 1971, respectively. During 1977-1978, coho spawning peaked in early November in Bigelow Creek and in late November in Pine Creek (Carl 1983), and chinook spawning in Baldwin and Pine Creeks during those years occurred from the end of September through mid-November, with maximum spawning in mid- to late October (Carl 1984). Studies in tributaries of Lake Ontario revealed that coho and chinook moved into the creeks to spawn from late September through early October (Keleher et al. 1985) and that peak spawning of chinook occurred earlier than that of coho (Johnson and Ringler 1981). Burner (1951) found Columbia River fall chinook spawned from September through mid-November. In British Columbia, Big Qualicum River chinook spawned from mid-October to early November, peaking in late October, and coho spawning peaked during the first half of December (Lister and Genoe 1970). Peak spawning of the coho and chinook in Prairie Creek could not be determined; when counting redds, I often did not see fish associated with them.

It is interesting to note the significant difference between numbers of spawners above the dam and those below the dam. Possibly the dam is a definite barrier to these fish. Banks (1969) refers to many studies showing that light is needed by anadromous salmon to pass obstructions when they would otherwise choose darker or more turbid conditions when migrating upstream. Also, salmonids may have a range of flows in which they can swim over dams. Possibly the flows during fall 1989 were low enough to impede some of the spawners. It should be noted that 30% of the area below the dam was sampled; only 5% of the area above the dam was studied. Areas above the dam with high densities of redds could have been overlooked due to the sampling method.

II) Spawning Returns: 1990.

Results for 1990 were very different than those in 1989. Only two redds were counted, and two carcasses were the only salmon observed. They were not found with the redds but may have been carried downstream. Many factors may have influenced these results: floods during fall when these fish were deposited as eggs inhibiting spawners from upstream migration or washing out the eggs; heavy harvesting of those spawners preventing them from depositing eggs; anchor ice slowing intragravel flow and decreasing the amount of oxygen transported to eggs; floods in early spring washing the hatching and emerging fry downstream, causing higher mortality; high temperatures in Prairie Creek limiting survival of coho fry during their first summer after hatching; intense predation on the fry or smolts that made it to the Grand River; predation, harvesting and disease, among other things increasing mortality of these fish as they grew in Lake Michigan; high angling pressure on spawners on the lower Grand River; and high flows and turbidity in Prairie Creek during the fall of 1990 impeding their upstream migration.

Of course, all these factors apply assuming the returning salmon are wild. If these salmon were stocked fish that had strayed into Prairie Creek, those factors mentioned that limit the egg-to-presmolt phase would not apply. Widespread straying of coho and chinook within the Great Lakes is a well-known phenomenon (Rybicki 1973; Scott and Crossman 1973; Patriarche 1980; Wenger et al. 1984). Wenger et al. (1984) found that 51.4% of returning radio-tagged coho and chinook in Lake Erie strayed to tributaries other than those into which they were originally released. Evidently, Great Lakes salmon are much more likely to stray than Pacific Coast populations (Scott and Crossman 1973; Wenger et al. 1984). And the last year that chinook were stocked in the Grand River upstream of Prairie Creek was 1984; those spawners returning in fall 1989 may have been the last remnants of that population that happened to stray into Prairie Creek (A. Hilt, MDNR, personal communication). Therefore, it is possible that many of the salmon returning to Prairie Creek in 1989 were of hatchery origin and were mixed with wild fish.

Those naturally-produced chinook that would have returned to Prairie Creek to spawn in 1990 were probably progeny of fish that spawned in fall 1985 or 1986. Although no spawners were sampled for age in this study, it is likely that they were mainly ages 0.3 (zero years in the stream and three years in the lake) and 0.4, as reported by Hay and Houghton (1990). According to Rybicki et al. (1990), coho in the Great Lakes have a three-year life cycle and spawn

when they are age 1.1. Therefore, the spawning coho of 1990 were most likely deposited as eggs in fall 1987.

The precipitation data for Ionia indicates slightly higher than normal rainfall in fall 1985 (R. Moore, NOAA, unpublished data). Heavy precipitation in southern Michigan in fall 1986 produced record high (100-year) floods (Rakoczy and Nelson 1990), and gage readings on the Grand River at Ionia were twice as high as normal in September and October of that year (Table 3). Fall 1987 saw no unusually high water levels; they were similar to those of fall 1989. Although no actual flow data are available for 1985 and 1986, the abnormally high water levels may have impeded the upstream migration of spawning salmon, especially in 1986.

Table 3. Monthly high gage levels (in feet) of the Grand River at Ionia, Michigan during fall 1985-1989 (R. Moore, NOAA, unpublished data).

| MONTH | | | YEAR | | |
|---|---|---|---|---|---|
| | 1985 | 1986 | 1987 | 1988 | 1989 |
| Sept. | 14.96 | 23.22 | 9.27 | 13.36 | 8.75 |
| Oct. | 11.89 | 22.97 | 8.79 | 8.60 | 15.41 |
| Nov. | 17.40 | 11.07 | 12.10 | 12.64 | * |
| MEAN | 14.75 | 19.09 | 10.05 | 11.53 | 12.08 |

* Data not available.

