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thesis entitled

MIGRATION OF WILD CHINOOK AND COHO SALMON SMOLTS
FROM THE PERE MARQUETTE RIVER, MICHIGAN

presented by

David Jon Zafft

has been accepted towards fulfillment
of the requirements for
The Master of Science degree in Fisheries and Wildlife

Major professor

Date February 11, 1992

DATE DUE	DATE DUE	DATE DUE
~~FEB 2 4 1997~~ 11 18 01 NOV 1 7 2001		

MIGRATION OF WILD CHINOOK AND COHO SALMON SMOLTS FROM THE PERE MARQUETTE RIVER, MICHIGAN

By

David Jon Zafft

A THESIS

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

MASTER OF SCIENCE

Department of Fisheries and Wildlife

1992

ABSTRACT

MIGRATION OF WILD CHINOOK AND COHO SALMON SMOLTS FROM THE PERE MARQUETTE RIVER, MICHIGAN

by

David Jon Zafft

Downstream migrant chinook (*Oncorhynchus tshawytscha*) and coho salmon (*Oncorhynchus kisutch*) smolts were sampled with large drift nets from May to July in 1988, 1989, and 1990. Age-0 chinook smolt yield averaged 88,285 (260-410 smolts per hectare) and age-1 chinook smolt yield averaged 4,909. A few age-1 coho smolts were also captured. Age-0 smolts always migrated during late May and early June a few weeks after the age-1 migration. Age-0 chinook smolts averaged 80 mm total length and age-1 chinook and coho smolts averaged 141 mm and 138 mm, respectively. The onset of smolt movement was closely related to smolt size and photoperiod. Day to day variation in yield of age-0 chinook smolts was related to decreasing water temperatures, rainfall, and increased discharges. Yield of age-0 chinook smolts was highly correlated with cumulative river discharge following emergence. The number of age-1 chinook smolts may be related to discharge during the previous year.

To my parents.

ACKNOWLEDGMENTS

I would like to thank my major professor, Dr. Niles Kevern, for his continued support throughout this project. I would also like to thank my committee members, Dr. Tom Coon, Dr. Patrick Muzall, and Dr. Paul Seelbach for their support, assistance, and advice. A special thanks to Dr. Scott Winterstein for all of the time and effort he spent deriving many of the statistical procedures used in this study and to Jane Thompson for her assistance as an expert equation typist.

I would like to express my sincere thanks to those who assisted me in the field and in the lab: Lisa Dekraker, John Jackoviak, Holly Jennings, Bill LaVoie, Dave Schnepp, Scott Sowa, and Rich Tryan. A special thanks to Rob Elliott, who began this project in 1988, for all the time and hard work he invested in this research.

I would also like to thank Tom Rozich, Harry Westers, and all of the Michigan Department of Natural Resources personnel who provided valuable hatchery fish and equipment. Tom's sincere interest and support throughout this project was greatly appreciated.

Thanks are also extended to the Dow Chemical Company, the Michigan Department of Transportation, and Crosswinds Marina for access to their properties.

This publication is a result of work sponsored by the Michigan Agricultural Experiment Station, the Michigan Sea Grant College Program, and the Ludington Charter Boat Association.

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BACKGROUND AND INTRODUCTION

Chinook (*Oncorhynchus tshawytscha*) and coho salmon (*Oncorhynchus kisutch*) are two very closely related species of *salmonids* (Hoar 1976). The two species have similar social behaviors and physiological and genetic characteristics. Coho salmon regularly reach lengths of 457 to 610 mm and weights of 3.64 to 5.45 kg. Chinooks grow larger than the other Pacific salmons, generally reaching 968 mm in length and 13.64 to 18.18 kg (Scott and Crossman 1973).

Adults of both species migrate from the ocean into gravel areas of freshwater streams to spawn in the fall. These migrations are divided into three more or less distinct classes, and the fish are referred to as spring-run, summer-run, and fall-run, according to the time they leave the ocean and begin moving upstream to spawn. The characteristics of the preferred spawning habitat and redds were described in detail by Burner (1951). The eggs, which are deposited into the gravel redds excavated by the females, begin to hatch in early spring. The alevins of both species remain in the gravel for two to three weeks before emerging as fry. Although some salmon fry migrate downstream almost immediately to the sea (Beauchamp et al.

1983), most chinook salmon undergo a period of smoltification and begin migrating to the sea later in their first year of life.

Smoltification involves changes in the physiology, morphology, and behavior of juvenile salmon in April and May. Condition factors decrease, parr marks fade, serum thyroxine and gill (Na+K)-ATPase activity levels increase, and the onset of seaward migration begins (Ewing and Birks 1982). Hoar (1976) provided a detailed discussion of the evolution of smoltification and the behavioral and physiological changes associated with this transformation.

Although most chinook salmon smolt during their first year of life, others remain in their natal stream for an entire year and migrate as smolts the following spring. Coho salmon generally spend at least one year in freshwater, but occasionally juvenile coho remain in freshwater for two years before smolting. The age at which these two species of salmon undergo smoltification may be largely related to size. Healey (1983) presented evidence that chinook salmon which spend a year or more in freshwater before migrating to sea and those which migrate during their first year of life may actually be distinct races.

During the past decade, considerable research has been done to determine the preferred habitat of juveniles of the two species. In general, although both species are commonly found in similar habitats, chinook juveniles tend to be found in habitats with faster currents while juvenile coho tend to prefer slower backwater habitats and pools (Hartman 1965; Lister and Genoe 1970; Murphy et al. 1989; Ruggles 1966; Swales and Levings 1989).

Coho and chinook salmon were indigenous to the rivers of southern California, northward to Point Hope, Alaska in North America and from northern Hokkaido, Japan northward to the Anadyr River in northeast Asia. Chinook salmon were introduced into New Zealand rivers in the 1880s and after the early 1900s they became established on South Island (Unwin 1986).

Both species were first introduced to the Great Lakes in Lake Erie between 1873 and 1878, but these introductions were not successful. Another attempt was made to establish coho in Lake Erie in 1933, but the stock did not succeed. Chinook were introduced into Lake Ontario from 1874 to 1881, into the Saint John River from 1881 to 1882, into Lake Ontario from 1919 to 1925, and into Lake Erie in 1933 (Scott and Crossman 1973). All of these early attempts were apparent failures. The reason for these early failures remains largely unknown. The salmon may have been unable to compete with well established populations of large native fishes for available forage species (zooplankton and forage fishes).

During the last half of this century, the fish communities of the Great Lakes have changed dramatically. Rainbow smelt (*Osmerus mordax*) were introduced to Lake Michigan in 1912 and subsequently spread throughout the upper Great Lakes. The alewife (Alosa pseudoharengus) and sea lamprey (Petromyzon marinus) invaded the Great Lakes via the Welland Canal. The invasion of the sea lamprey was largely responsible for the decimation of large commercial fishes such as the lake trout (Salvelinus namaycush). This permitted the alwewife to attain high abundance. The large populations of rainbow smelt and alewife lead to extreme reduction or extinction of native species. As stated by Stewart et al. (1981), "the present fish populations of Lake Michigan form a management-dependent system dominated by exotic fishes."

As part of a Michigan Department of Natural Resources (MDNR) rehabilitation program for the Great Lakes, coho and chinook were again introduced to the Great Lakes in 1966 and 1967, respectively. In 1964, coho eggs were obtained from the Oregon Fish Commission. These eggs were taken at the Bonneville Dam on the Columbia River. The yearlings that were reared from the eggs were released during the spring of 1966 into the Platte River; Bear Creek, a tributary of the Manistee River; and Chinks Creek, a tributary of the Big Huron River (Taube 1975). Subsequently, coho salmon eggs have been obtained from the Cascade River, Oregon; the Toutle River, Washington; and Alaska. Michigan became self-sufficient in the production of coho eggs in 1967. The Alaskan strain, which was originally perpetuated from spawning runs in Thompson Creek, has since been lost (MDNR 1989).

In 1967, chinook salmon were successfully introduced into the Great Lakes using fall run stocks from the Toutle River and Green River hatcheries, Washington. These later introductions of Pacific salmon were successful largely because of the excellent forage base provided by large populations of alewife. Michigan now obtains all of its salmon eggs from fall spawning runs trapped at weirs within the state.

At the onset of the salmon stocking program, it was generally accepted that natural reproduction of salmon in Great Lakes tributaries would be minimal because Pacific salmon were believed to require a period of saltwater rearing to successfully complete the processes of smoltification and continue to grow and mature (Carl 1984). Therefore, the introduced populations would provide a put, grow, and take fishery that could be controlled and maintained by hatchery production and stocking. This type of management was complicated in Lake Michigan due to the individual stocking programs of the four shoreline states (Illinois, Indiana, Michigan, and Wisconsin). By 1975, the MDNR alone was planting over 1.9 million coho fingerlings and over 2.8 million chinook in Michigan tributaries to Lake Michigan. In addition, successful natural reproduction by both coho and chinook salmon was occurring in Michigan streams as early as 1973 (Rybicki 1973; Taube 1974).

The extreme success of the introductions during the 1960s resulted in a very valuable sport fishery for Pacific salmon. From 1985 to 1987, chinook and coho salmon made up 50 to 58 percent and 13 to 20 percent, respectively, of all the salmonids harvested in Lake Michigan. Fishery managers were well aware of the influence the large populations of chinook and coho, as well as other salmonids, might have on the salmonid-forage relationship in Lake Michigan (Stewart et al. 1981). In 1987, as an apparent result of a poor 1984 year class, chinook catch rates and adult returns to MDNR weirs declined significantly from an historical average of about 6 to 9 percent, to about 2 percent in 1984. While returns now appear to be gradually increasing, the need to develop a better understanding of salmon populations in the Great Lakes has become apparent.

Pacific salmon research in the Great Lakes is still in its youth. Attempts have been made to determine juvenile migrations and food habits (Stauffer 1975), adult movements and harvest rates (Close et al. 1984; Patriarche 1980), growth rates, abundance, and the effects of interspecific competition (Carl 1982 and 1983; Close et al. 1989; Stauffer 1977; Taube 1975), fecundity, reproduction, and recruitment (Avery 1974; Colvin et al. 1985; Peck 1974; Stauffer 1976). The contribution of naturally reproduced Pacific salmon to the Great Lakes remains largely unknown.

In 1976, Carl began a four year study to determine the extent of natural reproduction by salmon in Michigan streams (Carl 1982, 1983, and 1984). He estimated mid-June populations of chinook salmon within seven large Lake

Michigan tributaries by extrapolating earlier estimates using daily mortality rates from an intensive three year study of three smaller streams (Carl 1983). The lengths of each of the larger streams were measured using county contour maps, and smolt yield was calculated by multiplying the appropriate estimate by the spawning distance measured for that stream. He estimated that for the Michigan waters of Lake Michigan, a minimum of 23 percent of the smolts produced in 1979, (630,500 ± 17,700) came from natural reproduction in the lower peninsula (Carl 1982). The second largest smolt estimate in this study was from the Pere Marquette River, a system that has never been stocked with chinook. Plants of coho salmon in 1968 and 1969 into Ruby Creek, a tributary of the Big South Branch of the Pere Marquette River, were the only introductions of Pacific salmon into this river system (MDNR 1968, 1969). The present population of chinook salmon in the Pere Marquette River most likely became established from straying of hatchery-produced fish in the late 1960s and early 1970s.

Seelbach (1985, 1986) estimated salmon smolt outmigration on the Little Manistee River, Michigan. Considerable natural reproduction by Pacific salmon has also been documented in streams tributary to Lake Ontario (Johnson and Ringler 1981; N.H. Ringler, State University of New York at Syracuse, personal communication) and Lake Superior (R.B. DuBois, Wisconsin Department of Natural Resources, personal communication). These studies have documented the survival of Pacific salmon fry in tributaries of the Great Lakes and have indicated that the potential contribution of smolts from natural reproduction may be substantial. This potential, however, may be restricted by predation and physical barriers that inhibit successful movement of smolts out of a river system (Raymond 1979).

As the evidence for the existence of substantial natural reproduction by salmon within many of the tributaries to the Great Lakes continues to grow, there is still a lack of consensus among fishery managers regarding the significance of the natural contribution when compared to the large number of hatchery fingerlings that are released annually. Knowledge of the smolt migrations of wild salmon is valuable for the operation of effective planting programs, but this information is scarce for the Great Lakes Region (Seelbach 1985).

The objectives of this study were to 1) accurately estimate the number of salmon smolts that survive downstream migration and leave one of Michigan's larger rivers, the Pere Marquette River; 2) compare this estimate to the estimate made by Carl (1982); 3) determine the size and age at which salmon smolts migrate; 4) describe the timing of the downstream migration; and 5) describe the relationship between a number of environmental factors on the timing of the smolt outmigration.

STUDY SITE DESCRIPTION

The Pere Marquette River is a fourth order stream that flows in a westerly direction for more than 160 km through Michigan's Lake and Mason Counties and empties into Lake Michigan at Ludington. It is a free flowing, naturally productive, high quality stream that maintains substantial populations of brown trout (Salmo trutta) and spawning grounds for steelhead trout (Oncorhynchus mykiss) and coho and chinook salmon. In 1978, a 106 km section of the Pere Marquette River was classified as a National Scenic River. The portion of the watershed above Highway-37 (Figure 1) consists primarily of Winterfield sand. Tawas and Roscommon soils are common in oxbows and depressions. Tawas is also found on ridges and mounds. Below Highway-37, Tawas-Roscommon soils predominate.

Using county contour maps, I estimated that the Pere Marquette drains approximately 2000 km^2 and has an average gradient of approximately 0.34 m/km. Average annual discharge is 19.4 m^3/sec. Historical maximum and minimum flows are 182.4 m^3/sec and 8.8 m^3/sec, respectively (Blumer et al. 1989). Mean maximum annual flows (April) and mean minimum annual flows (August) are 19.3 m^3/sec and 13.2 m^3/sec, respectively. There are no impoundments on the Pere Marquette or any of its major tributaries.

The upper river is fed by three major tributaries; the Little South Branch, the Middle Branch, and Baldwin Creek.

The Little South Branch and Middle Branch come together at "the Forks" southeast of the village of Baldwin to form the Pere Marquette River. About 2.5 km downstream from the Forks, the Baldwin empties into the Pere Marquette (Figure 1). The upper 13 to 16 km of the Pere Marquette are characterized by numerous bends with deep, slow holes interspersed with large riffle areas. The high banks in this portion of the watershed are densely forested with white pine (*Pinus strobus*), red pine (*P. resinosa*), oak (*Quercus sp*.), and elm (*Ulnus sp*.). The lower portions of these three tributaries and the upper portions of the mainstream contain most of the salmon spawning habitat. During November, 1971, MDNR personnel counted 504 salmon redds in the segment of stream between location (A) and "the Forks" (Figure 1). Salmon may also spawn successfully in a number of the smaller tributaries to these streams (Appendix A). During April 1989, salmon fry were found as far downstream as Weldon Creek.

