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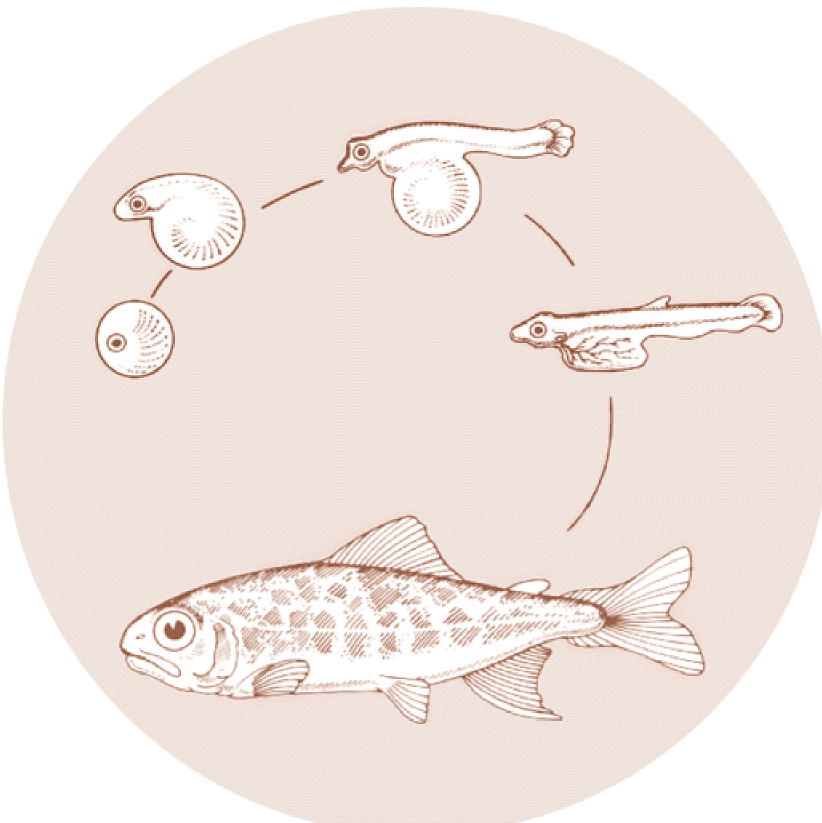
WILLAMETTE HATCHERY OXYGEN SUPPLEMENTATION STUDIES

Annual Report 1993



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Bonneville Power Administration
Environment, Fish and Wildlife Division
P.O. Box 3621
905 N.E. 11th Avenue
Portland, OR 97208-3621

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WILLAMETTE HATCHERY OXYGEN SUPPLEMENTATION STUDIES

Annual Report 1993

Prepared by:

R. D. Ewing
S. K. Ewing

Biotech Research and Consulting, Inc.

J. E. Sheahan

Oregon Dept. of Fish and Wildlife

Prepared for:

U.S. Department of Energy
Bonneville Power Administration
Environment, Fish and Wildlife
PO Box 3621
Portland, Oregon 97208

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INTRODUCTION

Hydropower development and operations in the Columbia River basin have caused the loss of 5 million to 11 million salmonids. An interim goal of the Northwest Power Planning Council is to reestablish these historical numbers by doubling the present adult runs from 2.5 million to 5.0 million fish. This increase in production will be accomplished through comprehensive management of both wild and hatchery fish, but artificial propagation will play a major role in the augmentation process. The current husbandry techniques in existing hatcheries require improvements that may include changes in rearing densities, addition of oxygen, removal of excess nitrogen, and improvement in raceway design. Emphasis will be placed on the ability to increase the number of fish released from hatcheries that survive to return as adults.

Rearing density is one of the most important elements in fish culture. Fish culturists have attempted to rear fish in hatchery ponds at densities that most efficiently use the rearing space available. Such efficiency studies require a knowledge of cost of rearing and the return of adults to the fisheries and to the hatchery.

It is widely accepted that the limitations on survival imposed by rearing densities are dependent upon oxygen availability. The models of Westers (1970), Liao (1971), and Banks et al. (1979) are based on the limitations of oxygen availability at various densities, temperature, and sizes of the fish being reared. In the past oxygen limitations have been overcome by increased flow, but in recent years, addition of oxygen to the raceways has become an acceptable alternative.