Although Banks (1969) reviewed many studies that show no correlation between discharge and migration, he concluded that the rate of flow is probably the main factor influencing migration. Light intensity and temperature may also influence migration when coupled with discharge. Huntsman (1948) reported that Atlantic salmon began to ascend a stream as a freshet started, with the majority ascending just after peak discharge as water levels fell. However, Hunter (1959) stated that chum and pink salmon had a maximum flow above which migration would be impeded, and Wenger et al. (1984) stated heavy rainfall that produced unusually high water levels inhibited the migration of coho and chinook in tributaries of Lake Erie. This may have been the case during the record flows of fall 1986. The water levels of fall 1985, though, were about average and probably did not impede migration of spawners.

Stream levels that are too low can also inhibit migration, at least until the salmon are very mature, at which time they will migrate regardless of streamflow (Banks 1969). However, in a study by Keleher et al. (1985), chinook and coho failed to move far upstream, possibly due to low discharge. It is possible that the flows during fall 1987 were low enough to inhibit the passage of salmon over the dam and would have produced similar results to those found in 1989. If this is the case, suitable spawning

habitat above the dam, if present, would not have been fully utilized, and therefore less production would have resulted.

High stream flows in 1986 may have not only prevented spawner migration, but also washed out redds and the eggs contained therein before they are covered by the female (Braum 1978; Quinn and Tallman 1987). If not washed out, the eggs could have been damaged if gravel in the redd was shifted by the strong flows; in addition, these flows could have deposited silt on the redds, suffocating the eggs (Wickett 1958; Foerster 1968).

Harvesting of spawners is probably a major factor limiting natural production of salmon in Prairie Creek. The MDNR has determined that the Grand River produced over 34,000 angler hours of salmonid fishing in 1986 (Rakoczy and Rogers 1987) and over 81,000 in 1987 (Rakoczy and Rogers 1988). On the Kalamazoo River, Michigan, almost 22,000 angler hours were fished between September and November, 1985 (Rakoczy and Lockwood 1988). Within the tributaries of Lake Ontario studied by Keleher et al. (1985), 78 per cent of the returning tagged salmon were taken by angling and snagging. Carl (1982) reported heavy harvesting of spawning chinook on the Manistee and AuSable rivers, with females taken off their redds. He presumed that this led to lower egg deposition thereby limiting production in these streams. This is likely the case with Prairie Creek. Many anglers were observed there in fall 1989, and the creek has been very popular for salmon fishing in years past (A. Hilt, MDNR, personal communication). No angler-use data have been collected on Prairie Creek, though.

Of those eggs actually deposited in falls 1985, 1986 and 1987 and not washed out by high flows, some may have been susceptible to mortality during the winter months. Anchor ice, observed over redds in winter 1989/1990, probably was present in earlier years and may have decreased the intragravel flow of water, important for bringing oxygen to eggs and washing away waste products (Vaux 1968). However, even if flows were significantly diminished, the water probably contained sufficient oxygen to sustain the eggs; those eggs found during winter 1989/1990 were alive and appeared healthy.

Silver et al. (1963) studied the effect of different water velocities and oxygen concentrations on the development of chinook eggs and found that changes in oxygen had more effect on timing of hatching and on size of embryo than changes in velocity. In the above study, at dissolved oxygen (D.O.) concentrations below 2.5 mg/l, no hatching occurred. At 2.5 mg/l or above, the hatching rate was high, although post-hatching survival was lower at lower concentrations. Increasing velocity tended to increase post-hatching survival, but with high D.O., not as high a velocity is needed to transport sufficient D.O. to the developing embryos. Embryos reared at a high D.O. were

larger than those reared at a low D.O., and embryos reared at a high velocity were larger than those in low velocity. Differences in embryo size were more pronounced with changes in D.O. concentrations than with changes in velocity. Therefore, even if anchor ice lowered intragravel water velocity in the redds, the very cold water was probably saturated with oxygen and provided more than enough D.O. to produce high egg and post-hatching survival.

Another source of mortality includes flooding in the early spring that may displace the emerging fry and wash them out of the stream. Extensive flooding of Prairie Creek in the spring is not unusual. High water levels were observed in spring 1989 and 1990. Gage height readings taken in the Grand River at Ionia during April and May of 1986 and 1987 show water levels approximating average annual levels (Table 4). March of 1986 and March through early April, 1988, however, had much higher than average levels, and March 1986 readings were 75% higher than those of the same month in 1987 and 1988.

According to Scott and Crossman (1973), coho salmon emerge from the gravel during March and April. Ottaway and Clarke (1981) determined that salmon fry are more vulnerable to flow at younger stages, and they agree with McDonald (1960) that upon losing visual contact with the substrate and other stationary objects at night, salmon may lose positioning in the stream. The emerging fry in Prairie

Table 4. Monthly high gage levels (in feet) of the Grand River at Ionia, Michigan during spring 1986, 1987, 1988, and 1990 (R. Moore, NOAA, unpublished data).

| MONTH | YEAR | | | |
|---|---|---|---|---|
| | 1986 | 1987 | 1988 | 1990 |
| March | 21.62 | 12.38 | 13.90 | 20.74 |
| April | 12.96 | 10.83 | 18.51 | 13.30 |
| May | 12.71 | 9.98 | 9.81 | 13.41 |
| June | * | * | 8.13 | 10.09 |
| MEAN | 15.76 | 11.06 | 12.59 | 14.39 |

* Data not available

Creek could easily have been displaced by the swift current, especially in 1986, and carried downstream, possibly to the Grand River. These fry might have then encountered less available food, higher predation and overall harsher conditions, all leading to higher mortality.