The largest tributary to the Pere Marquette, the Big South Branch, enters the river approximately 110 km downstream from the Forks. The Big South Branch contributes about 35 percent of the Pere Marquette's total discharge. In sharp contrast to the rest of the Pere Marquette, this stream is characterized by slow moving waters with a tannic acid color. The murky colored waters are caused by its drainage from oak-pine uplands and surrounding cedar swamps. Although salmon undoubtedly stray into the Big South Branch

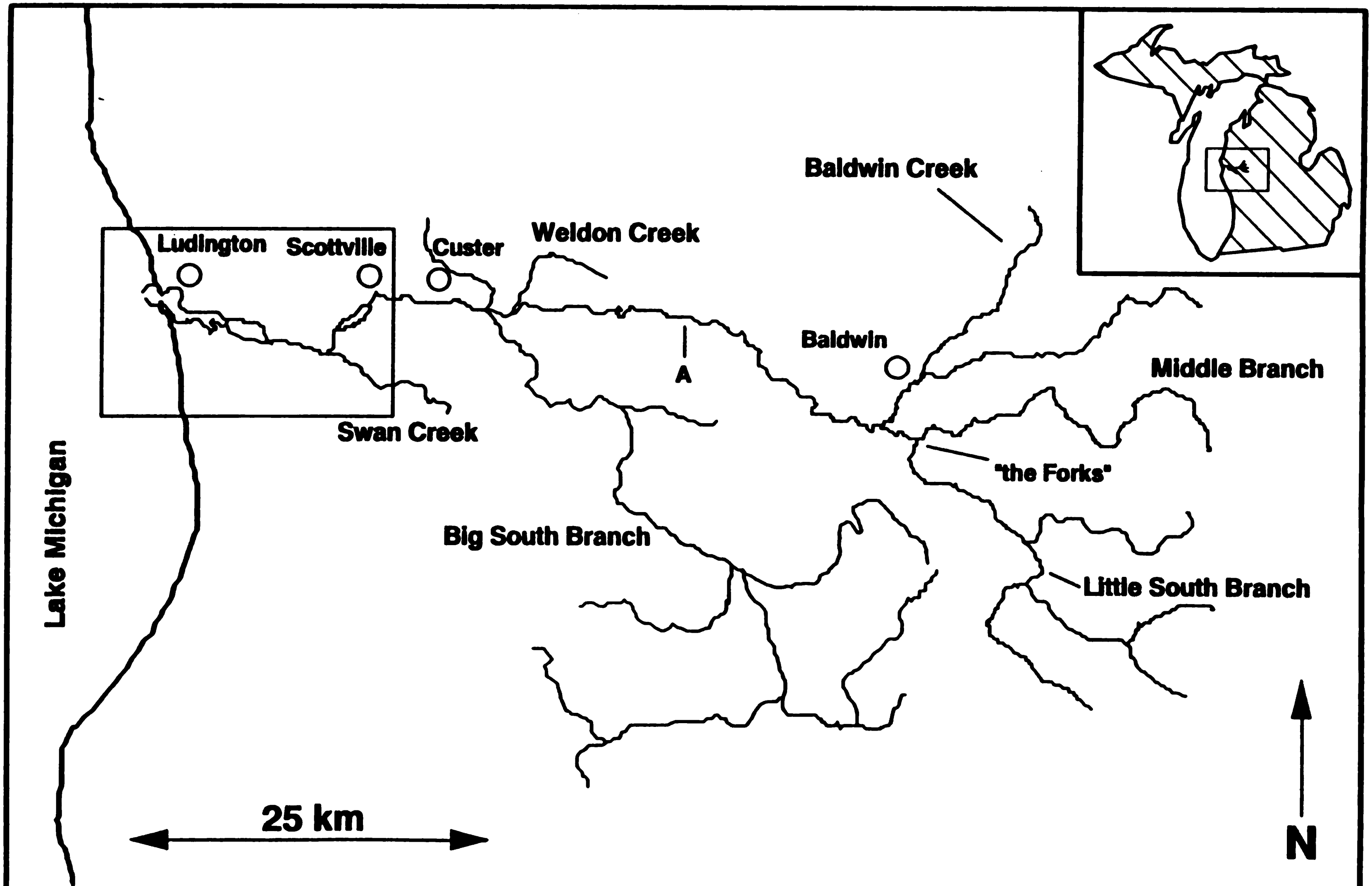


Figure 1. The Pere Marquette River and major tributaries (the rectangle shows the area which is enlarged in Figure 2).

and its many tributary streams, successful natural reproduction by salmon is most likely very limited due to the lack of suitable spawning habitat.

The lower Pere Marquette River gradually becomes more turbid due to drainage from the agricultural lands of western Mason County. Downstream from Scottville (Figure 2), the river channel becomes braided for a short distance and the river banks are often separated by large expanses of cattail marsh. Below Scottville, the river again flows as a single channel until just above old U.S. Highway 31. Here the river branches and enters a wide floodplain. The two primary channels come together just upstream from a bridge owned by Dow Chemical Company. Immediately below this bridge, the river enters Pere Marquette Lake (265 ha) prior to emptying into Lake Michigan.

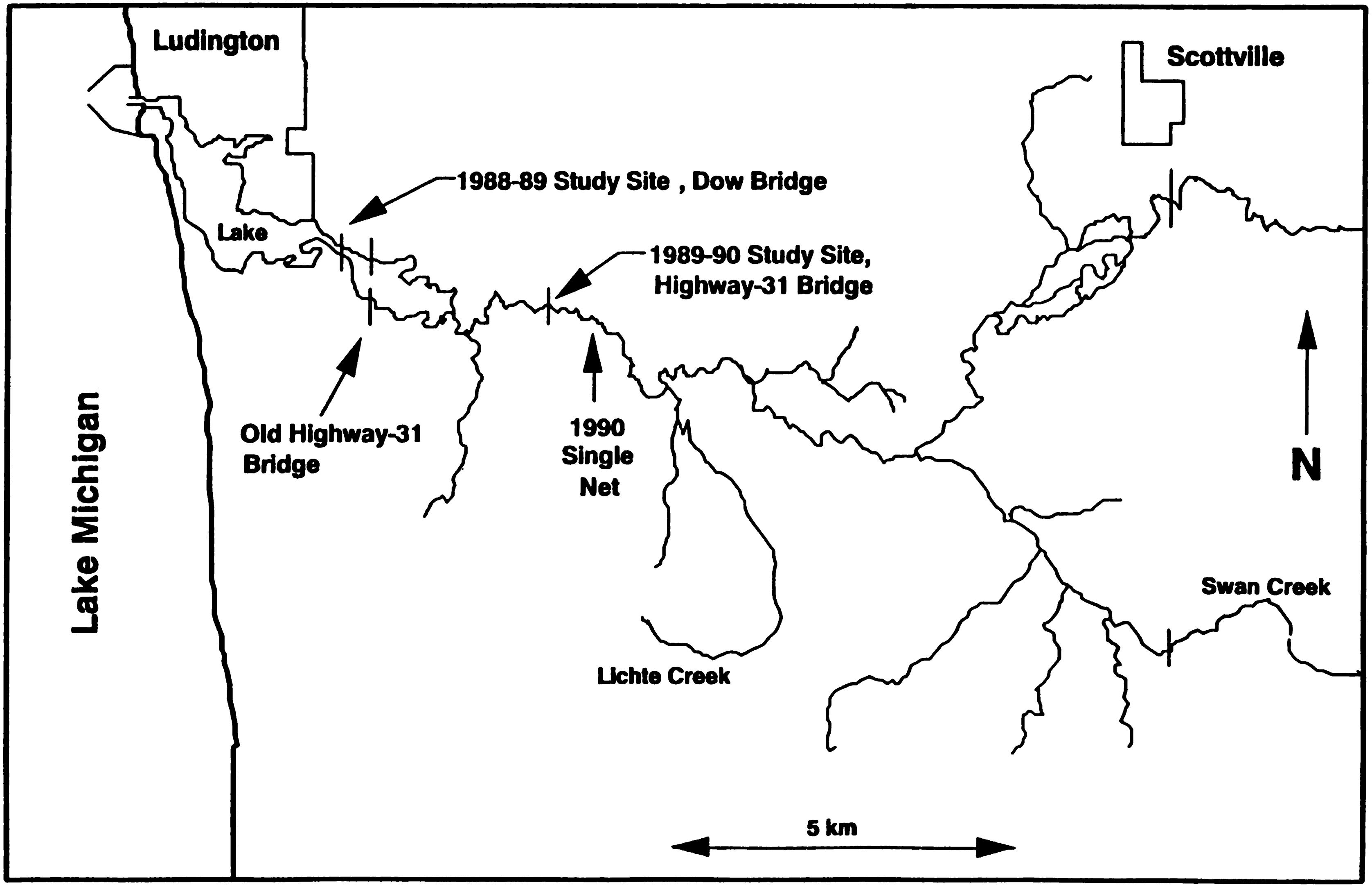


Figure 2. The Pere Marquette River below Scottville. Trapping locations from 1988 to 1990 are shown (Dow bridge, Freeway-31 bridge, and the single net upstream from F-31).

MATERIALS AND METHODS

In order to account for as much of the actual smolt yield from the Pere Marquette River as possible, the Dow bridge (T18N,R18W,S23,SE) was chosen as the study site in 1988 (Figure 2). This location was chosen for a number of reasons:

1) Most, if not all, of the natural reproduction and smolt rearing habitat is located upstream.

2) All smolt losses to predation, other than predation within Pere Marquette Lake itself, would occur upstream.

3) The location is made up of a single, narrow (35.1 m) channel of fairly uniform depth (3.2 m), thereby facilitating representative sampling using drift-net type gear.

4) The site was readily accessible (by boat from a marina on Pere Marquette Lake).

5) Because the surrounding shoreline is private property and boat travel around the bridge is limited, the likelihood of vandalism was minimized.

The unforeseen problem of periodic river backing, apparently due to west-east seiches in Lake Michigan, periodically reduced the efficiency of the trap. Subsequently, during the spring of 1989, we chose a second study site to be used in addition to the Dow site. This study site was located 5.6 km upstream from Dow at the Freeway-31 bridge (T18N,R18W,S30,NW1/4, SE1/4), which was under construction at the time. This site also satisfied the above criteria, although there may have been some additional smolt losses due to predation in the lower river. The river is approximately 30.5 m wide and has an average depth of about 2 m at the Freeway-31 (F-31) bridge. Both sites were used in 1989 to test for substantial differences in results due to study site location. During the spring of 1990, the Dow site was abandoned in order to concentrate efforts at a single, satisfactory location.

Trap Selection and Design

A number of traps have been designed to capture and hold salmonid smolts. In small to medium sized rivers (less than 15 m^3/sec), stake nets (Hare 1973) and inclined-screen traps (Lister et al. 1969; Seelbach 1985, DuBois et al. 1991) have been used successfully. However, stake nets require water less than one meter deep and inclined-screen traps require a weir or similar structure for their attachment. In larger rivers, floating scoop-traps (Todd 1966) and modified fyke nets are generally used (Craddock 1959 and 1961; Davis et al. 1980; Dlugokenski and Hager 1981; Milner and Smith 1985). Scoop traps are expensive and are not capable of sampling a significant portion of a large river. Fyke nets are relatively inexpensive, but usually require considerable attention to keep them free of debris.

A modified fyke net was chosen for use in this study. Fyke nets generally require a shoreline water-surface anchoring system that may pose problems to navigation. Due to the expense and the likelihood of maintenance problems associated with an underwater pulley and cable anchoring system similar to that described by Davis et al. (1980), existing bridges and trees were used to anchor nets.

Nets and live boxes were constructed from 4.8 mm Delta 20 kg knotless nylon netting. Nets had 3.05 x 3.05 m openings and tapered 9.14 m to a 61 x 61 cm square frame of 9.5 mm solid tubular aluminum. The frame was attached to a removable 61 cm x 121.9 cm live box frame made of the tubular aluminum. The live box contained a funnel that tapered 91.4 cm to a 10.2 x 10.2 cm opening at the rear of the live box. The top of the net on the upstream end was attached to a 3.35 m section of PVC pipe and the bottom of the upstream end was lashed to a 3.35 m section of 2.54 cm steel pipe. Both the top and bottom of the net were anchored to a cable strung between two bridge pillars or large trees (6.4 mm diameter cable was used for single nets and 12.7 mm diameter cable was used to for anchoring multiple nets in order to minimize sagging and keep the cable well above the water surface). Details of net design are shown in Appendix B.

By floating a stable 4.88 m (or larger) boat beneath the bottom ropes, two people could use the ropes to pull the bottom pipe to the surface and close the net, thereby reducing the current flow through the net and facilitating the removal of the live box. The boat could then be passed beneath the bottom and top ropes a second time and drifted downstream under the length of the net while shaking the net free of debris before attaching the live box. While this procedure proved to be very strenuous, two people could close a net, remove and empty the live box, shake the net free of debris, attach the empty live box, and reopen the net in less than 10 minutes.

Upstream Sampling

Prior to the onset of the smolt outmigration various locations within the Pere Marquette River and the upper tributaries were sampled with seines and electrofishing gear in order to collect additional juvenile salmon size data and estimate upstream densities. All salmon were anesthetized, identified to species using the morphology of the anal fin (Stein et al. 1972), counted, measured to the nearest millimeter in total length, and released. Densities were estimated using the depletion method of population estimation (Zippin 1956, 1958). Growth rates were calculated by dividing the difference in mean length of successive samples of fry measured during sampling by the number of days between samples. The growth rates were adjusted for the recruitment of newly emerged fry into the study section between sampling dates (Carl 1984).

In an attempt to validate the earlier assumption regarding the apparent lack of suitable salmon spawning habitat in the Big South Branch and most of its tributaries, nets were set at upstream locations for two nights in May. On 11 May, a single net was set at Landon Bridge on the Pere Marquette; near point (A) in Figure 1. The following night a single net was set in the Big South Branch approximately 3 km upstream from its confluence with the Pere Marquette. Assuming that the amount of juvenile salmon movement was similar on both nights, I compared the number of salmon captured at each location.

Smolt Trapping 1988

During the spring of 1988, a single trap was fished in the center of the river channel at the Dow bridge on 60 percent of the nights and 25 percent of the days between 15 May and 1 July (Figure 3). The net was usually opened between 2100 and 2200 h and fished continuously until between 700 and 800 h. The net was initially reset in the morning and fished until 2100 h. Because very few smolts were captured during the day, the net was only fished periodically in order to estimate the fraction of smolts that did move downstream during the day.

Salmon captured during smolt trapping were handled like those that were captured during upstream sampling and then released downstream of the traps. Salmon smolts were aged using the size frequency method (Nielson and Johnson 1983).

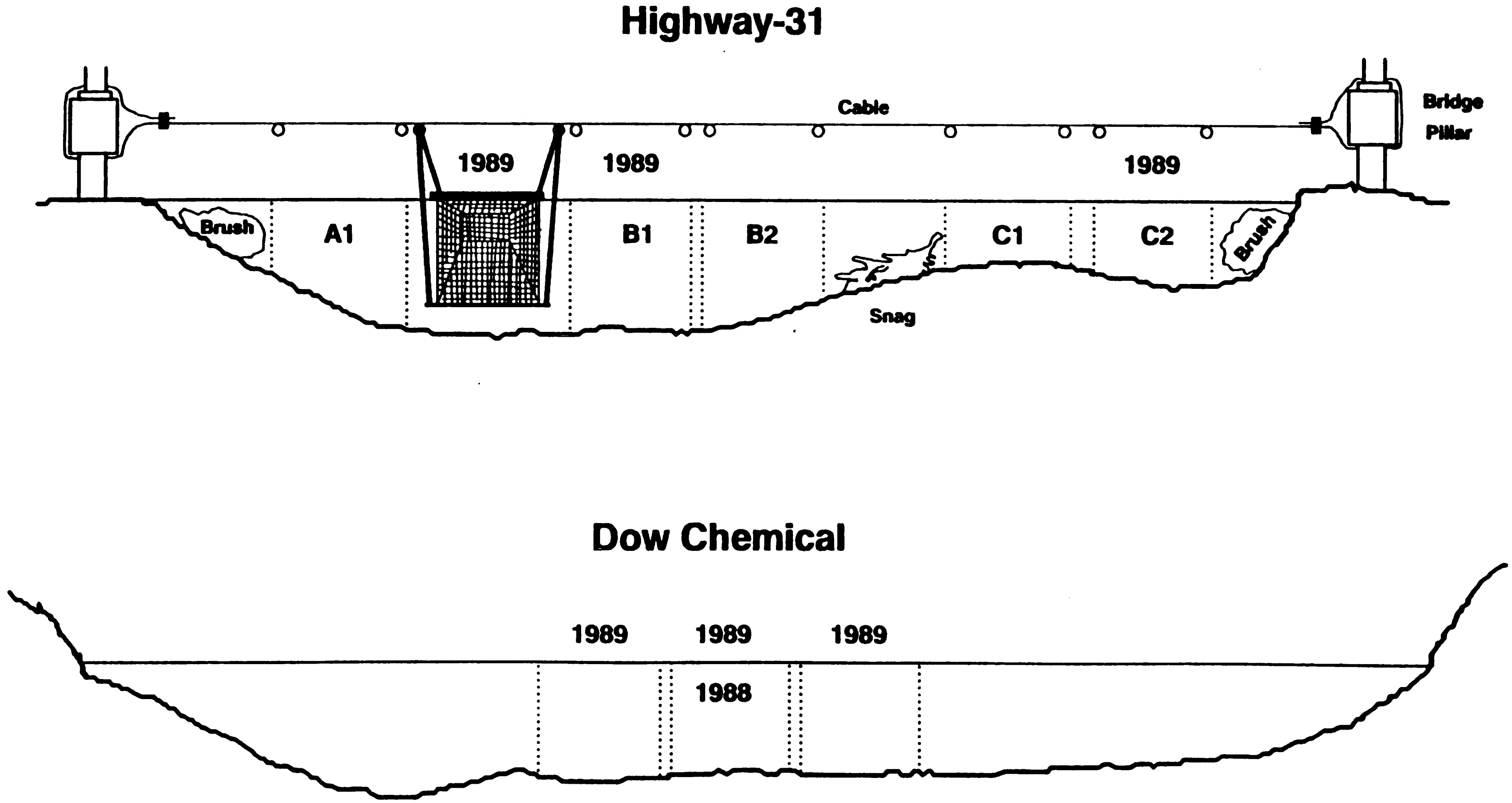


Figure 3. Cross sectional profiles of the Pere Marquette River at Freeway-31 (top) and Dow (bottom) study sites. Net positions are shown for 1988, 1989, and 1990. 1990 net positions are shown as A1, A2, B1, B2, C1, and C2. A single net is shown at position A2.