In spite of the acceptance of oxygen as the limiting factor in fish culture at the present time, there has been little information on the relationship between oxygen availability to cultured salmon and their subsequent survival after release to adulthood. This project will extend that information by examining the effects of oxygen supplementation in a surface water hatchery on the rearing and survival of spring chinook salmon. The first four years of the project will look at the operational aspects of the use of oxygen, the effects on water quality on oxygen utilization, and overall quality of fish reared at high densities with supplemental oxygen. Results from the first two years of releases have already been described (Ewing and Sheahan 1990; Ewing and Sheahan 1991).

REVIEW OF EFFECTS OF CYCLIC OXYGEN CHANGES IN FISH

The effects of oxygen concentrations on fish physiology and behavior was reviewed in an early report (Ewing and Sheahan, 1990). Specialized areas of the effects of oxygen concentration on fishes were not included in the review at that time. Some of these areas which are relevant to the present study will be reviewed in our annual reports.

One of these specialized areas which is especially relevant to the present study is the effect of diurnal and circannual changes in oxygen concentration on fishes, especially salmonids. Unfortunately, the literature is very scanty on this subject, probably because these are very hard experiments to do.

The respiration of fishes undergoes a diurnal cycle, although this simple experiment is not well documented. Elliott (1969) used a polarographic oxygen analyzer to look at oxygen consumption in unfed chinook salmon in a raceway environment. He found that there was a sudden rise in oxygen consumption associated with first daylight, a steady increase from 1200 to 1700 hours, and a decrease to lowest levels by 2300 hours. He also demonstrated that the oxygen consumption of the fish depended on size of the fish, temperature of the water, and hatchery conditions such as feeding and cleaning. His conclusion was that measurment of oxygen consumption of salmonids was not as easy as one might first expect.

Kindschi and Koby (1993) provided some data on the diurnal oxygen consumption of cutthroat trout (*Oncorhvnchus clarki*). They found that the oxygen consumption of the trout rose abruptly from 500 to 700 hours, remained constant until 1300 hours, then slowly decreased throughout the remainder of the day. No information on temperature was provided.

These diurnal changes in oxygen consumption were largely ignored by Liao (1971), who presented equations that defined oxygen consumption of salmonids by size and temperature alone. No mention was made of the time of day that the measurements were made. In spite of this, a number of reconunendations for rearing densities have been made based on the equations of Liao (Banks et al. 1979; Walters, 1989).

The effects of diurnally fluctuating oxygen levels on fish have been examined in several species. Wiebe (1930) reported that the diurnal changes in dissolved oxygen in fish ponds could be as large as those from seasonal changes taken at a single date. More detailed studies (Wiebe, 1931) indicated that the variation in oxygen content was due to oxygen consumption by algae in the ponds. The algae could become so abundant on occasion that the lack of oxygen endangered fish life.

Algal growth has been a constant problem with catfish farmers. Uneaten feed and fish wastes stimulate algal growth so that the farmers must measure dissolved oxygen concentrations at intervals during the night to insure that sufficient oxygen is present for the catfish. Aeration is supplied when needed (Boyd et al., 1980). Lai-Fa and Boyd (1988) reported an experiment where they compared the harvest weight of fish from aerated ponds with those of unaerated ponds. They found significantly higher growth, conversion, and economic gain from fish reared under conditions of nightly aeration.

Carlson et al. (1980) examined the growth of channel catfish (Ictalurus punctatus) under laboratory conditions. They found that growth of catfish was reduced at oxygen concentrations below 5.0 ppm.

At 3.5 ppm, the fish ate their rations but conversion was low. At 2.0 ppm, they ate only a small amount. When the fish were subjected to diurnal changes in oxygen content, significant changes in growth were observed only at the lowest concentrations where oxygen cycled from 3.1 to 1.0 ppm. They also tried these experiments with yellow perch (Perca flavescens) and found that growth was only inhibited below 2.0 ppm. Cyclic changes in dissolved oxygen from 3.1 to 1.0 ppm did not inhibit growth significantly.