Many predators of salmonid fry and smolts inhabit the Grand River and its tributaries, including the steelhead (*O. mykiss*), brown trout (*Salmo trutta*), coho yearlings and largemouth bass (*Micropterus salmoides*) found in Prairie Creek during August 1986 (C. Bays, MDNR, unpublished data) and during spring 1990 when trapped in my nets. Other possible predators I found at that time were northern pike (*Esox lucius*), smallmouth bass (*Micropterus dolomieui*) and crayfish (Families Astacidae and Cambaridae). These predators, among others, may have caused extensive mortality on the fry and smolts in the riverine habitat and during the first year of lake residence. Predation has been postulated to be a major limiting factor on juvenile Atlantic salmon (MacCrimmon 1954) and the main determinant of juvenile to smolt survival (Symons 1979). Larsson (1985) reported that predation produced 35 to 70% mortality of a smolt run.

Because chinook smolt and migrate to the lake the same season they hatch, they are not affected by the stream water temperatures during the warmer periods of the year. Coho, however, spend their first summer and winter in the stream before smolting the following spring. According to Brett (1952), coho prefer temperatures between 12 and 14°C with an upper lethal limit of 25.0°C. The highest temperature I recorded during June 1990 was 22°C, which is near that upper limit. It is likely that Prairie Creek reaches or even exceeds 25°C during the summer months. No water temperature data were available for Prairie Creek during these months for any year, except that collected in August 1986 (C. Bays, MDNR, unpublished data). During this time, no temperatures over 20°C were reported. These measurements were few, though, and were collected over a short two-day sampling period. If water temperatures do rise above this 25°C limit, if only for a few days, coho production would be severely limited. Reduced growth and increased mortality could result. However, coho juveniles in Prairie Creek can escape this thermal stress by moving to pools or migrating farther upstream. Apparently, the brown trout and steelhead (other species with restrictive upper lethal temperature limits) that are stocked in the creek have been able to withstand the summer water temperatures. Perhaps these coho juveniles can also survive them.

Competition with brown trout, steelhead or even chinook juveniles could also push the coho young out of Prairie Creek early. Consequences of this, mentioned previously, include increased predation and harsher conditions. Definite size classes between coho and steelhead juveniles, though, may cause them to choose different food sources. While coho fry hatch in March or April, steelhead do not hatch until late May or June. And steelhead that had hatched the previous year would be much larger than those coho fry. Stein et al. (1972) found little interaction between trout and salmon in Sixes River. Rainbow (steelhead) fry inhabit faster water while coho fry prefer the slower water of pools and stream margins (Hartman 1965; Johnson and Ringler 1980). Bustard and Narver (1975) agree with this consensus; they also found that during winter, steelhead fry occupy rubble areas, whereas coho fry prefer roots, logs and bank cover areas. These studies did not relate this to time of emergence and growth of fry. But Carl (1983) states that competition is present between coho and steelhead and between coho and chinook and that it is minimized behaviorally through spatial segregation.

According to Lister and Genoe (1970), coho and chinook juveniles tend to be spatially segregated because the chinook hatch earlier and are always larger. In another study, though, coho emerged two weeks before chinook (Stein et al. 1972). Nevertheless, they were spatially segregated; coho preferred upstream areas and tributaries while chinook more often occupied the main river channel (Stein et al. 1972).

Populations of these salmonids in Prairie Creek are probably too low to induce much competition. And what little competition exists probably forces some individuals to migrate. Steelhead coevolved with coho and chinook on the Pacific Coast, and behavioral differences have evolved to minimize competition between these species (Rybicki et al. 1990). Everest and Chapman (1972) found little competition between chinook and steelhead due to disparate times of emergence. Additionally, coho-brown trout competition in the Great Lakes has been found to be fairly insignificant (Rybicki et al. 1990).

Once the coho and chinook reach Lake Michigan, they begin to grow at a rapid rate (Scott and Crossman 1973). During this time (eighteen months for coho and 3.5 to 4.5 years for chinook), predation, harvesting and diseases such as bacterial kidney disease can cause increased fatalities.

Mortality of young salmon in the lake is probably caused mainly by predation; as the salmon grow, harvesting becomes a more important mortality factor. Nevertheless, the percentage of any year class taken by harvesting is very low (Rybicki et al. 1990). Patriarche (1980) estimated that only 7.4% of the entire 1977 coho year class stocked in Lake Michigan was taken by the sport fishery.