The mean migration date was defined as the date at which 50 percent of the total outmigration was complete. Very few of the juvenile salmon captured in migrant traps displayed physical characteristics of smoltification (ie. silvering, loss of parr marks). However, due to the distinct annual patterns in the downstream movement of these juveniles they are referred to as "smolts".

Throughout the sampling period, the velocity of the river at the Dow bridge would occasionally decrease, sometimes to the point that the river would flow upstream for a short period of time. It is believed that these periods of river "backing" were due to west-east seiches in Lake Michigan. The lower end of the net was anchored downstream in order to keep the net from becoming fouled during brief periods of upstream flow. While periods of reduced velocity were rare and of short duration, the efficiency of the nets was probably reduced during these events.

Smolt Trapping 1989

During the fourth week of April, 1989, traps were set at the Dow and F-31 bridges. Because salmon were not yet leaving the river by 28 April, a trap was also set approximately 20 km upstream at the bridge south of Custer to check for downstream movement of salmon that had not yet reached the lower river. Following the capture of the first smolt at a downstream site, fishing effort at the Custer bridge was discontinued.

One and sometimes two of three net positions were used at each of the downstream bridges. Fishing effort at the Dow bridge was concentrated near the center of the channel as it was in 1988. Nets were set in the swift and deep portions of the channel at the F-31 bridge (Figure 3). Nets were opened between 2100 and 2200 h and fished continuously until between 800 and 1100 h. Nets were fished at one or both of the downstream sites on 56 percent of the nights and 21 percent of the days between 15 May and 1 July. Missing nights were due primarily to net damage caused during periods of increased discharge (usually greater than 45 m^3/sec). Damaged nets were removed from the river, repaired, and reset as quickly as possible. Salmon smolt length, weight, and age data were collected as in 1988.

<u>Smolt Trapping 1990</u>

During the spring of 1990, the smolt sampling regime was modified in order to sample a larger portion of the river at the F-31 site and to avoid the problem of missing data during periods of net damage associated with elevated discharge.

The river was then divided into three sections; A, B and C. Each section was then divided into two subsections and a net similar to those used in 1988 and 1989 was attached to the cable within each section (Figure 3). The shallow river margins and the area between sections B and C were avoided due to the presence of brush and large woody debris that might damage the nets. Each night the individual nets were randomly set at subsection 1 or 2 within each of the three appropriate sections. Approximately 1 June, a large snag drifted into position C2. After 2 June, the net in section C remained at position C1 for the duration of the sampling period.

In order to continue sampling during periods of discharge (> 45 m^3/sec) that would damage the other nets, an additional trap was designed for use during the spring of 1990. This net was designed like the three other nets, but was made of an outer layer of 12.7 mm knotted twine. The bottom 2/3 of the net contained a liner made of 4.8 mm Delta 20 kg knotless nylon netting.

The modified trap was secured to a 6.4 mm diameter cable strung between two trees on opposite banks approximately 500 m upstream from the F-31 site. This trap was also used to capture smolts for use in determining the efficiency of the three downstream traps.

Traps were fished on 98 percent of the nights between 15 May and 1 July in 1990. Nets were opened every night between 2000 and 2100 h. In order to reduce smolt mortalities and keep the nets free of debris, the live boxes were emptied and the nets were cleaned every night between 100 and 230 h. Traps were not fished during the day.

Sampling was terminated on 24 July. Salmon smolt length, weight, and age data were collected as in 1988 and 1989.

Estimation of Trap Efficiency

A series of mark and recapture operations were used to estimate the efficiency of the smolt traps. Captured smolts were marked with a partial pelvic or caudal fin clip and later released. The number of clipped smolts recaptured in each net was divided by the total number released to estimate the efficiency of each net.

On 10 occasions during the spring of 1988, age 0 smolts (average total length=80 mm) were released approximately 185 m upstream from the net. Similar attempts were made to estimate trap efficiencies in 1989. However, due to the high mortality of clipped smolts we were not able to release enough smolts to recapture significant numbers. Mortalities were most likely due to stress related to capture, excessive crowding within the trap's live box, and the additional stress related to clipping and holding. No successful estimates of trap efficiency were made in 1989.

In order to alleviate as much of the mortality associated with the marking operation as possible, a different technique was used in 1990. Each night, after setting the three nets at F-31, the upstream net was opened. The downstream nets were emptied and cleaned of debris at approximately 230 h each night. Immediately after resetting the downstream nets, the upstream net was closed and emptied. All species other than salmon were returned to the water at the upstream site. Captured smolts were counted and marked with a small notch in the upper or lower portion of the caudal fin and returned to the water. No anesthesia was used. I alternated between upper and lower caudal notches each night. The efficiency of the downstream nets was estimated by dividing the number of morning recaptures in each net by the total number of marked smolts released from the upstream net during the night. Recaptured smolts always had the clip that was used that night, indicating that downstream movement was not being disrupted by the capture and marking procedure.

Due to the mortality that consistently resulted from attempting to hold wild smolts for any period of time, smolts could not be held overnight to build up larger numbers (greater than 150) for estimation of downstream net efficiencies. In order to determine if there was a relationship between the net efficiency and the number of marked smolts released, a sample of chinook fingerlings from the MDNR Platte River State Fish Hatchery were used. On 7 June, the hatchery fingerlings were anesthetized, given a partial caudal fin clip and transported to a holding pen in the Pere Marquette River immediately downstream from the mouth of Lichte Creek (Figure 2). The fingerlings were held until they began to display characteristics of smolting; silvering and increased activity. On 11 June, a group of 496 healthy hatchery fingerlings were released at dusk. The average total length of these fingerlings was 86.7 mm (n=30, range=75 to 102 mm). The average weight was 5.8 g (n=30, range=3.8 to 9.7 g).

Estimation of Total Yield

The efficiency for each net position (including 1988 Dow positions) was estimated by averaging the individual efficiencies for each net position throughout the sampling period. Because positions A2, B1 and C1 at F-31 corresponded with net positions used in 1989, the efficiency estimates for these positions were also used to calculate the smolt yield in 1989.

For each night of catch data, the number of smolts captured in each net was divided by the average efficiency for that particular net position, thereby obtaining three individual estimates of the total number of smolts moving downstream on a given night. The three estimates were then averaged to estimate the actual outmigration each night. The smolt outmigration was estimated for those nights when no nets were set by using a weighted average of actual catch data before and after the missing night. The estimates for individual nights were then summed to estimate the total smolt yield during nights.

Daytime yield was estimated by dividing daytime catches by the appropriate efficiency estimate. Individual daytime yields were then divided by the average of the nightly yield on the previous night and the yield on the following night.

This fraction was considered to be the average fraction of all smolts that were outmigrating during daylight hours at that time. All of the resulting fractions were estimated for the three years of data in order to estimate the average fraction of smolts found moving during the day. This fraction was used for all three years of data. The total smolt yield during nights was then multiplied by this average fraction. The resulting number was then added to the night movement total in order to estimate total smolt yield for each year.

The confidence intervals for total smolt yields were determined using a modification of the formula on page 72 of Seber (1982). Details of the procedure used to calculate net efficiencies, nightly yield estimates, annual yield estimates, and confidence intervals are given in Appendix C.

Total smolt yields were also reported as smolts per hectare. The channel lengths of the Pere Marquette River and those tributaries that appeared to contain suitable spawning habitat were measured on quadrangle maps. Stream width data were taken from discharge surveys conducted by United States Fish and Wildlife Service Lamprey Control Biologists. Over 160 widths were estimated at 36 locations on 8 streams between 23 July and 14 August 1991. Total yield was divided by total surface area (near low flow) to calculate yield per hectare.

Environmental Data

Daily discharge data were obtained from United States Geological Survey (USGS) gauging station 04122500 located at the bridge south of Scottville (Water Resources Data 1988-1990). Daily air temperature and precipitation data were obtained from the National Oceanic and Atmospheric Association. Day length data (minutes of daylight between sunrise and sunset) were provided by the Michigan Department of Agriculture (MDA, Climatic Program, 417 Natural Sciences, Michigan State University, East Lansing, Michigan, personal communication 1991). During the 1990 outmigration, daily maximum and minimum water temperatures were recorded at the F-31 bridge using a Taylor maximum-minimum thermometer. Ryan recording thermometers were used to monitor water temperatures in upper portions of the Pere Marquette River in 1989 and 1990.

RESULTS

Upstream Sampling

Salmon fry were observed in portions of the Pere Marquette River and eight of its tributaries (Appendix A). Salmon were collected from several locations in 1988 and 1989. Juvenile salmon in these areas averaged between 38 and 46 mm and 0.4 to 0.6 g (Table 1). Based on the change in mean total length of juvenile chinook in Baldwin Creek between 22 April and 23 June, the growth rate was estimated to be 0.71 mm/day in 1988.

Population estimates were attempted on three occasions in the fry producing areas of the Pere Marquette to determine juvenile salmon densities, but very high densities and poor electrofishing efficiency for fry made accurate population estimates very difficult. The presence of large numbers of juvenile salmon made it impossible to sufficiently reduce the population size between electrofishing passes for calculation of estimates using the depletion method. When shocked, the salmon fry would often dive suddenly into the soft substrate. In addition, wading in areas of muddy substrate with little current immediately clouded the water and made the recovery of large numbers of shocked fry very difficult.

On April 27, a modification of the depletion method was successfully used to estimate the juvenile salmon population within an 84 meter section of the Baldwin River. The section was repeatedly seined in order to deplete the

Table 1. Mean total length (mm), standard deviation of lengths (SDl), mean weight (g), standard deviation of weights (SDw), and ranges for samples (n) of juvenile chinook salmon from the upper tributaries of the Pere Marquette River in 1988 and 1989.

Date	Tributary	Mean Length (n)	Range SD1	Mean Weight (n)	Range SDw
1988					
April 22	Pere Marquette Bowman's Bridge	40 (8)	39-41 0.74	0.4 (8)	0.3-0.4 0.05
April 22	Baldwin Creek	38 (8)	29-41 3.85		
May 5	Baldwin Creek	43 (38)	37-55 5.56	0.6 (36)	0.3-1.5 0.32
June 23	Baldwin Creek[1]	76 (9)	69-86 6.12		
1989					
April 11	Pere Marquette Bowman's Bridge	43 (41)	37-49 3.19	0.6 (41)	0.3-1.1 0.19
April 12 and 18	Middle Branch	40 (11)	38-42 1.81	0.4 (11)	0.4-0.6 0.07
April 13	Pere Marquette Rainbow Rapids	40 (28)	36-53 8.73	0.5 (28)	0.3-1.6 0.27
April 12 and 24	Little South	42 (9)	40-44 1.56		
April 19	Kinney Creek	46 (3)	36-54 9.07		
April 24 and 27	Baldwin River	42 (241)	25-49 3.07	0.5 (150)	0.1-1.0 0.15

[1] On 23 June, 13 juvenile coho salmon were also found in Baldwin Creek. Mean length = 74 mm, SD1 = 4.51, range = 65-79 mm.

existing fry population in the segment to a level that could be substantially reduced using barge-mounted, direct current electrofishing gear. The remaining population was then estimated using the depletion method. The number of fry removed by seining was then added to the resulting estimate to calculate the fry density within the stream segment. There were an estimated 768 fry in this section of stream, resulting in a density estimate of 0.72 fry/m^2.

On 11 May, 1989, one of the smolt traps was set at Landon bridge (point A in Figure 1). Salmon smolts had been captured at the Custer bridge by 3 May, but smolts were not yet leaving the mouth of the river. On 11 May, 506 chinook fry (average length=43 mm, range=31-63 mm, n=107) and 4 large juvenile chinook (average length=130 mm, range=114-145 mm, n=4) were captured at Landon Bridge. The following evening, the net was set at the mouth of the Big South Branch of the Pere Marquette River (Figure 2). On 12 May, 11 chinook fry (average length=38 mm, range=36-45 mm, n=9) and 1 large juvenile chinook were captured at this location.

Smolt Trapping

Two size classes of juvenile salmon were captured in the smolt traps. Using size frequency analysis, the two size classes were determined to be distinct age groups (Figure 4). Smolts less than 105 mm were classified as age 0 smolts. These salmon most likely emerged earlier in the spring and left the Pere Marquette River before their first

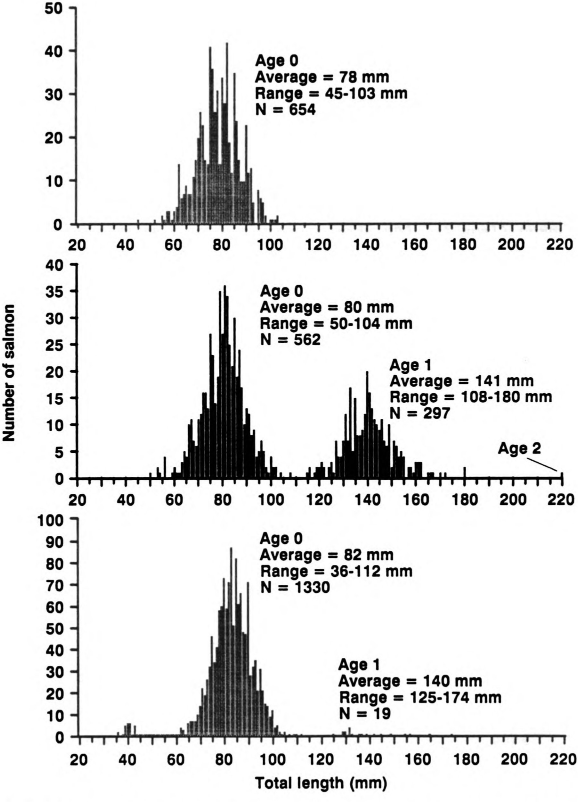


Figure 4. Length frequency diagrams for outmigrant chinook salmon smolts in 1988 (top), 1989 (middle), and 1990 (bottom).

summer. Smolts larger than 105 mm probably spent an entire year in the river before migrating to Lake Michigan during their second spring as age 1 smolts. Judging from the size distribution in Figure 4, the size frequency method was most likely a satisfactory method of aging smolts.

No age 1 smolts were captured in the smolt trap 1988. However, age 1 chinook smolts were captured in 1989 and a much smaller number were also captured 1990. A small number of coho smolts were also captured in 1990. Based on the size frequency distribution for chinook salmon, all of the coho smolts captured in 1990 were assumed to be age 1.

Age 1 chinook smolts were first captured on 17 May in 1989 and 28 April in 1990 (Figure 5). Mean outmigration dates were 22 May in 1989 and 10 May in 1990. Age 1 coho were first captured on 10 May in 1990 and the mean outmigration date was 17 May. Most of the age 1 chinook and coho smolts appear to have outmigrated by 1 June of both years. Age 1 chinook smolts averaged 141 mm total length in 1989 and 140 mm in 1990. The largest chinook smolt captured in 1989 was 220 mm in length. Although this individual may have been a fast growing age 1 smolt, it was most likely an age 2 smolt. Age 1 coho smolts averaged 138 mm in 1990.