There were some problems with these experiments, however. Fish were brought into the laboratory from different sources and fed to differing degrees. Many had ectoparasite infections and were treated with antibiotics repeatedly. The effects of these variables on the experimental results was not examined.

Stewart et al. (1967) looked at the effects of die1 changes in oxygen on largemouth bass (Micropterus salmoides). Dissolved oxygen was reduced to varying low concentrations. The fish were held at these concentrations for either 8 or 16 hours for time periods of about 15 days. In the fish held at variable dissolved oxygen regimes, growth was always less than that expected from the mean dissolved oxygen concentration. Fish exposed to 8 hours at low oxygen and 16 hours at high oxygen grew faster than those exposed to 16 hours of low oxygen and 8 hours of high oxygen. The authors suggest that "even when oxygen concentrations are near or above saturation levels during a large portion of the day, the growth of the fish may be inhibited by very low concentrations occurring during the remainder of the day". They suggest that average oxygen concentrations during the day may have very little meaning for the well-being of the fish.

Carlson and Herman (1978) examined the effect of die1 fluctuations in dissolved oxygen on the spawning success of black crappies (Pomoxis nigromaculatus). Variable ranges of oxygen were from 8.1 to 5.4 ppm, 7.0 to 3.6 ppm, 5.7 to 2.7 ppm and 4.1 to 1.8 ppm. Only at the lowest concentration was lack of spawning observed, although gonadal development occurred in both males and females at all oxygen concentrations. They concluded that dissolved oxygen concentrations of 2.6 or above were sufficient for spawning and that die1 fluctuations below this level may cause hypoxic stress and inhibit reproduction.

Bouck and Ball (1965) looked at physiological changes in blood of bluegills (Lepomis macrochirus), yellow bullheads (Ictalurus natalis), and largemouth bass (Microoterus salmoides) when dissolved oxygen was lowered to 3.5, 2.7, and 3.1 ppm, respectively, for 8 hours per day. The test was run for 9 days for bluegills and bullheads and 8 days for bass. Results of electrophoresis of blood proteins indicated that a change in the protein composition occurred at low oxygen concentrations in bluegills and bass, but not in bullheads. During the periods of low oxygen concentrations, the fish increased their ventilation rates and remained quiet. Food was generally ignored. Casual observation suggested that hypoxia might increase blood clotting rates.

Bouck (1972) continued these experiments with rock bass (Ambloplites ruoestris). He found that when dissolved oxygen was lowered to 3.0 ppm for 8 hours a day for a period of 9 days, blood protein components, measured by electrophoresis, were different from controls. The blood proteins were not identified. Hematocrits increased by 20% and hemoglobin and plasma protein concentrations increased 4% over controls. Ventilation rate increased from 60-65 vpm to 113 vpm at 3 ppm dissolved oxygen. The fish tended to lose their olive green color and appeared more silvery during hypoxia. When normal levels of oxygen returned, the fish regained their original color.

Whitworth (1968) built a device for opening and closing a nitrogen cylinder attached to a gas stripping column. In this way, he could regulate the concentration of oxygen in a tank of brook trout (Salvelinus fontinalis) to produce a die1 change in oxygen. Dissolved oxygen was decreased from saturated levels to 5.3, 3.6, 3.5, and 2.0 ppm for 14 hour periods. His results showed that growth was inhibited at all concentrations of oxygen.

Fisher (1963) showed that growth of coho salmon was not impaired by constant levels of dissolved oxygen above 5.0 ppm. During fluctuating oxygen regimes, where oxygen levels varied from 9.5 to 3.0 ppm and 18.0 to 3.0 ppm, he found that weight gain tended to mimic that found at the lowest oxygen level rather than the average oxygen concentration. This suggested that the growth rate was regulated by the lowest concentration of oxygen that the fish experienced during the day. However, in a second experiment, he varied oxygen concentrations from 9.6 to 2.3 ppm and 35.5 to 4.9 ppm and found no difference in growth between coho reared under these conditions and those reared at constant higher oxygen concentrations. The results of the second experiment negated those of the first.