Bacterial kidney disease (BKD) has become an important issue lately with agencies stocking coho and chinook in the Great Lakes. BKD occurs naturally in salmonids but usually is activated only by some environmental stress. The incidence of BKD in coho and chinook populations has increased in recent years, and a large die-off of chinook occurred in Lake Michigan during spring 1988 (Keller and Smith 1990b). Due to an environmental stress, these fish had much lower overall resistance and were stricken by BKD as well as other infections and stresses (Keller and Smith 1990b). The year classes of salmon that spawned in 1989 and 1990 were more than likely affected by this disease.

Although these mortalities of coho and chinook in Lake Michigan can be significant, it is generally hypothesized that the egg-to-smolt stages of salmonids undergo the heaviest mortality. For example, Foerster (1954) showed that high mortality of sockeye salmon occurs before seaward migration. Upon review of many studies, Braum (1978) also concludes that mortality among freshwater fishes is highest in the first year of life. Furthermore, Kocik and Taylor (1987) assert that factors limiting year-class strength affect pink salmon during the early part of their life while in the stream environment. Basically, "...it is the riverine ecosystem that plays the principal role in determining the recruitment of oncorhynchid populations" (Kocik and Taylor 1987).

If juvenile survival of those salmon spawning in 1990 had been high and effects of mortality factors in Lake Michigan were not significant, those fish may have encountered intense harvesting in the lower Grand River before they reached Prairie Creek. This is unlikely; the higher water levels and turbid conditions would lessen angler efficiency (Rakoczy and Nelson 1990). I may have missed the spawning altogether, if it did not occur during the same period as in 1989 (early October through early November). But spawners were observed climbing the dams on the Grand River during this time, although in greatly reduced numbers (A. Hilt, MDNR, personal communication). The higher flows and turbid conditions probably did not inhibit spawners in 1990. The flows were not unusually high, and, as stated previously, salmon prefer increased turbidity during migration (Banks 1969). Again, this higher turbidity may prevent passage of spawners over the dam, but no salmon were seen below the dam, either. Therefore, it appears that those year-classes of salmon that should have spawned in 1990 were very weak and that this poor spawner turnout was caused primarily by factors that affected these fish when they were juveniles.

III) Spawning Habitat Characteristics

Measurements of redd size and certain habitat characteristics associated with each redd were taken in fall 1989 in order to compare with those of other studies and also to discern the preferences of these salmon. The same measurements were planned for fall 1990, but because only two redds were observed and flows were very high and difficult to wade, I decided not to proceed with them.

Length measurements of all redds observed in the study sites averaged 2.3 m $\pm$ 0.49, and widths averaged 1.5 m $\pm$ 0.36. Therefore, these redds were probably less than 3.45 $m^2$ mean area. Fall spawning Columbia River chinook were observed to produce an average redd size of 5.1 $m^2$, which is quite a bit larger than those found in Prairie Creek (Burner 1951). In the same study, coho redds averaged 2.84 $m^2$. A study of sockeye salmon in the Taku River, British Columbia reported redd sizes with a mean width of 1.7 m, a mean length of 2.3 m and a mean area of 4.0 $m^2$ (Lorenz and Eiler 1989). The redds produced in Prairie Creek may have been produced mainly by coho; this would explain the smaller redd size. However, chinook in Prairie creek are probably smaller than those in the Columbia River and would build smaller redds.

In Prairie Creek, the mean depth of the water just upstream of the redds was approximately 0.38 m, and mean depth of each redd depression within the streambed was 0.1 m $\pm$ 0.02. Smith (1973) reported an average depth at the streambed of 0.39 m for fall chinook and 0.22 m for coho in Oregon. Chinook redds in Kalama and Toutle Rivers, Washington had mean depths of 0.37 and 0.31 m, respectively, and coho redds in the Toutle had a mean depth of 0.18 m (Burner 1951). Those chinook redds observed in a California study had a mean depth of 0.34 m, while the coho redds had a 0.15 m mean depth (Briggs 1953). Overall, the depths of redds in Prairie Creek were similar to those reported for chinook redds in these earlier studies.

In my study, water velocity was measured at 0.6 of the depth from the bottom and at the bottom of the water column over the ridge and the depression of each redd and over the streambed immediately upstream of each redd. The mean velocity over the streambed at 0.6 depth was 0.57 m/s $\pm$ 0.064. Smith (1973) also measured velocities just upstream of redds but always took measurements at 0.12 m from the bottom. Mean velocities were found to be 0.43 m/s for chinook and 0.44 m/s for coho (Smith 1973). Burner (1951) reported a surface water mean velocity of 0.61 m/s for chinook, and Briggs (1953) found mean surface velocities over chinook and coho redds of 0.61 and 0.58 m/s, respectively. Mean velocities over chinook redds in two Michigan streams were 0.42 m/s in Baldwin Creek and 0.50 m/s in Pine Creek (Carl 1984). Again, the data for Prairie Creek are comparable to those already reported.

Water temperature may be an important factor influencing salmon spawning. Snyder and Blahm (1971), contend that upstream migration of salmon is blocked by temperatures equal to or exceeding 20-21°C. However, Banks (1969) cites many conflicting studies of the relationship between temperature and migration. For example, Hayes (1953) found temperature did not trigger Atlantic salmon runs; on the other hand, Stuart (1953) concluded that brown trout would not migrate until the water temperature had fallen to 6 or 7°C for the first time each fall. Banks (1969) feels streamflow is the main factor influencing migration and that temperature, as well as other factors, may be secondary factors.