The age 0 chinook smolt outmigrations began after the age 1 chinook outmigrations. No age 0 coho smolts were captured. The onset of the age 0 chinook outmigration was very consistent between years. Age 0 smolts were first captured in the traps on 19 May in 1988 and 1990 and on 26

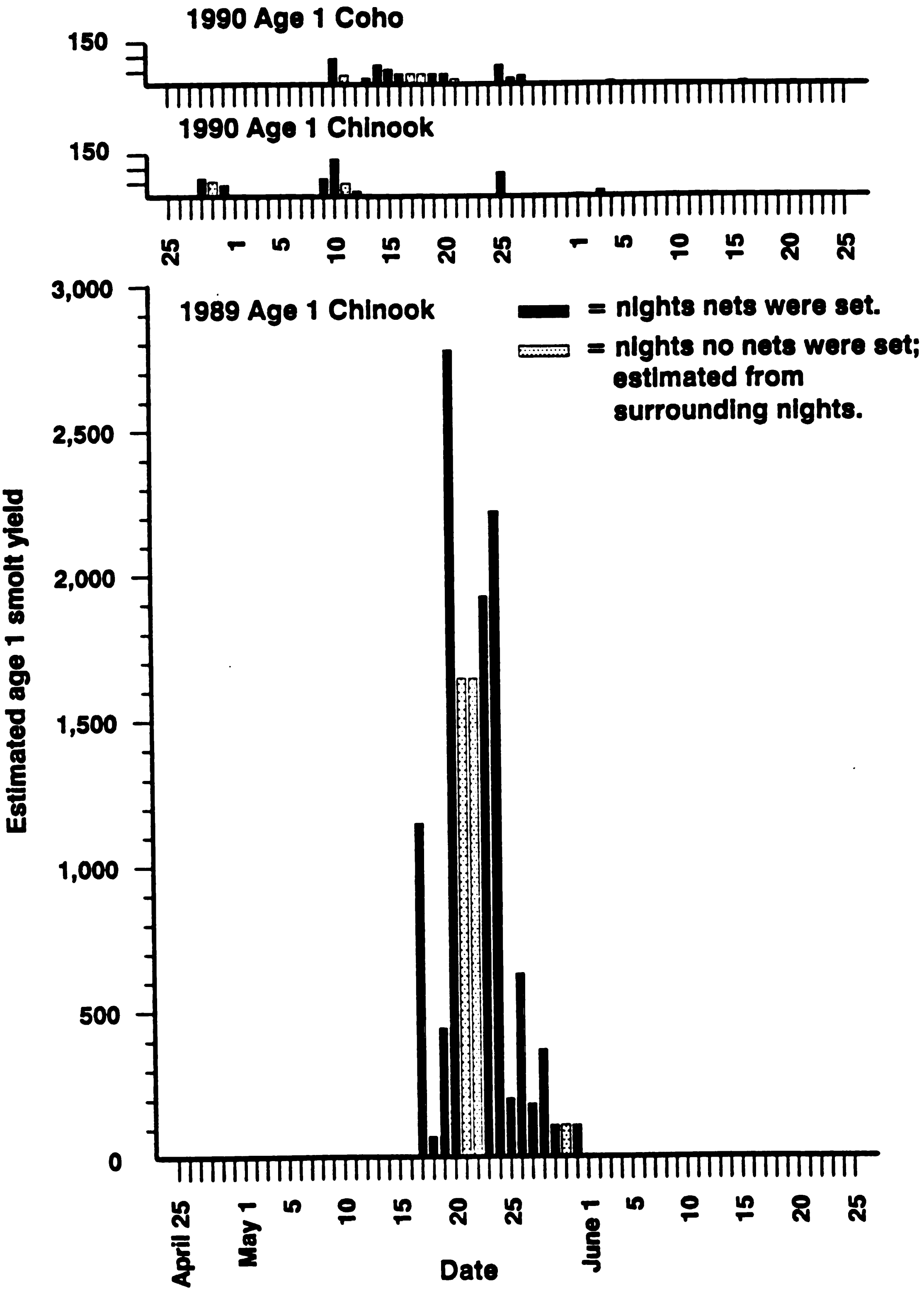


Figure 5. Estimated daily yield of age 1 chinook and coho salmon smolts from the Pere Marquette River in 1989 (bottom) and 1990 (top). Top and bottom graphs have the same scale.

May in 1989 (Figures 6, 7 and 8). However, the starting dates in 1988 and 1990 were based on captures of a single smolt. The first catch of more than one smolt occurred on 26 May 1988 (142 smolts), 26 May 1989 (25 smolts) and 25 May 1990 (29 smolts). Mean migration dates were 3 June in 1988 and 15 June in 1990. A mean migration date could not be determined for 1989 due to the inability to operate traps during the high water that occurred during the peak of the age 0 outmigration. However, judging from Figure 7, the mean migration date was most likely between 1 June and 15 June. The outmigration appears to have decreased to fewer than 50 smolts per night by 7 July of each year.

The average total length of the age 0 chinook smolts increased each year. Age 0 smolts averaged 78 mm, 80 mm, and 82 mm in 1988, 1989, and 1990, respectively. During the three years of study, the largest smolts were the first to begin outmigrating. Not only did the age 1 chinook smolt migrations generally precede the age 0 migrations in 1989 and 1990, but this size trend was evident within the age 0 smolt migrations as well. Generally, the first age 0 smolts to begin leaving the river were larger than the three year mean and the smolts moving during the peak outmigration were smaller than the three year mean (Figure 9). The last smolts to leave the river each year were the largest.

Average size data for all salmon smolts captured between 1988 and 1990 is summarized in Table 2. There were significant differences between average lengths of age 0

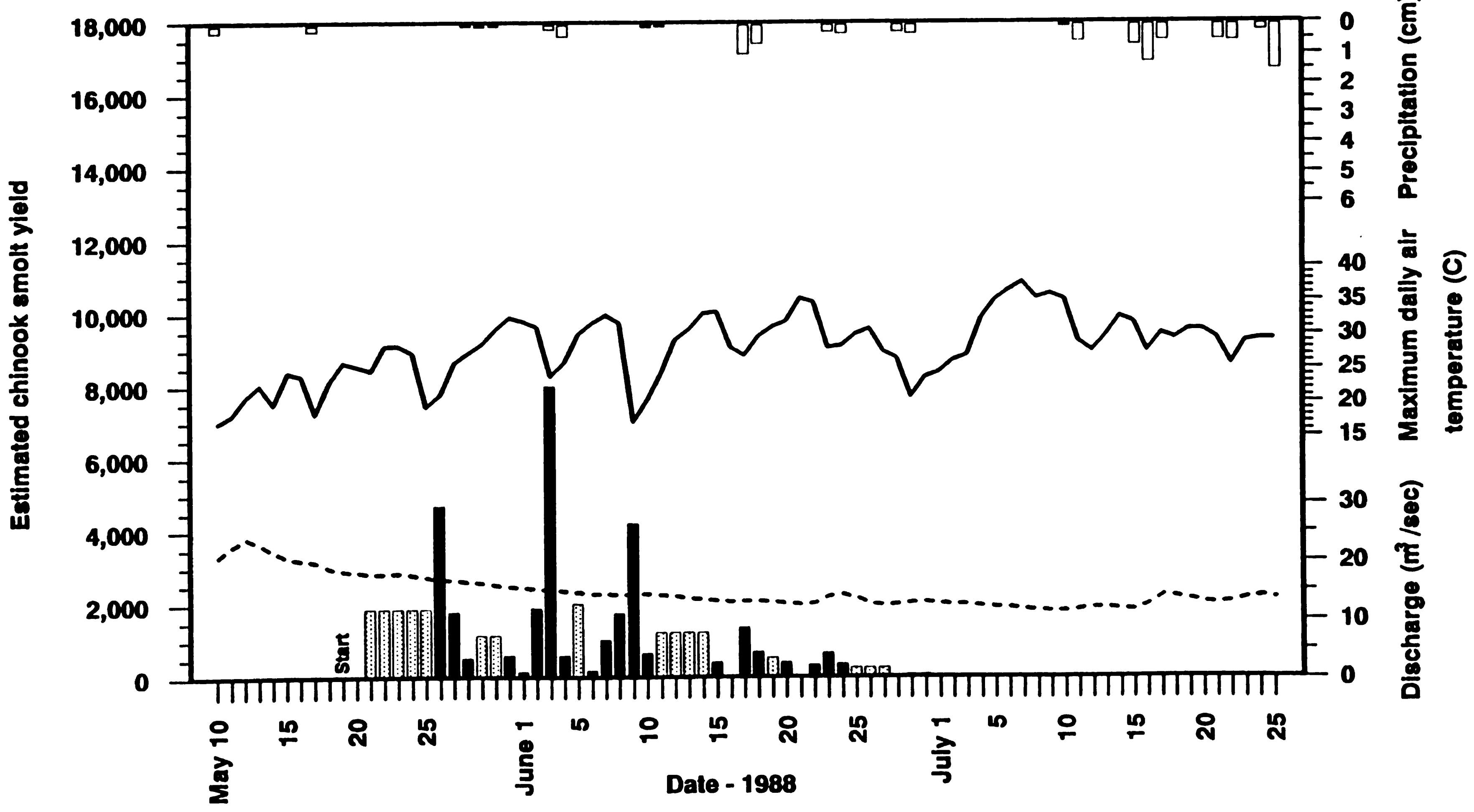


Figure 6. Estimated daily yield of age 0 chinook salmon smolts in 1988 (black bars = nights nets were set, shaded bars = nights no nets were set; estimated from surrounding nights), precipitation (open bars), maximum daily air temperature (solid line), and daily discharge at Scottville (broken line).

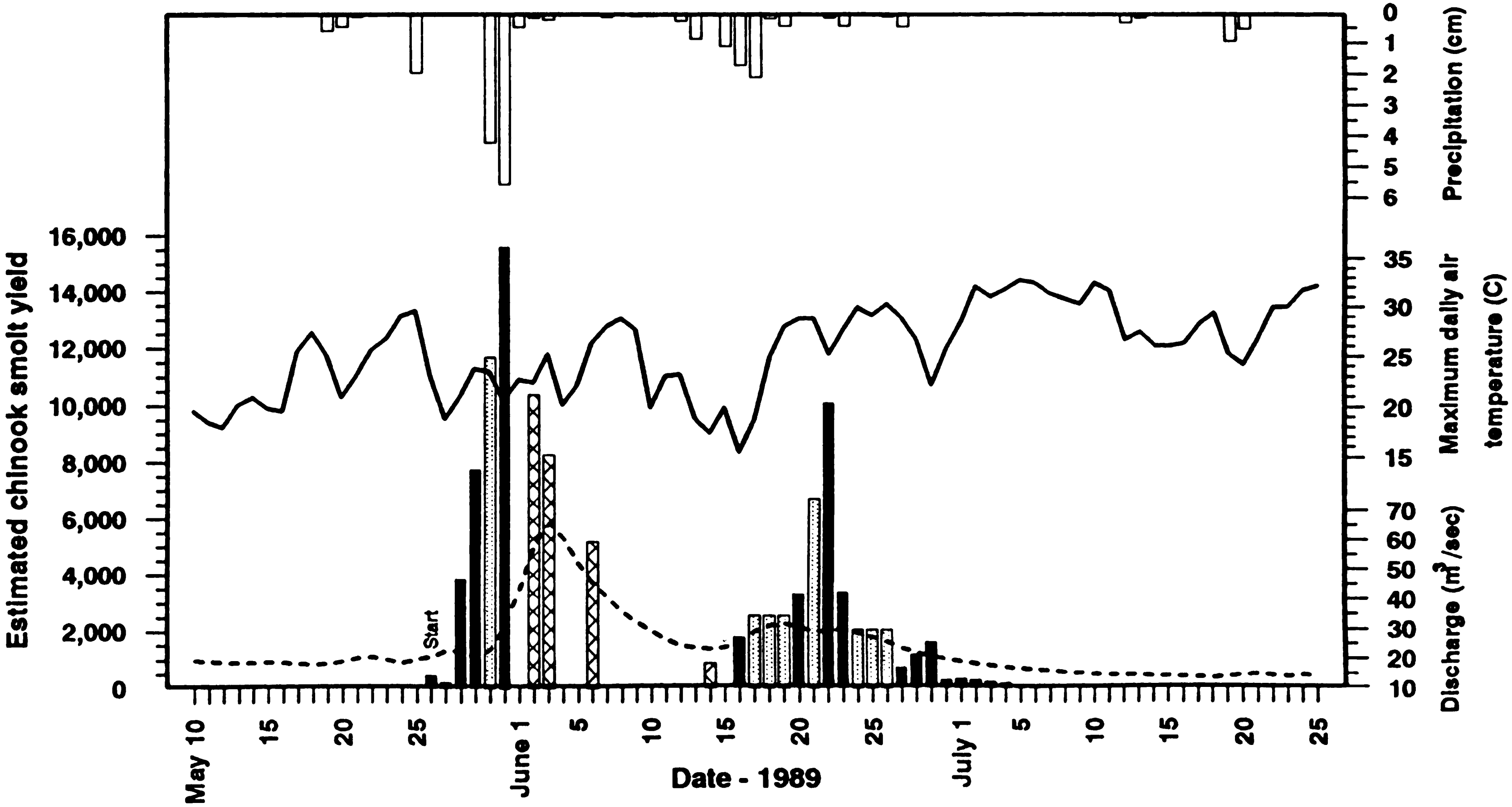


Figure 7. Estimated daily yield of age 0 chinook salmon smolts in 1989 (black bars = nights nets were set; shaded bars = nights no nets were set, estimated from surrounding nights; crosshatched bars = minimum estimates on nights nets were damaged), precipitation (open bars), maximum daily air temperature (solid line), and daily discharge at Scottville (broken line).

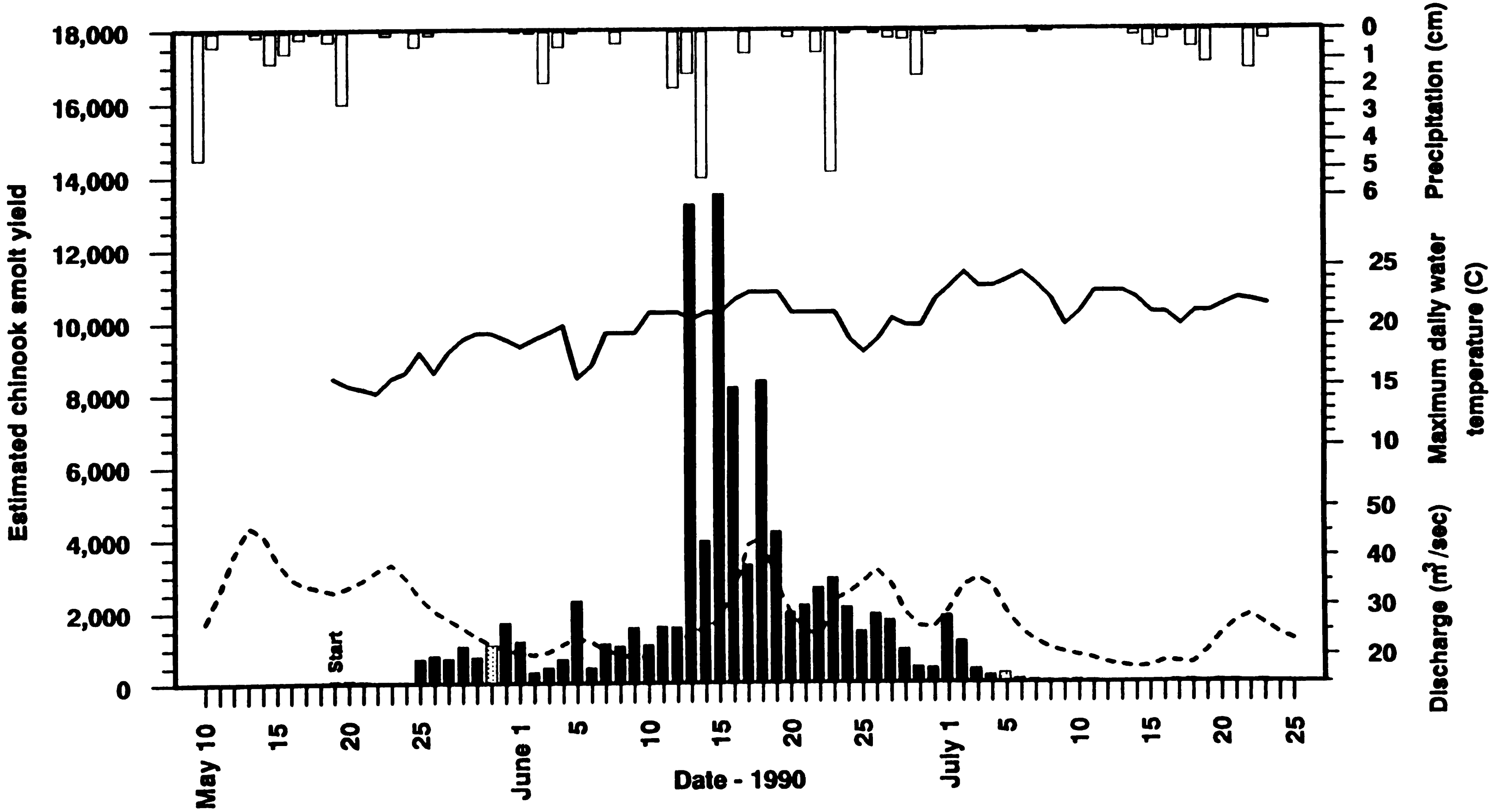


Figure 8. Estimated daily yield of age 0 chinook salmon smolts in 1990 (black bars = nights nets were set, shaded bars = nights no nets were set; estimated from surrounding nights), precipitation (open bars), maximum daily air temperature (solid line), and daily discharge at Scottville (broken line).