In summary, the literature on the effects of variable oxygen regimes on fish growth and performance is very sparse. The experiments have much greater levels of complexity than those using constant levels of oxygen. Because of this complexity the questions to be answered are multiplied: How wide a variation in oxygen concentration can be tolerated? How long at a given concentration is required before effects can be seen? How long does it take to recover from hypoxia? Are acute exposures to variable oxygen extremes as harmful as chronic exposure? Are the results similar at all times of the year?

The important thing to consider from these articles is best sumned up by Stewart et al. (1967) who concluded that "even when oxygen concentrations are near air-saturation levels during a large portion of each day, the growth of fish may be seriously inhibited if very low concentrations occur during the remainder of the 24-hour day". It is the lowest dissolved oxygen concentration of the day which may determine the performance of the fish. In this respect, the effects of low oxygen concentrations may be analogous to those observed for incipient lethal temperature (Golden, 1989). Cutthroat trout were subjected briefly to incipient lethal temperatures for a portion of the day, then restored to non-lethal temperatures. The effects of the exposure to near lethal temperatures tended to accumulate with time until mortality resulted. This suggested that physiological events were occurring within the fish which required a longer time period than 24 hours for correction. Similar experiments with lowered oxygen concentrations would be extremely interesting and useful for agencies responsible for setting dissolved oxygen concentrations for rivers and streams.

Respiration of salmonids in culture is rarely monitored over a 24-hour period. During stress conditions, such as pond cleaning, feeding, or transportation, dissolved oxygen levels may drop to levels below the standard of 5.0 ppm recommended for growth and performance. The effects of repeatedly experiencing these conditions is not known. If they are reared under semi-natural conditions, where weed or algal growth is prevalent, oxygen concentrations at night may reach levels where growth, immune function, or physiological functions may be compromised even though daytime measurements of oxygen concentration suggest that no problem should be evident.

REVIEW OF THE EFFECTS OF REARING DENSITY

ON SURVIVAL TO ADULTHOOD FOR PACIFIC SALMON

Introduction

In recent years, the threatened existence of certain salmon stocks has increased efforts to restore the runs to historic levels. Hydropower developement and operations, drought, pollution, and commercial fishery interests have all contributed to this decline in salmon production. To offset these sources of depletion and to augment wild stocks, government agencies, resource managers, citizens' groups and scientists on the west coasts of the United States and Canada have conducted a number of density studies to develop optimum rearing densities for cultured salmonids that will result in the maximum return of adults. The simple experiments that were originally conceived, however, have provided results that are complex and hard to interpret. In several cases, the completed experiments were simply not analyzed or summarized in final reports.

This review sunmmarizes the results from some of these experiments and attempts to provide similar bases for the interpretation of the final results. We have limited the review to adult yields of hatchery-raised, anadromous salmonid species reared in the Northwest. We have found few precedents for a review of this type. Banks (unpublished manuscript) summarized the results of rearing density experiments in the Northwest on adult yields of chinook salmon. He addressed the need for evaluating each facility for optimum rearing densities in terms of adult yields instead of juvenile carrying capacities. He suggested that such results are likely to be "site-specific". There have been several instances where the theoretical production potential has been calculated (Banks et al. 1979, Walters, 1989). However, there have been few studies where these theoretical potentials have been tested, using adult yields as a criterion for success.

Some basic parameters and their importance to our interpretation of the experiments require discussion. We have limited this review to hatchery experiments that have used coded wire tags to mark individual groups of salmon. Coded wire tags are 1 mm pieces of wire inscribed with a binary code that are inserted into the snouts of juvenile salmon (Jefferts et al. 1963). The juvenile salmon are also marked with an adipose fin clip so that they can be identified as salmon carrying wire tags. Sampling programs have been organized throughout the Northwest to obtain snouts of fish with coded wire tags from the ocean fishery. This sampling permits the fisheries agencies to determine the range of the fish and the extent of harvest. Adipose fin clips are thought to impose minimal mortalities. Tagging with coded wire is presently the easiest and most accurate means for marking large numbers of fish from a multitude of groups.