During salmon spawning in fall 1989, temperatures in Prairie Creek ranged from 6.5 to 12°C, well below the 20-21°C upper limit proposed by Snyder and Blahm (1971). Stream temperatures in a study of Lake Erie coho and chinook never rose above 18°C and did not seem to affect migration. When coho and chinook began upstream migration into certain tributaries of Lake Ontario, stream temperatures were already below 19-20°C (Keleher et al. 1985). Lorenz and

Eiler (1989) measured much colder stream temperatures (4.5-6.0°C) within sockeye salmon redds in British Columbia and Alaska. These redds were probably influenced more by groundwater and springs than by runoff, an important factor in Michigan streams.

The majority of redds sampled in Prairie Creek (70%) had fine gravel (4 mm to 4 cm diameter) as the main substrate, and another 16-17% had equal amounts of fine and coarse gravel (4.1 to 8 cm diameter). Only five redds had an appreciable amount of sand (0.25 to 3 mm diameter), ranging from 20 to 35% of the observed substrate. In the Entiat, a tributary of the Columbia River, summer chinook avoided gravel with silt and clay binders, probably due to insufficient water flow through the gravel (Burner 1951). Lorenz and Eiler (1989) found that the probability of use of habitat by sockeye spawners was greatest when the substrate was less than 15% fine sediment (in their study, less than 2 mm diameter).

As stated previously, redds containing eggs need sufficient intragravel flow to transport dissolved oxygen to the eggs and carry away their waste products; excessive silt and sand can block this flow. According to Lorenz and Eiler (1989), sockeye salmon chose areas with upwelling groundwater because those areas provide loose, uncompacted substrate and a more constant water temperature, both of which aid incubation of eggs. They concluded that substrate composition and surface water velocity are not as vital to survival of eggs and fry if spawning areas are not dependent on surface water to provide flow through the gravel. Although no data are available concerning the extent of upwelling groundwater in Prairie Creek, it is assumed to be of less importance than surface water velocity and substrate composition. Apparently the salmon chose spawning areas that had low proportions of sand and silt and that were subsequently less embedded.

IV) Egg Survival

Seven of the redds counted in fall 1989 were sampled for eggs during early winter 1989-1990. No eggs could be found in three of those redds. This does not necessarily mean that no eggs were present; rather they may have been overlooked due to problems with the sampling method. However, the absence of eggs may signify heavy fishing pressure in which females are pulled off redds before depositing eggs. Or it may denote egg retention, in which the female does not release all her eggs when spawning. Coho adults transferred to the Platte River Michigan in 1969-1971 were estimated to have between 44 and 67% egg retention which is abnormally high compared to West Coast rivers (Taube 1974). Kocik and Taylor (1987) feel egg retention is caused mainly by high spawner density. Taube (1974) offered handling as another possible cause and assumes there are other causes that have not been identified. No salmon were examined in fall 1989 to measure egg retention, but because spawner density was so low in Prairie Creek, any egg retention was probably due to some other stress factor.

The presence of live eggs and their apparent hearty condition, even when in redds covered by a thick layer of anchor ice, supports the theory that dissolved oxygen concentrations and the amount of intragravel flow within Prairie Creek are suitable for the incubation of salmon eggs. The eggs found were bright orange and ranged from 6 to 7 mm in diameter with a mean of 6.45 mm $\pm$ 0.819. This range coincides exactly with sizes of chinook eggs reported by Scott and Crossman (1973). They are also quite similar to coho eggs sampled in Lake Ontario tributaries (6.6 to 7.1 mm) and somewhat larger than those found on the Pacific Coast (4.5 to 6.0 mm) (Scott and Crossman 1973).

V) Fry and Smolt Migration

Between April 30 and May 31, 1990, eight salmonid fry were sampled. Most likely, at night these fry lost visual contact with the substrate and were displaced by rising flows which were occurring at this time according to R. Moore (NOAA, unpublished data). The peak of the chinook fry migration in a British Columbia river took place in early April and that of coho fry migration in early May (Lister

and Genoe 1970). This agrees with data from a tributary of Lake Ontario showing chinook emerging earlier than coho (Johnson and Ringler 1981). In another study, however, coho emerged before chinook in an Oregon stream (Stein et al. 1972). Carl (1984) found chinook fry drifted during early April through mid-June, 1978 and 1979 in Baldwin Creek and during May, 1978 in Pine Creek. More than 98% of all drifting fry sampled in both creeks were caught between dusk and dawn. Also, Carl (1984) estimated that of the emergent chinook fry produced in Baldwin Creek during 1978 and 1979, 25-30% drifted each year.

Lengths of Prairie Creek fry were 38-55 mm. Lister and Genoe (1970) reported coho fry between 38.4 and 41.6 mm and chinook fry between 42.9 and 69.3 mm moving downstream. Carl's study (1983) of Pine Creek, Michigan during 1977-1979 revealed mean coho underyearling lengths between 40.7 and 62.0 mm in May and June. In another study by Carl (1984), involving both Pine and Baldwin Creeks, Michigan during the same time period, chinook fry were 44-60 mm mean length. Those fry caught in Prairie Creek were coho or chinook or both; they were not identified to species. Nonetheless, the majority of fry drift of both species probably occurred before the net was set in late April.