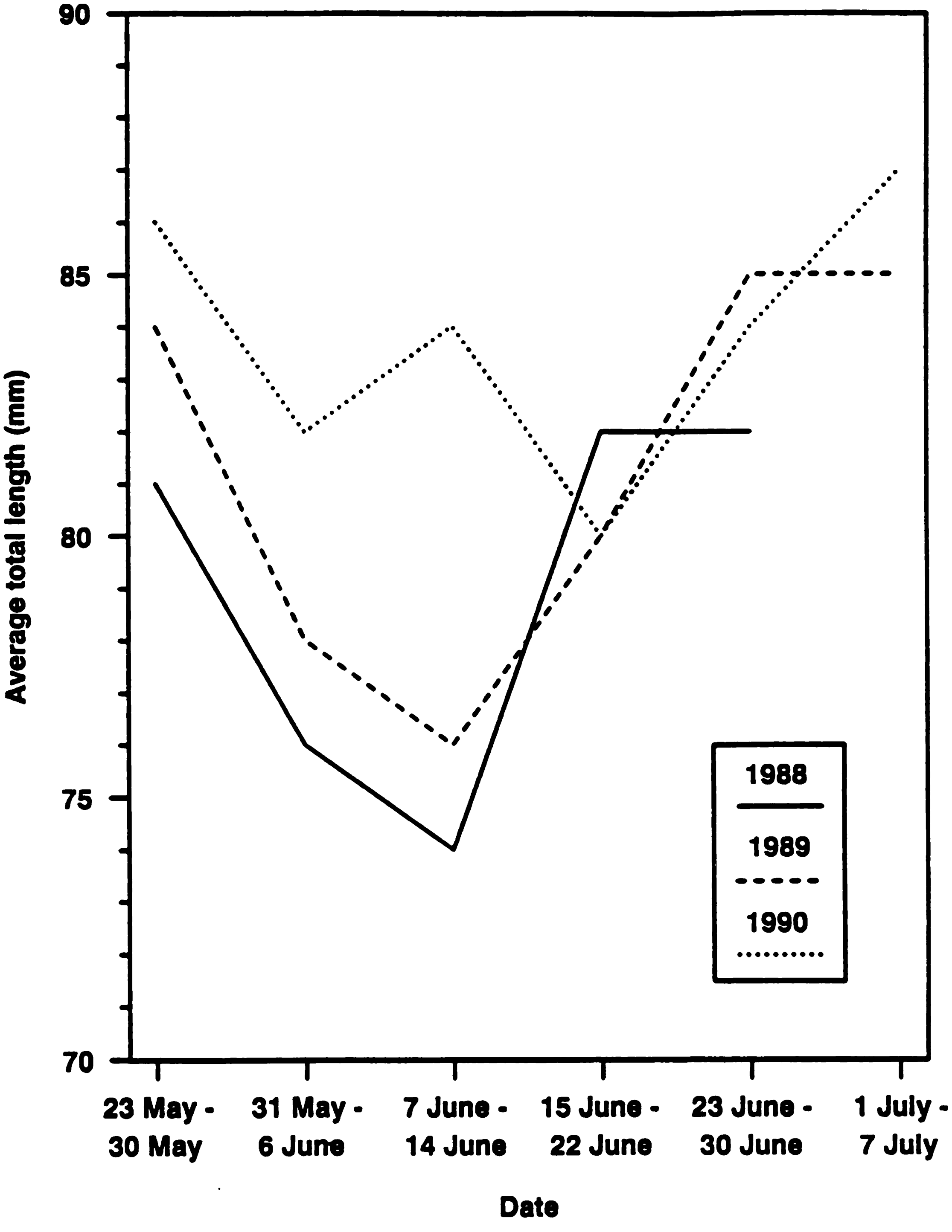


Figure 9. Average lengths by weekly intervals for outmigrating age 0 chinook salmon smolts from 1988 to 1990.

Table 2. Mean total length (mm), standard deviation of lengths (SDl), mean weight (g), standard deviation of weights (SDw), and ranges for samples (n) of different age groups of outmigrating chinook and coho salmon smolts in the Pere Marquette River from 1988 to 1990.

Age, Year and Species	Average Length (n)	Range SDl	Average Weight (n)	Range SDw
AGE 0				
1988 Chinook	78 (654)	45-103 8.95		
1989 Chinook	80 (562)	50-104 8.67	5.3 (56)	1.9-10.4 1.39
1990 Chinook	82 (1330)	36-112 9.96	5.4 (385)	1.9-10.6 1.38
AGE 1				
1989 Chinook	141 (297)	108-180 10.65	23.6 (79)	13.1-43.4 5.63
1990 Chinook	140 (19)	125-174 13.33	19.1 (12)	15.0-27.6 3.23
1990 Coho	138 (14)	105-155 14.87	21.1 (14)	9.3-29.1 5.65
AGE 2				
1989 Chinook	220 (1)		73.1 (1)	

chinook smolts between all three years ($p \leq 0.20$; z test). There were no significant differences in lengths of age 1 chinook smolts between 1989 and 1990, between species in 1990, or between species from 1989 to 1990 ($p > 0.20$; z test). There was a significant difference in weight between age 1 chinook smolts from 1989 to 1990 ($p \leq 0.05$; Kruskal-Wallis test). The length-weight relationships for various size classes of juvenile chinook salmon are given in Appendix D.

Estimation of trap efficiency

When using a drift net type trap in a large river, there are a number of factors that may affect the trapping efficiency of the net. First, nets can periodically become clogged. Second, the number of marked smolts used to determine trap efficiency must be large enough for a reasonable chance of recapture. Third, the trapping efficiency of a drift net may be affected by water velocity or discharge.

Live box funnels were partially or completely clogged by morning on the following dates: 1988 at DOW bridge = 1, 8, 16, and 21 June; 1989 at DOW bridge = 16 June; 1989 at I-31 bridge = 23 and 29 June. The efficiency of the net was probably reduced to some degree for at least a portion of these nights. Because it was impossible to discern how long the nets had been clogged, no attempt was made to adjust the catch data upwards on these dates. Rather, the estimated yield on these nights should be considered a minimum estimate.

Because the nets only sample a portion of the river, one might expect that there may be a relationship between an efficiency estimate based on a mark and recapture procedure and the total number of marked smolts released each night. Including releases of small numbers of smolts when calculating an average efficiency might decrease the accuracy of the efficiency estimates. The number of smolts released must be large enough that there is a reasonable chance of recapturing some of the individuals and that the recapture of a single individual will not result in an unreasonable estimate of net efficiency. For example, if a single smolt is recaptured from a release of four smolts, the estimated efficiency of that net would be 25 percent. One might consider this to be an unreasonable estimate of that nets efficiency if the net is only sampling 10 percent of the river width.

In order to determine the minimum size smolt release that should be used to calculate the average efficiency at each net position, the number of marked smolts released was compared to the resulting net efficiency estimates on the night of the release (Table 3). Although, there does not appear to be a discernable relationship between the number of smolts released and the fraction recaptured, small releases were more likely to result in zero recaptures. Four out of seven releases of less than 20 smolts resulted

Table 3. Individual net efficiencies, average net efficiencies based on releases of at least 20 smolts (Avg. Releases>19), sample sizes (n), and standard deviations (SD) for all releases of marked age 0 chinook salmon smolts in 1990 on the Pere Marquette River. Bold values indicate releases of at least 20 smolts.

Date	Number Marked Smolts Released	Percent Recaptures at Each Net Position A1	A2	B1	B2	C1	C2[1]
June 27	6		0		0		0
May 28	4		0			16.7	0
June 11	**496**[2]		**3.8**		**4.8**		**1.0**
June 13	**66**		**1.5**	**0**		**0**	
June 16	**146**	**0.7**			**3.4**	**2.1**	
June 17	**47**	**6.4**			**6.4**	**2.1**	
June 18	**103**	**5.8**			**3.9**	**0**	
June 19	**87**	**1.1**		**8.0**		**3.4**	
June 20	**45**	**8.9**		**6.7**		**4.4**	
June 21	**32**	**0**			**12.5**	**6.3**	
June 22	**32**	**3.1**			**6.3**	**3.1**	
June 24	**37**	**0**		**2.7**		**2.7**	
June 25	13	0		0		0	
June 26	**51**		**3.9**		**0.1**	**3.9**	
June 27	**43**	**0**			**0**	**4.7**	
June 28	**44**	**2.3**			**4.5**	**4.5**	
June 29	12	0			0	0	
July 1	8	25			0	0	
July 2	14		0		0	0	
July 3	5		0		0	0	
Avg. Releases>19:		2.8	3.1	4.4	4.7	3.1	---
n:		10	3	4	9	12	---
SD:		3.2	1.4	3.7	3.7	1.87	---

[1] A large snag drifted into position C2 approximately 1 June, the net in section C remained at position C1 for the duration of the sampling period. An average efficiency of 3.1% (calculated from C1 was used to calculate yield at position C2 on those nights before 1 June.

[2] Release of hatchery smolts.

in total downstream net efficiency estimates of zero. When more than 20 smolts were released, single net efficiency estimates were rarely above 8 percent and never exceeded 12.5 percent. Therefore, six of the seven efficiency estimates based on releases of less than 20 smolts appear to be biased either high or low. Personal judgement was used in determining that smolt releases of less than 20 individuals would not be included in determining the mean net efficiencies.

The third factor that might affect the efficiency of a drift net is water velocity or discharge. As water velocities increase, one might expect that smolts might be less able to avoid the nets. On the other hand, increased water velocities are associated with increased discharges. When water levels increase, the wetted perimeter of a river channel increases and the area sampled decreases. As a result, the efficiency of the nets might decrease with increasing discharge. A plot of discharge vs. net efficiency for the F-31 site in 1990 does not appear to result in a discernable relationship (Figure 10). No attempt was made to adjust nightly yield estimates due to changes in discharge.

Another factor that affects the determination of trapping efficiency is net avoidance. The estimates of trapping efficiency can be applied to the age 0 migrants with little bias since the smolts which were marked and released came from this same population or were very similar

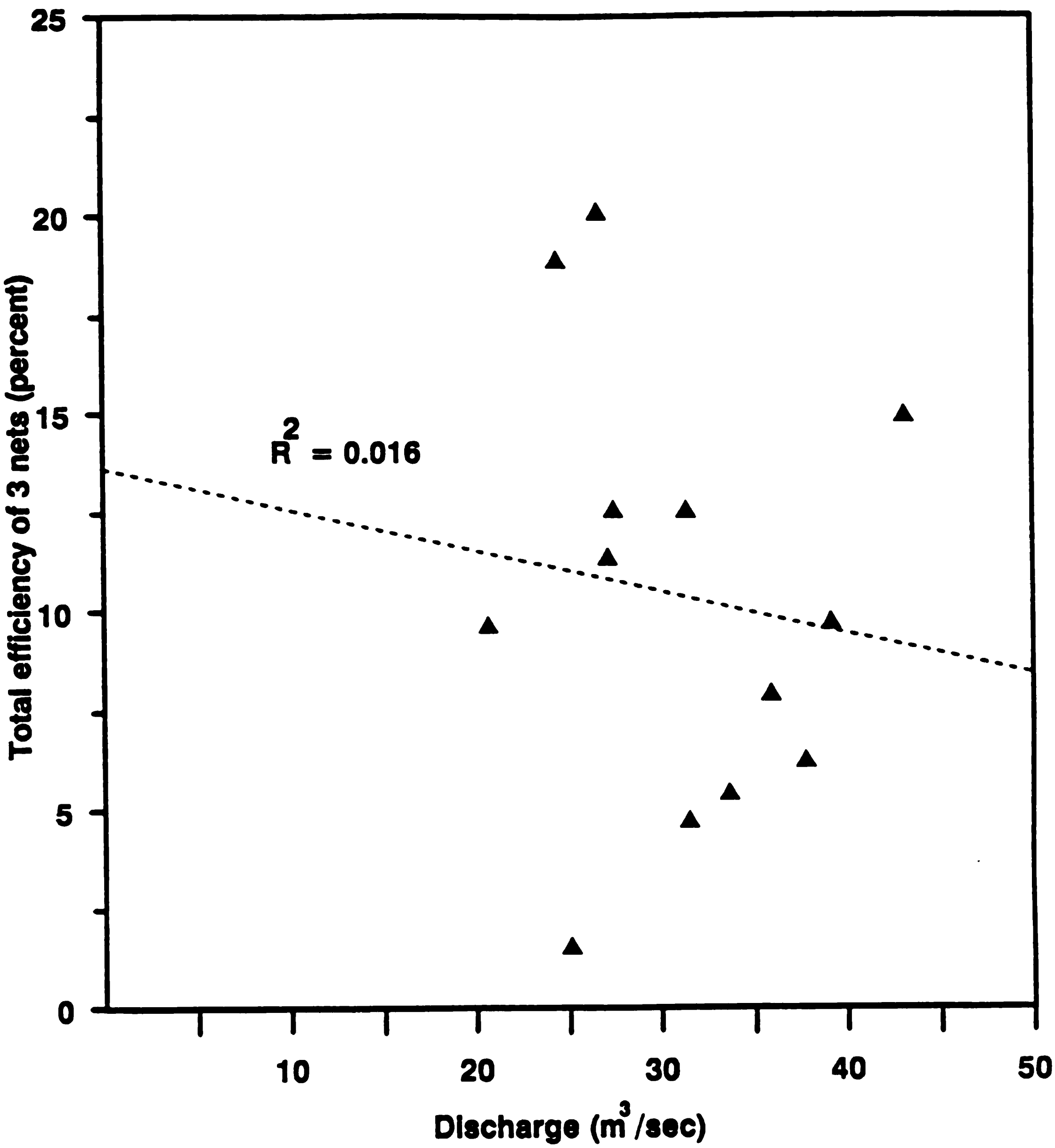


Figure 10. Relationship between discharge and the total efficiency of the three downstream nets at Freeway-31 in 1990. The dashed line is the functional regression line for all points.

in size (hatchery smolts in 1990 averaged 86.7 mm, range= 75-102 mm; see Figure 4). However, we were not able to mark and release significant numbers of age 1 smolts. Because efficiency estimates based on recaptures of age 0 smolts were used to estimate age 1 smolt yields, these estimates are undoubtedly low. While larger smolts are more likely to avoid this type of trap, the magnitude of this bias remains unknown.

Based on the recaptures from releases of at least 20 marked smolts, the trapping efficiencies at F-31 ranged from 2.8 to 3.1 percent at the positions nearest the river banks to between 4.4 and 4.7 percent near the center of the channel (Table 3). The total efficiency of three nets fishing simultaneously at the F-31 site was approximately 11 percent. The trapping efficiency of a single net at the DOW bridge was estimated to be 3.6 percent (Table 4).

Estimation of total yield

The average fraction of age 0 smolts moving downstream during the day was 4.2 percent (n=15 days). Approximately 3.8 percent of the age 1 smolts outmigrated during the day (n=7 days).

Nets were only set at the Dow bridge a total of 11 nights during the 1989 outmigration. As a result, an estimate of yield based on the data collected at the Dow site could not be calculated with an acceptable level of

Table 4. Net efficiencies at the center position at Dow bridge, average net efficiency, sample sizes (n), and standard deviations (SD) for all releases of marked age 0 chinook salmon smolts in 1988 on the Pere Marquette River.

Date	Number Marked Smolts Released	Percent Recaptures at Center Net Position
May 26	30	6.7
May 27	20	0
June 2	28	0
June 3	193	0
June 8	65	9.2
June 18	47	2.1
Avg. Efficiency:		3.0
n:		6
SD:		4.0

confidence. The 1989 yield estimates were calculated using data collected at the F-31 site.

Between 25 May and 2 June, the discharge in the Pere Marquette rose from 19.7 m^3/sec to over 59 m^3/sec. Nets could not withstand the elevated discharges and were repeatedly damaged between 2 June and 14 June. The four nights of data between 2 June and 14 June are based on partial nights of fishing. On 2 June, the net was damaged after 90 minutes of fishing and subsequently removed. During those 90 minutes, an estimated 10,194 smolts migrated downstream. No attempt was made to estimate the total nightly yield on nights that nets were damaged. Therefore, the nightly yield estimates on 2, 3, 6, and 14 June are very conservative.

The total estimated smolt yields and confidence intervals for each age group of salmon are shown in Table 5. Adding the additional yield based on the four nights of partial data during the 1989 flood to the yield estimate increases the total yield by 25,479 age 0 chinook smolts; from 87,247 to 112,726. Due to the lack of sufficient data during the flood, no attempt was made to estimate the missing data on the 11 remaining nights between 1 June and 15 June when nets were not set. Therefore, the adjusted estimate of age 0 chinook yield may still be considered a conservative estimate. The three year average yield was 88,285 age 0 chinook salmon smolts. Numbers of age 1 chinook smolts were highly variable from year to year. No

Table 5. Estimates of total yield, with adjustments for day movement and 95 percent confidence intervals, for all age groups of salmon smolts sampled in the Pere Marquette River from 1988 to 1990.

Age, Year, and Species	Estimated Nightly	Adjustment for Day Movement	Estimated Total Yield
1988			
Age 0 Chinook	50,590	+2,125	**52,715** ± 8,199
1989			
Age 0 Chinook	83,730	+3,517	**87,247** ± 27,414[1]
Age 1 Chinook	13,602	+517	**14,119** ± 5,254
1990			
Age 0 Chinook	95,408	+4,007	**99,415** ± 17,093
Age 1 Chinook	586	+22	**608** ± 85
Age 1 Coho	596	+23	**619** ± 147

[1] The total yield shown for 1989 is a minimum estimate. The total yield and confidence interval do not include data during the flood from 1 June to 15 June. Including the four partial nights of data during this period increases the total yield estimate from 87,247 to 112,726. The estimated yield of 112,726 does not include the other 11 nights of missing data during this period. Even this estimate may therefore be considered a conservative estimate of age 0 chinook yield in 1989.

age 1 chinook smolts were captured in 1988 and few were captured in 1990. However, in 1989, the estimated yield was over 14,000 age 1 chinook smolts.