A number of terms have been used in conjunction with density experiments. "Density" is used in a context similar to that in the physical sciences, that is, weight per unit-volume. In fish culture, the density of reared fish is usually expressed as pounds of fish per gallon of water. Because there is a general trend toward the simpler metric system, densities in this review will be referred to as kilograms of fish per cubic meter of water. "Load" is defined as weight of fish per water flow, usually referred to in the English system as pounds of fish per gallon per minute. We will use the metric equivalent of kilograms of fish per cubic meter per minute. "Density Factor", a variation of density, takes the length of the fish into consideration and is defined as density per unit length in inches (Piper et al. 1982). Because of the variation of release sizes in each experiment, it is difficult to use this parameter for comparisons so we have not calculated this parameter in the experiments described.

The two measurements for carrying capacity in raceways, density and load, vary considerably in their interpretation. Density is a measure of the space in which a fish resides in relation to other fish. Water quality may vary considerably in different studies because the replacement of water is not considered in its calculation. In contrast, load measures the weight of fish in relation to flow so that the effects of water quality on the fish health and behavior is considered. Density tends to emphasize the psychological aspects of rearing space while load emphasizes the physiological changes resulting from water quality.

A third parameter is occasionally used that relates the total weight of fish to the surface area of the rearing pond. It is usually defined as kilograms per square meter of surface area. However, surface area seems to have little importance in an understanding of the rearing capacity requirements, unless oxygen diffusion is limited by surface area. Such a situation is unlikely to be encountered in the culture of salmonids. If surface area alone is considered, a deep water body and a shallow water body are equivalent if they have the same surface area. Similarly, a water body with no current and one with a fast current are considered equivalent if they have the same surface area. There seems to be little behavioral or physiological bases for using this measurement in rearing capacity experiments. We have therefore omitted these calculations from this report.

In view of our current knowledge of limiting factors for fish production, load is probably the most important factor. Load takes into consideration that the rearing water is being replaced regularly with water of higher quality. Oxygen is probably the chief factor that limits carrying capacity of a water body. Little is known of any psychological aspects of rearing density that would tend to limit carrying capacities.

The sampling techniques by which density and load are derived determine the error associated with the measurements. It is often difficult to determine total fish weights without knowing how the pond counts were made. The number of samples taken for pond counts will determine the degree of precision of the estimate (see Appendix 6). Similarly, flow is often estimated rather than determined by flow meters or by pond filling. The accuracy of these estimates will determine the error associated with load deteminations.

Even with the best measurements, density and load are never constant in the raceway because of the growth of the fish. Most fish hatcheries project the growth of their fish by formulas relating feeding rate and average water temperatures so that the fish reach the desired size at the appropriate time for stocking. Densities and loads reported here refer only to the final values attained inmediately before stocking.

Density and load are parameters that can usually be calculated for each study. However, the variability of each parameter is determined by the foresight and control imposed by the experimenter. The following are some other issues that we have regularly encountered in these analyses that increase the complexity of the interpretation of the results:

Rearing Space - This aspect is very important to an interpretation of the results of density studies. The rearing space may be an open lake, a concrete raceway, or a fiberglass tank. The type of rearing space influences feeding patterns, surface/depth ratios and die1 synchrony. With the few studies available, it is not possible to compare the effect of rearing space on density/survival relationships so we will simply note the type of rearing space while describing the experimental design.

Flow - Flows are often variable throughout the rearing cycle and thereby cause variation in the loads unrelated to fish size or numbers.

Volume - The volume of a rearing area is often stated only as raceway dimensions rather than an actual volume. Calculations based on these dimensions probably result in an overestimate of the pond volume and therefore an underestimate of the density attained.

Temperature - Variations in temperature can affect metabolic activity and therefore oxygen consumption. Thus, during changes in water temperature, water quality can change appreciably without apparent changes in load.

Mortality - Mortality of the juveniles is an indicator of stress and disease susceptibility in the population. It is often given less attention than it warrants, because it seems to increase with rearing density. Where possible, we will display these rates in the experimental results.