Fry that resist displacement downstream continue to grow until they reach the smolt stage. At this time, these fish undergo physiological changes that prepare them for

life in the ocean, and they proceed to migrate out of their streams (Bley 1987; Hoar 1976; Rybicki et al. 1990; Scott and Crossman 1973). They become thinner, lose their parr marks and appear silvery and more streamlined (Bley 1987; Hoar 1976). During spring 1990, 66 chinook smolts were captured in Prairie Creek. This is an estimate of the total number of smolts above the dam. The recruitment of smolts from the area below the dam is unknown.

Smolts were caught between May 28 and July 1, 1990, with 97% migrating between June 8 and June 24. The peak of coho smolt migration occurred in late May in the Big Qualicum River, British Columbia (Lister and Genoe 1970). Coho smolts in a Michigan stream were reported to migrate in April (Carl 1983), whereas the chinook smolts migrated mainly in June (Carl 1983, 1984). The coho in a study by Seelbach (1985) smolted in mid-May, and the chinook smolted in June.

The weighted mean migration date of smolts in Prairie Creek was June 14. Calculated mean migration dates for coho in the Little Manistee River were May 15 in 1982, May 16 in 1983 and May 21 in 1984 ; chinook mean migration dates were June 13 in 1982, June 19 in 1983 and June 20 1984 (Seelbach 1985). The results for chinook smolt migration from Prairie Creek correspond well with these other Michigan studies.

No coho smolts were caught in 1990. They may have migrated in April, before the net was installed. Or they may have migrated during sampling and somehow avoided the net. Davis et al. (1980) found that coho smolts up to 150 mm fork length were collected in fyke nets at higher velocities ($\geq$ 0.7 m/s), but at lower velocities, the net seemed to select smaller fish. In early May 1990, velocities in Prairie Creek were quite high, and although this may have decreased the efficiency of the net, migrating coho smolts would not have avoided it as well. Later in the spring, the entire stream cross-section was sampled effectively during the lower water levels. Coho smolts, though large, could not have avoided the nets at this time.

Movement of smolts in 1990 occurred mainly at night, which corresponds well with the findings of Carl (1984) in his study of chinook in Pine Creek, Michigan. Migration of Atlantic salmon has also been reported to occur at night (Thorpe and Morgan 1978) as well as at dusk and dawn (Fried et al. 1978).

Lengths of the chinook smolts ranged from 48 to 95 mm with a mean of 76.2 $\pm$ 3.11. This is similar to chinook smolts in the Little Manistee River, Michigan which range from 70 to 90 mm (Seelbach 1985) and to those in the Sacramento-San Joaquin Estuary, California, which are 70-80 mm (Kjelson and Raquel 1984). Fessler and Wagner (1969) propose that the winter steelhead parr-smolt transformation is dependent on size. Refstie et al. (1977) also found that

the timing of Atlantic salmon smolting is also based on size and not on age.

During the nights that smolts were caught, temperatures were mainly 16°C or above. Increases in temperature at the time smolts began migrating might indicate that temperature plays a role in triggering smolting and migration. Other factors, such as stream flow and photoperiod, may also affect the onset of migration, alone or in conjunction with temperature. White (1936), Fried et al. (1977) and Solomon (1978) all agree that the main stimulus for Atlantic salmon smolting is increasing water temperature, with migration peaks occurring when water is 10°C or more. Becker (1973) correlated migration of young chinook with an increase in flow followed by a decrease with corresponding warmer temperatures. Kwain (1983) determined that rainbow trout smolting was caused by lower stream flow and rising water temperatures. Hoar (1976) noted water temperature and photoperiod, together with size of fish, triggered smolting, and photoperiod had a greater influence than temperature.

However, other studies declare that water temperature does not induce smolting but does affect the length of time of migration (Zaugg and Wagner 1973; Wagner 1974). In another study, chinook smolts moved out of streams only during high water after heavy rains (Carl 1984). Seelbach (1985) found that daylight length alone corresponded with peak migration dates of coho and chinook smolts. Daily mean water temperatures in his study were 7°C or higher during migration, but no relationship was established between temperature and smolt movement. Also, peak migrations were not associated with the few fluctuations in flow that occurred (Seelbach 1985). Finally, Bjorrn (1971) noted that migration of smolts "...frequently coincided with changes in water temperature and streamflow..." However, Bjorrn "...could not establish a consistent causal relationship and concluded that photoperiod and perhaps growth must initiate the physiological and behavioral change associated with seaward migration." The stimuli of chinook smolting and migration in Prairie Creek might very well be photoperiod and growth, but this could not be confirmed.

Very few smolts were captured in spring 1990. This could be due to debris clogging the opening of the net(s) during high water. It could also be due to the fact that only one net was used to block the river for a majority of the sampling period and during most of the periods of high flow and was not as efficient at capturing the fish as two nets. A total of 66 smolts was captured on Prairie Creek, and because the nets were effectively sampling the entire river at this time, that total is probably a good estimate of total chinook smolt production above the dam. However, total production of the stream's 1990 chinook year class and its supplement to the Lake Michigan salmon fishery are unknown.