The total surface area of the smolt producing areas was estimated to be 341 hectares. Suitable spawning habitat is restricted largely to the upper portions of the watershed. If the Pere Marquette below Reek Road (near Weldon Creek confluence; Figure 1) is excluded, the total surface area of the smolt producing areas is reduced to 214 hectares. Excluding the main river below Reek Road, the age 0 chinook yield ranged from 246 smolts per hectare in 1988 to 527 smolts per hectare in 1989 (Table 6).

Environmental Influences and Timing of Outmigration

Photoperiod

Photoperiod was consistently related to the onset of the age 0 smolt outmigrations. The first age 0 chinook smolts were captured on 19 May in 1988 and 1990 and 26 May in 1989. Day length at this time was between 892 minutes on 19 May and 905 minutes on 26 May. The first catch of more than one age 0 smolt occurred on 25 or 26 May each year. Photoperiod is the only environmental variable that is as consistent between years.

The age 0 mean migration dates occurred at 914-928 minutes day length. The downstream movement of age 1 chinook smolts began as day length reached 840-888 minutes. The age 1 chinook mean migration date occurred on 20 May in

Table 6. Estimates of total smolt yield per hectare for all age groups of chinook and coho salmon smolts sampled in the Pere Marquette River from 1988 to 1990.

		Smolt Yield per Hectare	
		All spawning habitat (341 Hectares)	Spawning habitat Above Reek Road (214 Hectares)
Chinook			
Age 0			
1988		155	246
1989		331	527
1990		292	465
	Means	259	413
Age 1			
1988		0	0
1989		41	66
1990		2	3
	Means	14	23
Coho			
Age 1			
1988		0	0
1989		0	0
1990		2	3
	Means	<1	1

1989 at 898 minutes day length and on 10 May in 1990 at 872 minutes day length. In 1990, age 1 coho movement began as day length reached 872 minutes and the mean migration date coincided with 888 minutes day length.

Temperature, Precipitation and Discharge

Due to periodic problems with the upstream thermographs throughout the study, water temperature data were incomplete. The incomplete water temperature data were used to test for correlation with air temperature data. Maximum daily air temperatures in 1988 and 1989 were highly correlated with water temperatures (n=42, r=0.88 and n=64, r=0.87 respectively). Air temperatures were used to identify relationships between fluctuating temperatures and changes in numbers of smolts outmigrating in 1988 and 1989. Daily water temperatures measured at the study site using a Taylor maximum/minimum thermometer were used for the 1990 analyses.

The onset of the age 1 chinook outmigrations may have been related to rising water temperatures. In 1989, maximum daily water temperatures dropped from approximately 13 C near the end of April to 9 C on 9 May. The age 1 chinook outmigration began on 17 May as water temperatures rose to 17 C. Similarly, maximum daily water temperatures in 1990 ranged from 6 to 11 C throughout March and early April. Age 1 chinook were first captured 27 April following an increase in water temperatures to between 17 and 20 C. Following the onset of the migration, most of the age 1 chinook smolt movement in 1989 appears to have occurred during periods increased temperatures (Figure 11). Although the peak age 1 outmigration in 1989 occurred during a period of precipitation, there was no apparent relationships between age 1 chinook smolt movement and changes in precipitation or discharge. Due to the small number of age 1 chinook and coho smolts captured in 1990, I did not attempt to relate fluctuations in daily yield to changes in temperature, precipitation or discharge.

Temperature fluctuations appear to have been related to peaks in the downstream movement of age 0 chinook smolts in 1988 (Figure 6). Peaks in emigration on 26 May and 3, 9, 17, and 23 June were all associated with decreasing air temperatures. This type of relationship was not evident in 1990 (Figure 8). The lack of data during much of the 1989 outmigration made it very difficult to draw any conclusions regarding the influence of environmental factors on the timing of age 0 smolt movement in 1989.

The movement of age 0 smolts also appears to have been related to periods of precipitation. There was very little precipitation from May to June in 1988. However, three of the four peaks in movement during the month of June were associated with small amounts of precipitation (Figure 6). Following a small peak in discharge on 12 May, the subsequent lack of precipitation resulted in a very stable,

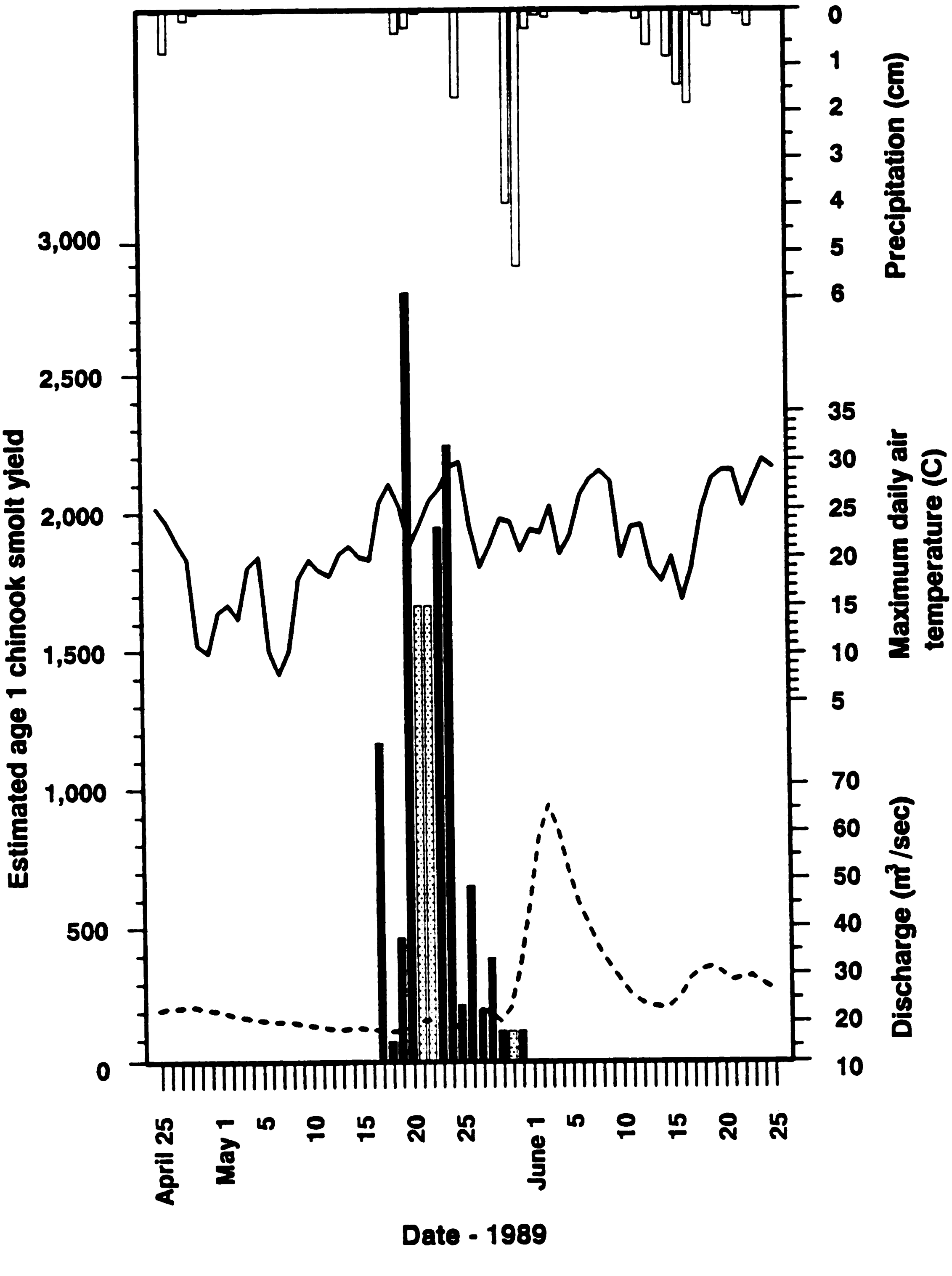


Figure 11. Estimated daily yield of age 1 chinook salmon smolts in 1989 (black bars = nights nets were set, shaded bars = nights no nets were set; estimated from surrounding nights), daily precipitation (open bars), maximum daily air temperature (solid line), and daily discharge at Scottville (broken line).

gradually decreasing discharge pattern. It is unlikely that discharge affected smolt migration in 1988.

Periods of precipitation and elevated discharge were apparently related to increased outmigration of age 0 smolts in 1989 and 1990. Although traps were only set on 56 percent of the nights between 25 May and 1 July in 1989, large numbers of smolts apparently outmigrated following periods of heavy rainfall as stream discharge began to increase (Figure 7). Similarly, in 1990 most of the peaks in the age 0 outmigration occurred shortly after periods of rainfall as stream discharge began to increase (Figure 8). The age 0 outmigration peaked after the first period of heavy rainfall (> 5 cm) in June.

The total yield smolt was compared to river discharge following emergence. The juvenile growth rate was estimated to be 0.71 mm/day. Assuming salmon fry emerge at approximately 35 mm and reach 80 mm by the third week in May, emergence probably begins about mid-March. Cumulative discharge from emergence to the end of downstream movement (approximately 30 June) was found to be highly correlated (r=0.998) to total age 0 chinook yield (Figure 12).

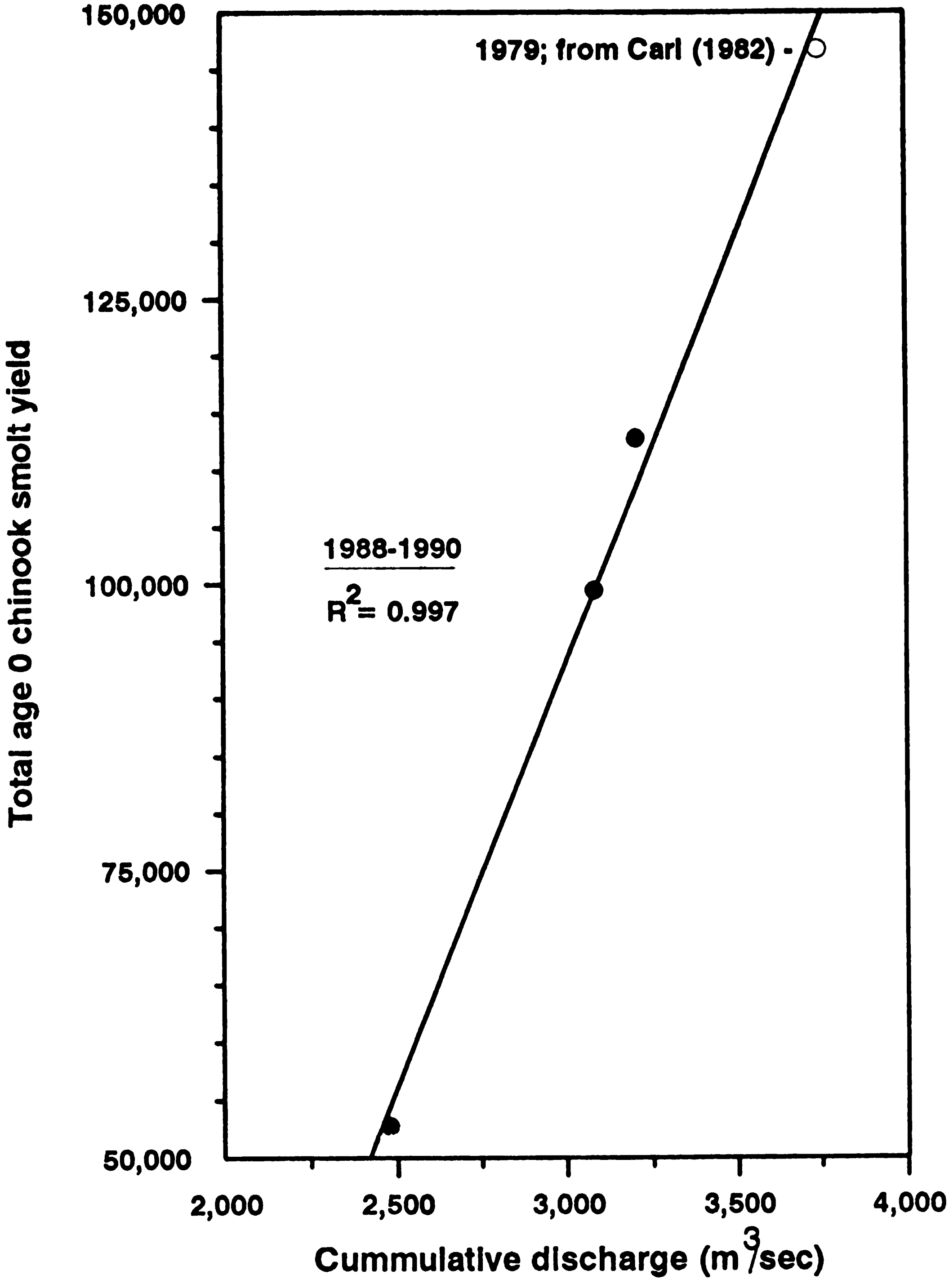


Figure 12. Relationship between total age 0 chinook smolt yield and cummulative river discharge between fry emergence and the end of the smolt outmigration (approximately 15 May-30 June) from 1988 to 1990. Solid line is functional regression line.

DISCUSSION

The modified fyke net trap proved to be a suitable method for sampling migrant salmon smolts at discharges less than 45 m^3/sec. Considering that a single trap sampled approximately eleven percent of the river width, equating trap efficiency to the proportion of the river width sampled would result in an underestimate of total yield. Seelbach (1985) was able to achieve an estimated 31 percent efficiency while sampling only 10 percent of the river width by using pipe weirs and chain-link fence to guide smolts toward inclined-screen traps. DuBois et al. (1991) estimated the efficiency of a modified inclined-screen trap which sampled approximately six percent of the Bois Brule River width to be five percent (range, 2-17%). Considering that the Pere Marquette River is over three times the size of the Bois Brule and Little Manistee Rivers, trap efficiencies of 2.8 to 4.7 percent are not uncharacteristically low.

The average length and weight of juvenile salmon in late April and early May, 1990 were very similar to those found by Carl (1984) between 1977 and 1979. Similarly, the density of salmon fry in Baldwin Creek on 27 April 1989 was within the range of densities estimated in late April and early May from 1977 to 1979 (Carl 1984). The juvenile growth rate also appears to have remained constant and similar to growth rates in streams and estuaries in other parts of the world. Carl estimated that the average growth rate of juvenile chinook salmon in Baldwin Creek from 1977 to 1979 was 0.66 mm per day during March. This is very close to the 1988 estimate of 0.71 mm per day between late April and late June.

Unwin (1986) estimated growth of juvenile chinook in Glenariffe Stream, New Zealand to be 0.29 mm per day. Becker (1970) reported that fry in the Columbia River grew from 40 to 80 mm over a three month period, equivalent to 0.44 mm per day. Chinook salmon in a tributary to the Salmon River, New York grew from 37 mm in May to 65 mm in July at an estimated 0.47 mm per day (Johnson 1980). Fisher and Pearcy (1990) estimated growth of two groups of fall chinook in Coos Bay, Oregon at 0.29 mm per day and 0.54 mm per day. Dawley et al. (1986) estimated a rate of 0.60 mm per day in the upper Columbia River estuary and Levings et al. (1986) reported 0.46 to 0.70 mm per day in Campbell River estuary. Argue et al. (1986) reported 0.97 mm per day in Cowichan Bay and Healey (1980) estimated an unusually high growth rate of 1.32 mm per day in Nanaimo Estuary.

Carl (1983) found that chinook fry between 41 and 47 mm began drifting out of Baldwin Creek in early April and continued until mid-June, while juveniles longer than 50 mm moved downstream sporadically in late May and early June usually during the high water following heavy rains. By early May, 1990, fry were found as far downstream as Custer, below most of the spawning habitat within the river. Based on the number of salmon fry captured at Landon Bridge on 11 May and the number captured at the mouth of the Big South Branch on 12 May, very few of these fish were leaving the Big South Branch.

Very few salmon fry were ever captured as far downstream as the F-31 and Dow study sites (Figure 4). This scenario appears to suggest that the downstream movement of fry may be largely a displacement mechanism. Chapman (1965) found that the number of salmon fry moving downstream was proportional to the density of fry. Aggressive behavior among fry begins within the first week after emergence (Mason and Chapman 1965) and as the density of fry increases to a certain threshold carrying capacity, fry begin moving downstream. Similarly, Unwin (1986) hypothesized that the downstream movement of coho fry was due to competition for habitat resulting in the displacement of smaller or subordinate fish to habitat unsuitable for settling and holding (Chapman 1962).