Pond-splitting - Pond splitting occurs when the density of fish in a pond increases to a point considered deleterious by the hatchery manager. The numbers of fish in the pond are decreased by transferring some of the fish to other ponds. Multiple pond-splitting imparts a saw-tooth profile to plots of fish density with time. The density under such conditions is never constant and the relationship between pond density and survival is difficult to interpret.

Type of Release -Two types of release have been described: volitional and forced. In general, we have considered all density experiments to constitute forced releases. Short-period volitional releases accomplished by opening of pond screens with a subsequent sweep of the few remaining fish essentially constitutes a forced release. True volitional releases over a period of months would result in uninterpretable results for density studies.

Release Dates - Release dates are varied both for the species raised and for the facilty. We have tried to minimize these effects by comparing only groups released at the same time. No effort has been made to determine if density effects are different at different release dates.

Observed vs. Expanded Recovery Rates - Observed recovery rates of adults usually refer to the number of individuals recovered from a particular area or group. Observed recovery rates for ocean fisheries are usually expanded to reflect the sampling percentage for each area. Expanded rates are therefore a more accurate reflection of the total survival of a group of fish. In this review, we use expanded recovery rates unless they are not available.

Mathematical errors - The most common mathematical error encountered in these studies is that of the 'rounding error". Occasionally, discrepancies in calculated parameters, such as adult yield or adults/m^3, can be traced to numbers which have been rounded off and which are then used for other calculations. Ye have added footnotes to tables where our calculations of parameters have differed from the authors.

In order to make comparisons of various studies at different hatchery facilities, we devised a model. This model consists of four sections, all in table form. The first table incorporates brood-year, pond number, fish population number at release, mean weight in grams, total fish weight in kilograms, flow at release in liters per minute, density in kilograms per cubic meter, and load in kilograms per liter per minute for each population. A mortality rate (percentage) is presented as the sum of mortalities from disease, accident, or any other form of expiration. It will be given as a factor only within the most recent pond-split or period of rearing in which a treatment group is formed.

The second table of the model consists of subsampling data for the treatment groups, when available. It contains brood-year, pond number, coded-wire tag codes, number and percent of each population tagged, tag retention percentages for each population, mean forklength in centimeters with standard errors, mean weight in grams with standard errors, and the number of fish sampled from each population or treatment group. This data is useful for comparing sizes at release and making necessary corrections to the recoveries of adults. However, the majority of the density experiments did not report this information.

The third table lists the various adult and jack recoveries for the treatment groups. Like the previous tables, it has identifying characteristics like brood-year, pond number, or density, and tabulated coded-wire tag codes. This table represents the raw data from which the calculations of percent yield, adults per density, adults per load, and total adults are calculated.

Finally, the fourth table is a tabulation of our calculations from analyzing the experimental data. For each density group, there are the respective percent yields, total adult yields per pond, total adults per cubic meter of rearing space, and total adults per flow. In some instances, these results will be presented as total yields, the result of including jack salmon recoveries in the parameters. The data from this table is used to determine the relationships to density and load of juvenile rearing.

The design of each density study dictated the statistical analysis used. After examining the various designs, we chose three methods of analysis. If the groups were replicated, analysis of variance was used for comparison of the results. If statistical significance was found, then Tukey's t-test was used to determine the statistically significant groups. If the experiment had four or more treatment groups but no replicates, regression analysis was used to determine if there was a linear relationship between the density or load and adult yield. If the experiment had less than four treatment groups with no replicates, we used simple graphic analysis to determine if a relationship between density or load and yield appeared to exist. In all three approaches, we examined data only within a single release year. Comparisons between years more often reflect differences in ocean conditions than in effects of treatment groups. Yields between years could have been normalized to remove between-year variations, but the results would have been essentially the same as we present here.

The following hypotheses were tested for each experiment:

1) Increased rearing density caused lower percent survival.

2) Increased load caused lower percent survival.

3) Increased rearing density resulted in more adults per pond.

4) Increased load resulted in more adults per pond.

5) There were interactive effects between rearing density and load. Negative effects of rearing density could be offset by increased flow.

6) Increased rearing density resulted in greater mortality of juvenile fish.