Although many redds were seen during fall 1989, not all of them may have been productive and yielded smolts the following spring (due to heavy harvesting, egg retention, mortality of eggs and fry, etc.). Wright (1981) feels that spawning counts are good for assessing past management practices. In his study of Baldwin and Pine creeks, Carl (1984) found that "number of smolts produced in both streams appeared to be independent of the adult density the previous spawning season." Foerster (1954) determined that 60% of the variation in sockeye spawner returns were a function of smolt size and numbers together, and he and McLemore et al. (1989) agree that the numbers of returning spawners can be predicted by the actual numbers of outmigrating smolts. Therefore, this evidence suggests that for estimating a stream's total production of an anadromous salmonid, it may be more beneficial to enumerate smolt yields rather than spawner returns and that the latter can be used to evaluate previous management strategies.

# CONCLUSION

In summary, natural reproduction of coho and chinook was found to occur in Prairie Creek in fall 1989. Apparently, good spawning habitat is available in Prairie Creek. However, the dam could be a barrier to utilization of upstream spawning habitat and could limit salmon production. The lack of reproduction in fall 1990 was probably due more to the poor year-classes of the spawners, the absence of hatchery fish returns, and the overall decline in salmon populations in the Great Lakes than to inadequate spawning habitat conditions.

Previous studies and actual conditions on Prairie Creek during this time period suggest that highest mortality of the wild salmon probably occurred in their early life history, through the time of smolt migration. Rearing habitat, especially for coho fry in the summer, may be limiting. However, it is very likely that a majority of the fry are washed downstream during increased spring flows and sustain considerable mortality.

Timing of spawner migration, redd sizes and habitat characteristics such as substrate size, water temperature and water depth and velocity in Prairie Creek were comparable to other studies of salmonids. Of the redds sampled in winter 1989/1990, some contained live, apparently healthy eggs, while others had no eggs at all. The eggs may have been overlooked in these redds due to crude sampling methods. The lack of eggs, however, may be indicative of the occurrence of heavy angling pressure on spawners before the females can deposit their eggs. A few chinook smolts were caught during spring 1990, indicating that at least some of the spawning habitat was satisfactory for the incubation of eggs and the rearing of fry. Again, most of the fry had probably been displaced earlier in the spring, before the sampling period.

Salmon production in Prairie Creek and in the Great Lakes are probably limited by a number of factors working in conjunction. This trend of decreasing production may just be a temporary situation in a fluctuating population. But because the salmon sport fishery is so important economically, it behooves us to closely monitor these fluctuations and also the forage base supporting the salmon. Any dramatic decrease of forage fish populations may necessitate stronger management initiatives, such as heavier restrictions of the commercial harvest of these species.

If Prairie Creek were to be managed for natural reproduction, angling pressure on spawners should be monitored and possibly restricted to ensure egg deposition. Also, the dam and fish ladder should be checked to assess the ease with which salmon ascend them during upstream migration. Dams such as this have been used in the past for trout management by preventing passage of non-game species that may compete with salmonids. Other dams on streams in Michigan are used for the production of hydroelectric power. Still others are presently not used for any known purpose. Managers and the public at large must decide if these dams are serving their needs and are cost effective. If people decide that their streams should be managed for salmon, it may be necessary to dismantle the dams for easier passage. Or if the dams are serving a purpose, but salmon reproduction in the stream is desired, fish passage structures such as fish ladders should be installed to allow upstream migration. The key is access by spawners to upstream areas where habitat may be suitable.

In order to evaluate and quantify production in the stream, it would probably be better to sample smolt outmigration rather than redd density, as number of smolts has been found to be independent of number of redds. The results of this study suggest that sufficient spawning habitat may be present in many of these southern Michigan marginal trout streams and that they may be managed for salmon production.

# APPENDIX A. Supplemental data.

APPENDIX A. Supplemental data.

Table 5. Redd dimensions (in meters), Prairie Creek, Michigan, fall 1989.

| REDD | SECTION | LENGTH | WIDTH | DEPTH |
|---|---|---|---|---|
| 1 | 1 | 2.0 | 1.3 | 0.07 |
| 2 | | 3.4 | 1.5 | 0.13 |
| 3 | | 1.4 | 0.8 | 0.20 |
| 4 | | 1.4 | 1.2 | 0.12 |
| 5 | | 1.9 | 1.0 | 0.14 |
| 6 | | 3.7 | 2.1 | 0.16 |
| 7 | | 3.3 | 1.7 | 0.10 |
| 8 | | 6.5 | 4.7 | 0.17 |
| 9 | | 2.6 | 3.0 | 0.10 |
| 10 | | 1.6 | 1.3 | 0.04 |
| 11 | | 2.8 | 1.3 | 0.18 |
| 12 | | 2.8 | 1.4 | |
| 13 | | 2.3 | 1.3 | 0.11 |
| 14 | | 1.5 | 1.1 | 0.11 |
| 15 | 2 | 5.1 | 2.5 | |
| 16 | | 1.7 | 1.1 | 0.12 |
| 17 | | 1.6 | 1.0 | 0.03 |
| 18 | | 5.1 | 3.2 | 0.10 |
| 19 | | 2.2 | 1.7 | 0.10 |
| 20 | | 3.2 | 1.5 | 0.07 |
| 21 | 3 | 2.4 | 2.7 | 0.05 |
| 22 | | 0.9 | 0.5 | |
| 23 | | 1.8 | 1.1 | 0.15 |
| 24 | | 2.4 | 1.1 | 0.08 |
| 25 | | 1.6 | 0.8 | 0.10 |
| 26 | | 4.0 | 3.8 | 0.17 |
| 27 | | 0.9 | 0.7 | 0.07 |
| 28 | | 1.1 | 0.7 | 0.04 |
| 29 | 4 | 1.2 | 0.9 | 0.04 |
| 30 | | 1.8 | 0.8 | 0.06 |
| 31 | | 1.0 | 0.6 | 0.06 |
| 32 | | 1.3 | 0.6 | 0.06 |