In the Baldwin River, fry habitat apparently becomes limiting by early April at which time fry begin moving downstream into the Pere Marquette River. Mason (1969) demonstrated that displaced fry could re-establish stream residence when placed in unoccupied space. Although large numbers of fry were found moving downstream from the upper river in May, most are apparently able to find suitable habitat within the lower main river since very few salmon under 60 mm were captured in outmigrant traps.

Hopkins and Unwin (1987) describe a similar situation in Glenariffe Stream, a tributary to the Rakaia River in New Zealand. During the spring, substantial numbers of fry averaging 35 mm fork length moved downstream from Glenariffe Stream and other tributaries where most of the spawning occurred and entered the Rakaia River. Many fry remained in the main river and, after a period of growth, migrated downstream at 60 to 90 mm fork length in late spring or early summer. The authors hypothesized that the amount of time the juveniles spent in the main river was probably influenced by the succession of spring floods. Reimers (1973) also found that fry migrated into the main channel of the Sixes River in Oregon and resided there until they had reached 70 mm fork length. He discussed the advantages to survival that arise through dispersal of newly emerged fry away from spawning areas; "tributary crowding is relieved and more efficient use is made of the greater rearing capacity of the main river."

Age 1 smolts were also captured at the Custer bridge as early as 27 April 1989, while the first 55-109 mm juveniles were not found this far downstream until they began leaving the river in the third or fourth week of May. The larger age 0 salmon were probably more able to occupy habitats upstream than were fry and had not yet entered the lower portions of the main river. The age 1 smolts were the first to leave the lower portion of the river. Shortly after the peak of the age 1 outmigration, large age 0 smolts began migrating downstream. Seelbach (1985) also found that wild age 0 chinook smolts began outmigrating from the Little Manistee River near the peak of the age 1 coho smolt migration.

The average size of the age 0 outmigrants decreased following the onset of the migration. Average smolt length, as determined by a weekly averages, was smallest during the peak outmigration and began to increase shortly thereafter. The largest age 0 smolts outmigrated last. The fast growing juveniles and individuals that hatched earlier than the majority of the population were apparently the first to reach the critical size and begin moving downstream. The slow growing individuals and those that hatched late in the spring smolted later and may not have emigrated until the following spring.

Irvine and Ward (1989) described a similar situation in the Keogh River and speculated that because large smolts leaving in the fall were larger than those that left in mid-May, they could not have waited until next spring to emigrate. They hypothesized that these smolts emigrated in response to an increase in stream flow and may have left even later if that had been when the next freshet occurred. Similarly, in the Pere Marquette River, the outmigrations of large age 0 smolts in late June and early July occurred during periods of elevated discharge. Irvine and Ward (1989) also backcalculated the lengths of age 2 smolts migrating in the spring to give last years lengths and found that they had been significantly smaller than the previous years age 1 smolts. The age 2 smolts had apparently not reached the proper state of readiness during their first spring, but were the first to migrate the following spring.

Smolt sizes and the timing of the smolt migrations were very similar between years and nearly identical to the sizes and the timing in the nearby Little Manistee River (Seelbach 1985). Photoperiod and body size are probably the most important factors influencing the timing of smolt migrations in the Pere Marquette River. Photoperiod is the only environmental variable that is constant between years. Hoar (1976) stated "there appears to be a strong endogenous component involved in triggering the morphological, physiological and behavioral changes typical of smolting. Fish that reach a certain critical size show at least some of these changes under controlled laboratory conditions. However, there is also ample evidence that light and temperature are involved and that the lengthening of the days in the spring is probably the most important factor either synchronizing or regulating the precise timing of these changes; the role of temperature appears to be a subsidiary to photoperiod."

Ewing et al. (1979) stated that "there may be a minimum length which a juvenile must attain before it can respond to the appropriate photoperiod" and hypothesized that this length is 80 mm for spring chinook in the Rogue River, Oregon. Lister and Walker (1966) found that in the Big

Qualicum River, British Columbia, chinook fry emigrated first at 40 to 48 mm fork length and 70 to 80 mm juveniles left later, starting in mid-May and peaking the first week in June. In Alaska, juvenile chinook salmon typically do not reach this length until age 1, but still migrate in May and June as age 1 smolts (Meehan and Siniff 1962; Loftus and Lenon 1977). Similarly, chinook salmon in Johnson and Fork Creeks in Idaho smolt at 85 mm in late May and early June at age 1. Other authors have also related the timing of smolt migrations to photoperiod (Eriksson and Lundqvist 1982; Holtby et al. 1989; Thorpe 1988) and critical size (Bjornn 1971; Folmar and Dickhoff 1980). Age 0 chinook salmon begin migrating from lower Michigan streams as day length reaches 890 to 905 minutes at a critical size of approximately 80 mm.

Although the onset of smolt movement appears to be most strongly influenced by photoperiod and body size, a number of environmental factors appear to influence the day to day variability in the numbers of juvenile salmon migrating downstream. Periods of rainfall (Baggerman 1960; Grau 1981), rising water levels (Bilby and Bisson 1987; Bustard and Narver 1975; Chapman 1965; Hartman et al. 1982; and Raymond 1979) and falling water temperatures (Bilby and Bisson 1987; Bjornn 1971; Hartman et al. 1982) may be related to the outmigrations of juvenile salmon.

Although peaks in the movement of age 0 smolts in 1988 appear to have been related to decreased water temperatures, there was no consistent relationship between water temperature fluctuations and smolt movement between years. Chinook and coho salmon prefer water temperatures between 12 and 14 C (Scott and Crossman 1973). Most smolts in 1989 and 1990 outmigrated when water temperatures were between 17 and 20 C. Although rising water temperatures may have simply coincided with increasing day length, it is possible that the downstream migration may have been stimulated in part by rising water temperatures.

Periods of rainfall and associated increases in stream discharge were related to peak movements in 1989 and 1990. Discharge patterns may also have influenced the number of juveniles that outmigrated as age 0 smolts or remained in the river until age 1. There was very little precipitation during the spring and early summer of 1988 and subsequently, there were few, if any, peaks in discharge during the smolt outmigration. Assuming periods of elevated discharge stimulate age 0 smolts to outmigrate, fewer age 0 smolts would have left the Pere Marquette River in 1988 and many would have remained in the river to smolt at age 1 the following spring (Table 5). Conversely, 1989 was a very wet spring with extended periods of elevated discharge. Large numbers of age 0 smolts left the Pere Marquette River and few remained to smolt at age 1 in 1990. During the spring of 1990, the discharge pattern was closer to normal with short periods of elevated discharge, but no large floods or periods of drought. As a result, the yield of age 0 smolts in 1990 was intermediate between 1988 and 1989 (Table 5) and we might hypothesize that the age 1 migration in 1991 was relatively small.

Based on smolt yield estimates in Seelbach (1985) and area stream flow records, similar relationships were identified in the Little Manistee River. The highest age 1 chinook smolt yield from the Little Manistee River between 1982 and 1984 was in 1983. The stream flow pattern during the previous year was gradually decreasing with very few fluctuations to stimulate salmon to outmigrate at age 0. An unusually large number of salmon may have remained to smolt at age 1 in 1983. The largest age 0 chinook smolt outmigration occurred in 1984. The 1984 outmigration coincided with periods of heavy rain and substantially elevated discharges.

Other investigators have hypothesized that age 1 coho yields are related to the minimum stream flow during the summer previous to emigration (Lister and Walker 1966). Presumably, the amount of juvenile salmon habitat could become limiting during the low flow period. Salmon may begin outmigrating in the fall or winter as the amount of habitat becomes limiting. Increasing levels of competition and predation during this period may also result in higher smolt mortality during low flow years. This does not appear to have been the case in the Pere Marquette River. The number of age 1 chinook smolts in the Pere Marquette River fell from 14,000 in 1989 to approximately 600 in 1990, but minimum summer flows during the previous summers were very similar. In fact, the minimum flow during the late summer of 1988 was lower than the 1989 low flow.

Although the ages and timing of wild smolt migrations in Michigan streams are very similar to streams in other parts of the country, yields from Michigan streams are comparatively low. The yield of age 0 chinook from the Pere Marquette River averaged 259 smolts per hectare. When the lower portion of the river was removed from the estimate of spawning area, the average yield estimate increased to 413 smolts per hectare. The average yield estimates from the Pere Marquette River are probably conservative for a number of reasons. Firstly, the 1989 yield estimate does not include 11 nights during the flood. Secondly, the trapping efficiency of age 1 smolts was probably overestimated because efficiencies based on age 0 smolts were used to estimate the yield of age 1 smolts although net avoidance was probably higher for age 1 smolts. Lastly, estimates were not inflated for those few nights when traps became clogged with debris.

Seelbach (1985) estimated age 0 chinook yields in the Little Manistee River ranging from 214 to 992 smolts per hectare. Using Carl's (1980) estimates, Seelbach calculated that Michigan's best chinook-producing streams yielded between 1000 to 2000 smolts per hectare. The yield of wild age 1 coho smolts from the Little Manistee River was much higher than from the Pere Marquette River, 76 to 307 smolts per hectare and less than one smolt per hectare, respectively. This discrepancy may be due to seasonal differences in the outmigration of age 1 coho smolts and/or to differences in the availability of suitable winter habitat between streams.

Smolt yield is generally higher in northwestern coastal streams. Crone (1980) reported yields for coho between 970 and 4200 smolts per hectare in Oregon, British Columbia, and Alaska. Lister and Walker (1966) reported a yield of 1900 smolts per hectare from British Columbia. Chapman (1965) reported 3400 to 5000 smolts per hectare for Oregon streams and Baranski (1989) reported 800 to 2600 smolts per hectare for a number of Puget Sound streams.

The yield of age 0 chinook from the Pere Marquette River was highly correlated with cumulative river discharge following emergence of fry. Presumably, higher flows provide additional rearing habitat for juvenile salmon in the form of shallow channel margins and flooded backwaters. Carl (1982) estimated that the smolt yield of the Pere Marquette River was 146,700 ($\pm$ 19,000) in 1979. The cummulative post-emergence discharge in 1979 was 3,750 m^3/sec. Carl's estimate is supported by the 1988-1990 yield-discharge relationship (Figure 13). Carl (1982) estimated that 630,500 chinook salmon smolts were produced in the Lower Peninsula tributaries of Lake Michigan. Based on the results of my study, there is no reason to believe this estimate is not fairly accurate.

It is difficult to explain why few coho salmon smolts were captured in the Pere Marquette River. The number of age 1 coho smolts leaving the Little Manistee River was nearly equivalent to the number of age 0 chinook migrants in 1982 and 1983 (Seelbach 1985). Significant numbers of juvenile coho salmon are usually found by MDNR personnel during electroshocking surveys in the upper portions of the Pere Marquette River in August and September. In fact, there appear to be at least as many 60 to 112 mm juvenile coho salmon in the river at this time as there are juvenile chinook. However, few coho smolts appear to actually leave the river in the spring. It is possible that age 1 salmon may undergo significant outmigrations at other times of the year. However, the availability of suitable winter habitat and competition from juvenile chinook may be limiting coho smolt survival. Chinook salmon prefer faster currents and channel margins (Murphy et al. 1989), while juvenile coho tend to prefer slower habitats such as small tributary streams and riverine ponds (Peterson 1982a, 1982b), pools, and undercut banks with large wood debris or root wads (Brown and Hartman 1988; Bustard and Narver 1975; McMahon 1989; Swales and Levings 1989; Ruggles 1966).

In a survey of 60 streams in lower Michigan, Carl (1982) found that juvenile coho salmon were found in nearly as many streams as chinook salmon, but at much lower densities. Coho were also present in more small tributary streams (< 5 m wide). A lack of suitable winter habitat may cause significant numbers of juvenile coho to outmigrate in the fall or winter and/or limit the overwinter survival of coho smolts in larger rivers such as the Pere Marquette. A comparison of the amount of suitable juvenile coho and chinook habitat in the Little Manistee and Pere Marquette Rivers may help explain the difference in the magnitude of the spring age 1 outmigrations.

Because the timing of migration of hatchery smolts is believed to be very similar to that of wild smolts, it is often assumed that time of planting must be closely matched with the readiness to migrate in order to reduce mortality and impacts on resident communities (Ewing et al. 1984; Peck 1974). However, Ewing and Birks (1982) found that it was apparently not valid to use migration timing as a means for determining release times for maximum survival of hatchery chinook salmon. They found that Deschutes River spring chinook released in June showed excellent migration but extremely poor survival (based on adult returns). Similarly, juvenile chinook released from Cole Rivers Hatchery migrated quickly downstream but did not yield high returns. These smolts may haved moved downstream before fully imprinting on the stream to which they were planted. Therefore, these plants may not have actually resulted in higher mortality, but rather in an increased incidence of straying. If returns to the planted stream are to be optimized, imprinting might be more effective and the incidence of jacking minimized if juveniles are planted at a smaller size and allowed to fully imprint before being released. The MDNR's current net-pen rearing operation should provide additional time for juveniles to imprint, while keeping mortalities to a minimum.

Carl (1982) hypothesized that angling pressure in the Manistee River below the first impassable dam was probably resulting in low egg deposition and the subsequent low density of juvenile chinook salmon. However, MDNR personnel have recently found large numbers of juvenile salmon below Tippy Dam on the Manistee River following a period of stable flows (Tom Rozich, MDNR, personal communication). Although fishing pressure is undoubtedly high during the fall spawning season, there is little existing evidence that smolt yield is actually limited due to excessive harvest of spawning adults. Improved fish passage and favorable flows would probably improve natural reproduction in a number of Michigan streams.

Chinook and coho salmon will continue to provide valuable sport fisheries in the Great Lakes. The evidence from the Little Manistee (Seelbach 1985), the Pere Marquette, and other Michigan streams (Carl 1982) indicates that the yield of naturally reproduced chinook smolts is substantial and may prove to be very important in the maintenance of the fisheries. The marking of all salmon planted into Lake Michigan will provide a valuable tool to differentiate between hatchery and wild salmon and accurately evaluate their respective contributions to area fisheries.

SUMMARY

Natural reproduction in the Pere Marquette River contributes approximately 93,400 salmon smolts to Lake Michigan each year. Age 0 chinook smolt yield was between 260 and 410 smolts per hectare. Natural reproduction is undoubtedly significant in other Michigan streams as well, although it may be limited by impassible barriers and altered flow regimes.

The density, growth, and movements of juvenile chinook salmon in the Pere Marquette River appear to be very comparable to other parts of the U.S. and the world. Chinook salmon fry are found in the lower main river during April and May, but very few salmon leave the river as fry. The downstream movement of fry may be due to competition for habitat in the upper portions of the river resulting in the displacement of smaller juveniles. Chinook salmon smolt primarily at age 0 in late May and early June at approximately 80 mm total length. Slightly larger individuals predominate in the early and late portions of the age 0 outmigration. Some chinook and all coho salmon overwinter and outmigrate at age 1 at an average of 140 mm and 138 mm respectively, just prior to the age 0 outmigration. The number of age 1 smolts appears to be related to the discharge pattern during the spring and early summer of the previous year.

The onset of the smolt outmigration is related primarily to body size and increasing day length, although rising water temperatures may also have some effect. Day to day variation in smolt movement may be due to decreasing water temperatures, precipitation, and increasing discharge. Total age 0 chinook smolt yield was highly correlated with cumulative river following emergence.

APPENDICES

APPENDIX A

Table 7. Results of tributary sampling in April 1989 using backpack electrofishing gear, seines, and visual observation. Tributaries are listed in order from downstream to upstream. F = salmon fry found, H = spawning habitat may exist, NH = no spawning habitat found.