APPENDIX A. Supplemental data.

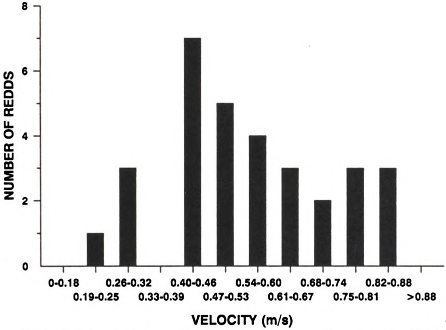


Figure 11. Redd frequency over a range of water velocities. Prairie Creek, Michigan, fall 1989.

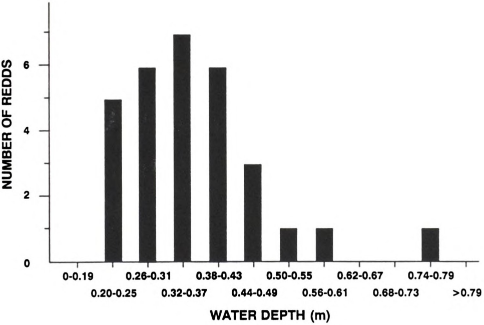


Figure 12. Redd frequency over a range of water depths. Prairie Creek, Michigan, fall 1989.

APPENDIX A. Supplemental data.

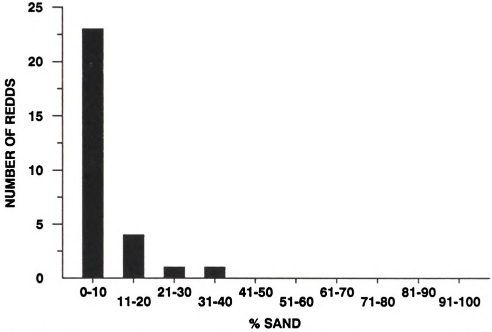


Figure 13. Sand as per cent of total substrate associated with redds in Prairie Creek, Michigan, fall 1989.

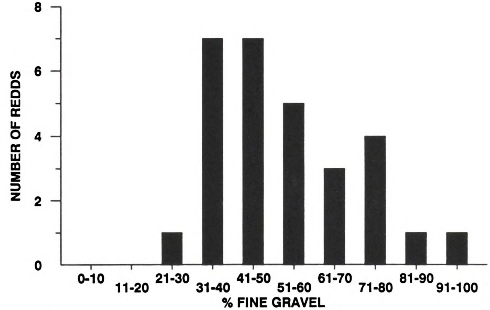


Figure 14. Fine gravel as per cent total substrate associated with redds in Prairie Creek, Michigan, fall 1989.

APPENDIX A. Supplemental data.

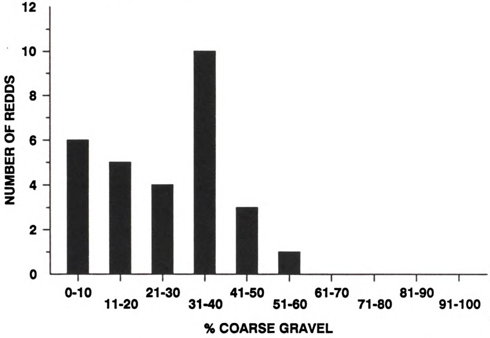


Figure 15. Coarse gravel as per cent of total substrate associated with redds in Prairie Creek, Michigan, fall 1989.

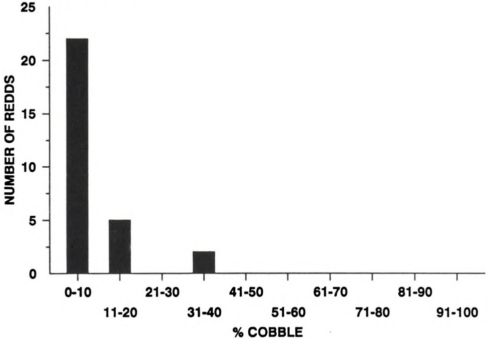


Figure 16. Cobble as per cent total substrate associated with redds in Prairie Creek, Michigan, fall 1989.

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