PERE MARQUETTE RIVER TRIBUTARIES	
Mosquito Creek	NH
Swanson Creek	NH
St. Clair Creek	NH
Lichte Creek	NH
Swan Creek	NH
India Creek	NH
Black Creek	NH
Big South Branch Pere Marquette	NH
Weldon Creek	F
Tank Creek	NH
Sweetwater Creek	F
Kinney Creek	F
Donahue Creek	F
Baldwin Creek	F
Sandborn Creek	F
Little South Branch Pere Marquette River	F
Middle Branch Pere Pere Marquette River	F

LITTLE SOUTH BRANCH OF PERE MARQUETTE TRIBUTARIES	
Pease Creek	H
McDuffee Creek	H

MIDDLE BRANCH OF PERE MARQUETTE RIVER	
Blood Creek	NH
Baker Creek	H

BIG SOUTH BRANCH OF PERE MARQUETTE RIVER	
Ruby Creek	H
Allen Creek	H
Freeman Creek	NH
Cedar Creek	NH
Tripple Lakes Creek	NH
Beaver Creek	NH
Winnepesaug Creek	NH
Bear Creek	NH
Tank Creek	NH

APPENDIX B

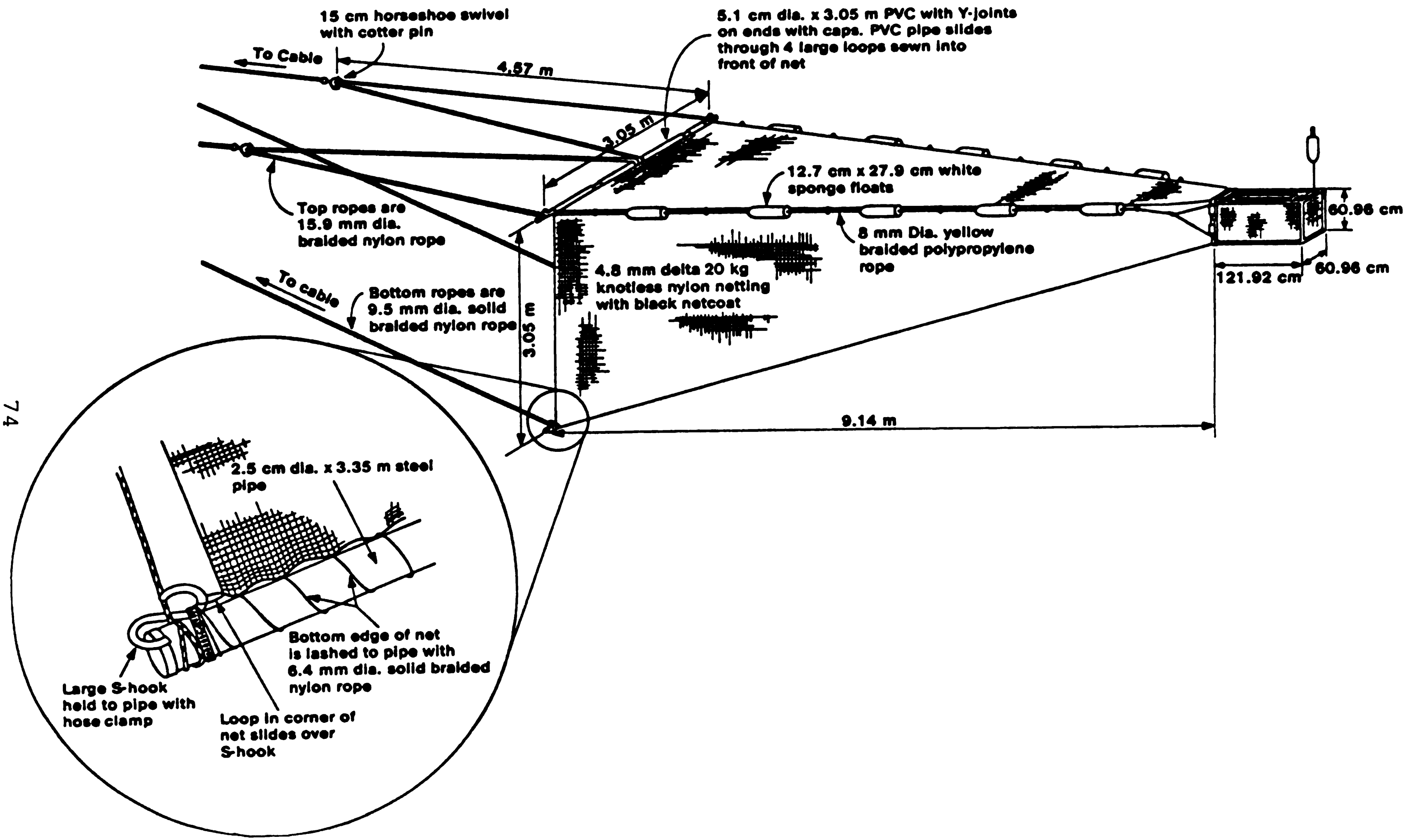


Figure 13. Design details of the modified fyke net trap for use in large rivers.

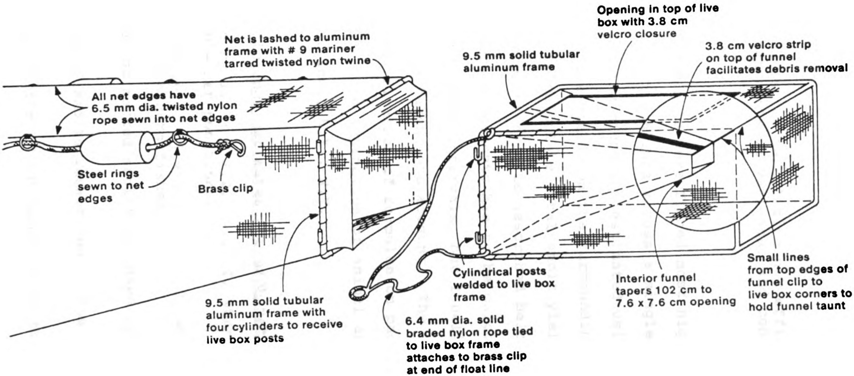


Figure 13 (cont'd).

APPENDIX C

Appendix C. Procedures for calculating net efficiencies, yield estimates, components of variance, and confidence intervals.

From one to three nets were fished most nights at a number of possible net locations across a single transect. The yield on the missing night was estimated using a weighted average of the yields on the surrounding nights. The procedure used to calculate total smolt yield and the associated confidence interval is described below. A number of different variance components had to be calculated to determine these confidence intervals, but I believe that all relevant factors were taken into account. The variance calculation is a modification of formulae on page 72 of Seber, G.A.F. 1982. The estimation of animal abundance. MacMillan Pub. Co. Inc., N.Y., N.Y.

<u>Calculate the efficiency estimates for each net.</u>

Nets are indexed by i. $i = 1,2, \ldots\ldots I$, where I is the number of possible net positions.

Nights are indexed by j. $j = 1,2, \ldots\ldots J$, where J is the total number of nights fished.

M_j = the number of marked smolts released upstream on the j^{th} night.

F_{ij} = the number of smolts recaptured in the i^{th} net on the j^{th} night.

$\hat{E}_{ij}$ = efficiency at the i^{th} net position on the j^{th} night.

$$\hat{E}_{ij} = \frac{F_{ij}}{M_j}$$

$$Var\ (\hat{E}_{ij}) = \frac{(\hat{E}_{ij})\ (1 - \hat{E}_{ij})}{M_j}$$

Determine the average efficiency for each net position.

$\bar{E}_i$ = Average efficiency for net position i.

$$\bar{E}_i = \frac{\sum_{j=1}^{J} \hat{E}_{ij}}{J}$$

$$Var\ (\bar{E}_i) = \frac{1}{J^2} \sum_{K=1}^{J} Var\ (\hat{E}_{ij})$$

Calculate the smolt yield for the individual nights on which nets were fished.

N_{ij} = number of smolts captured in i^{th} net on the j^{th} night.

$\hat{N}_j$ = smolt yield for the individual nights on which nets were fished.

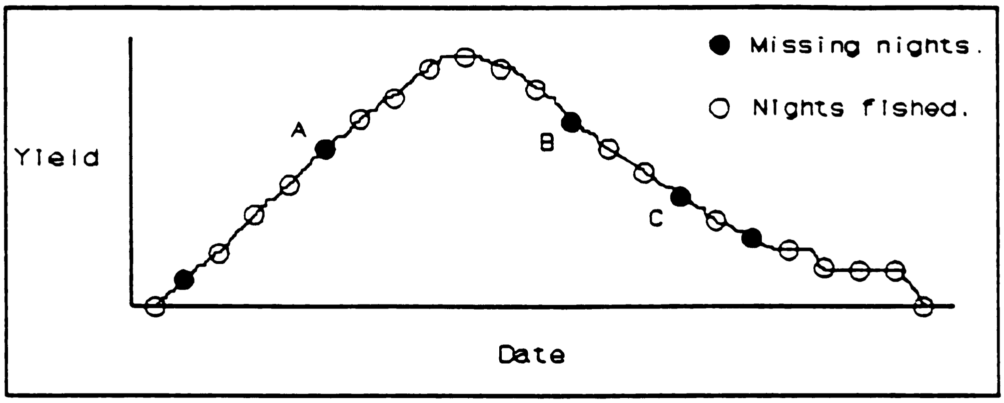
$$\hat{N}_j = \frac{\sum_{i=1}^{I} \frac{N_{ij}}{\bar{E}_i}}{I}$$

$\hat{N}_{nights}$ = total smolt yield for all nights nets were actually set.

$$\hat{N}_{nights} = \sum_{j=1}^{J} \hat{N}_j$$

$$Var\ (\hat{N}_{nights}) = \sum_{j=1}^{J} \left\{ \frac{1}{I^2} \sum_{i=1}^{J} \left[\frac{(N_{ij}/\tilde{E}_i)^2}{(\tilde{E}_i)^2}\ Var\ (\tilde{E}_i) \right] \right\}$$

<u>Estimate the number of smolts outmigrating on the individual nights that nets were not fished using a weighted average of the surrounding nights.</u>



Depending on the time period in question, three or more consecutive nights of data may have been available before and after the missing night (night A above) or only one (night C above) or two (night B above) nights of data may have been available both before and after the missing night. The missing night was estimated by weighting the nights before and after equally, so the maximum number of continuous nights of data that were available on both sides of the missing night were used (maximum of three).

d = the number of nights of data before or after the missing night to be used in weighted average.

For example, in the above figure on night A, there are three nights before and three after; d=3. On night B, there are three nights before and two after; d=2. On night C, there are two nights before and one after; d=1.

$\hat{N}_{ja}$ = yields on previous nights. a = 1,2 ..... n, where $\hat{N}_{j1}$ is the yield on the night just prior to the missing night.

$\hat{N}_{jb}$ = yields on the subsequent nights. b = 1,2 ..... n, where $\hat{N}_{j1}$ is the yield on the night just after the missing night.

$\hat{N}'_j$ = estimated yield on individual missing nights.

$$\hat{N}_j' = \frac{\sum_{a=1}^{d} (d+1-a)\,\hat{N}_{ja} + \sum_{b=1}^{d} (d+1-b)\,\hat{N}_{jb}}{\sum_{a=1}^{d} (d+1-a) + \sum_{b=1}^{d} (d+1-b)}$$

$$Var\,(\hat{N}_j') = \left\{ \frac{1}{\sum_{a=1}^{d} (d+1-a) + \sum_{b=1}^{d} (d+1-b)} \right\}^2 \times$$

$$\left\{ \sum_{a=1}^{d} (d+1-a)^2\, Var\,\hat{N}_{ja} + \sum_{b=1}^{d} (d+1-b)^2\, Var\,\hat{N}_{jb} \right\}$$

Estimate the total yield for all nights.

$$\hat{N}_{total} = \hat{N}_{night} + \sum_{j=1}^{K} \hat{N}_j'$$

where K = the total number of nights estimates were obtained.

Assuming covariance of $\hat{N}_{night}$ & $\sum_{j=1}^{K} \hat{N}_j' = 0$;

$$Var\,(\hat{N}_{total}) = Var\,(\hat{N}_{night}) + \sum_{j=1}^{K} (Var\,\hat{N}_j')$$

<u>Nets were periodically set during the day. Adjust the total yield to account for smolts moving during the day.</u>

D_{ij} = number of smolts captured in the i^{th} net on the j^{th} day.

n_{ia} = the number of smolts captured in the i^{th} net on the previous night.

n_{ib} = the number of smolts captured in the i^{th} net on the following night.

$\hat{D}_j$ = the average fraction of all smolts that outmigrated during the day.

$$\hat{D}_j = \frac{\sum_{j=1}^{S} \left\{ \frac{\left[\frac{\left(\sum_{i=1}^{I} D_{ij}\right)/I}{\left(\sum_{i=1}^{I} n_{ia}\right)/I} + \frac{\left(\sum_{i=1}^{I} D_{ij}\right)/I}{\left(\sum_{i=1}^{I} n_{ib}\right)/I} \right]}{2} \right\}}{S}$$

where S = the total number of days nets were fished.

$\hat{N}_{grand\ total}$ = total smolt yield including all nights and adjusted for the fraction outmigrating during the day.

$$\hat{N}_{grand\ total} = \hat{N}_{total}\ (1 + \hat{D}_j)$$

$$Var\ (\hat{N}_{grand\ total}) = (1 + \hat{D}_j)^2 \times Var\ (\hat{N}_{total})$$

<u>**Calculate the 95 percent confidence interval for the total yield estimate (CI).**</u>

$$CI = \hat{N}_{\substack{grand \\ total}} \pm 1.96 \sqrt{Var\ (\hat{N}_{\substack{grand \\ total}})}$$

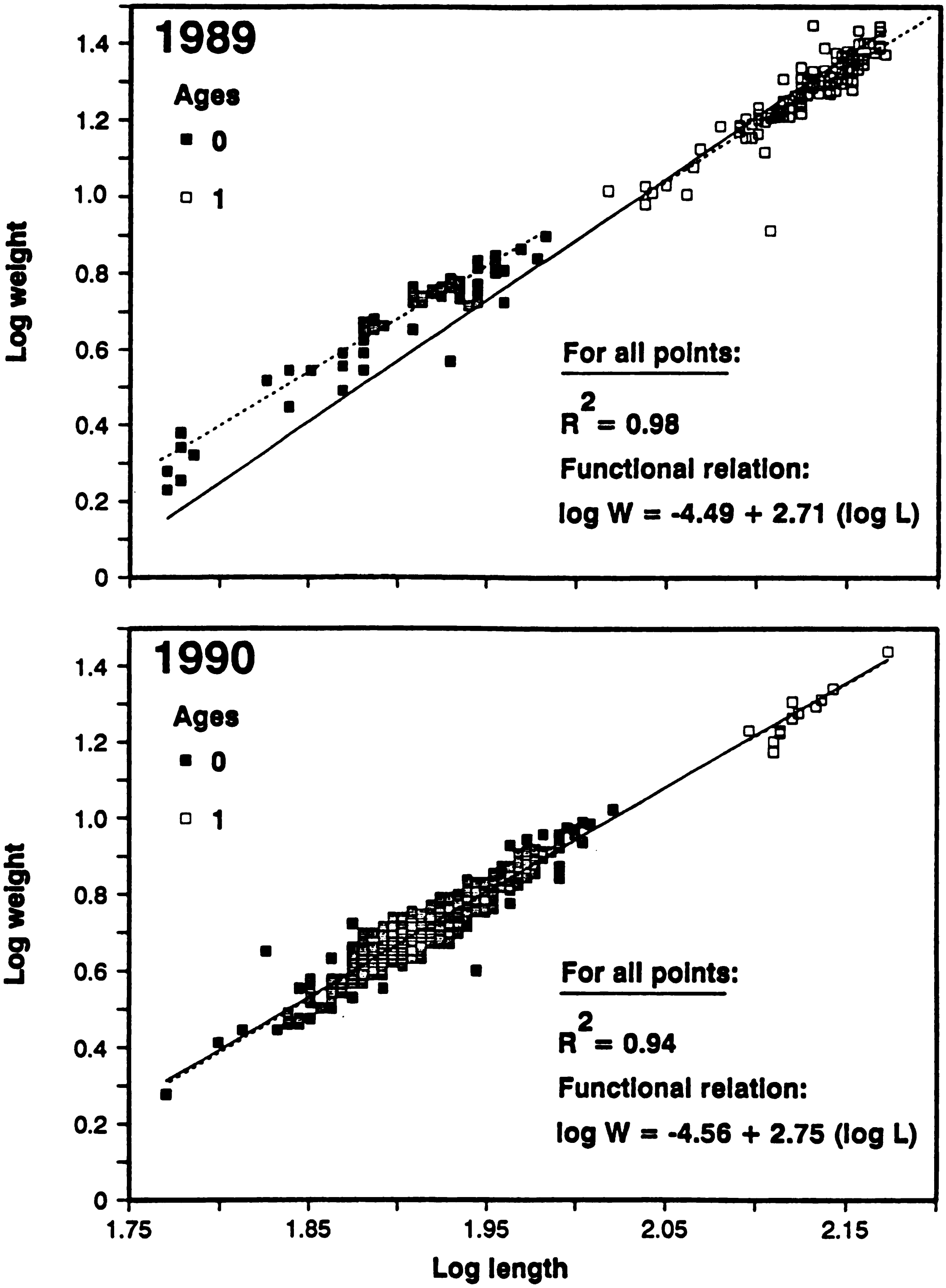


Figure 14. Plots of logarithms of weights against logarithms of lengths for 59 to 149 mm chinook salmon in 1989 and 1990. Solid lines are functional regression lines for all points. Dashed lines are functional regression lines for individual age groups.

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