Not all of these hypotheses could be tested for each experimental group but we examined as many as possible. All hypotheses were tested at the 95% level of confidence.

Ye hope that the following analysis of the results from rearing density studies can be used for future studies to avoid some of the common errors in experimental design which make analysis difficult. A compilation of the data in review form also should make it easier to formulate hypotheses to test by future hatchery biologists.

Coho Salmon

In 1975, the relationship between density, load and survival of coho salmon (Oncorhynchus kisutch) was tested at Sandy Hatchery, Oregon (Hemmingsen and Johnson, 1976). The execution of the experiment was carefully done (Table 1) in that mean sizes of the fish at release in all treatment groups were not significantly different (Table 2). However, this study was conducted for only a single year.

Results indicated that there was no significant difference in yield between release groups (Table 3). The authors suggested that increased water flow could offset the reduced yields resulting from high rearing densities (Table 4). However, they presented no evidence that, under their rearing conditions, the yields were decreased as a result of increased rearing densities. Without this additional data, the results could also mean that rearing density did not affect surival as indicated by other authors (see below). Without further information, we must consider the results of this study inconclusive.

Another rearing density experiment was run in 1975 at Capilano Salmon Hatchery, British Columbia (Sandercock and Stone, 1976). The objective was to determine the effects of rearing density on adult survival. A chlorination accident necessitated the use of eyed eggs from the Big Qualicum River Project (Vancouver Is.) instead of the indigenous stock. Conditions at release are shown in Table 5.

This experiment seemed simple enough: increasing numbers of fish were put into raceways of similar size. However, no reference was made to flow rates (Sandercock and Stone, 1979). We assumed and verified (Sandercock and Stone, 1981) that the flow rate was the same as that of later experiments with

Table 1. Conditions at release for 1975-brood coho salmon reared at Sandy Hatchery, Oregon.

Group	Flow (lpm)	Number of Fish	Average size (g)	Total kg	Density (kg/m^3)	Load (kg/lpm)
Low	462	29,290	27.8	814	11.7	1.76
Medium	924	58,570	25.9	1517	21.8	1.64
High	1893	117,140	24.9	2917	41.9	1.54

Table 2. Data at release for density study with 1975-brood coho salmon reared at Sandy Hatchery, Oregon.

Group	Tag Code	Number Tagged	Tag Retention	Length (cm)	Weight (g)	Number sampled
Low	09 05 14	24,893	0.97	13.5 ± 0.1	27.8 ± 0.1	223
	09 06 01	25,813	0.95	13.6 ± 0.1	27.8 ± 0.1	229
Medium	09 05 15	24,477	0.94	13.3 ± 0.1	25.2 ± 0.2	236
	09 06 03	22,854	0.91	13.4 ± 0.1	26.6 ± 0.2	210
High	09 06 02	20,139	0.91	13.2 ± 0.1	25.1 ± 0.3	247
	09 06 04	23,416	0.91	13.3 ± 0.1	24.7 ± 0.2	292

Lengths and weights are presented as means ± standard errors.

Table 3. Catch and escapement of 1975-brood coho salmon reared in the density experiment at Sandy Hatchery, Oregon.

Group	Tag Code	Jacks Hatchery No.	Jacks Hatchery %	Adults Fishery[a] No.	Adults Fishery[a] %	Adults Hatchery No.	Adults Hatchery %	Total[a] No.	Total[a] %
Low	09 05 14	24	0.10	216	0.87	212	0.85	452	1.82
	09 06 01	17	0.07	167	0.65	193	0.75	377	1.46
	Average		0.08		0.76		0.80		1.64
Medium	09 05 15	16	0.07	220	0.90	228	0.93	504	2.06
	09 06 03	20	0.09	165	0.72	180	0.79	365	1.60
	Average		0.08		0.81		0.86		1.83
High	09 06 02	16	0.08	189	0.94	208	1.03	413	2.05
	09 06 04	19	0.08	223	0.95	247	1.06	489	2.09
	Average		0.08		0.95		1.04		2.07

[a]Includes jacks.

Table 4. Comparison of production between treatment groups of 1975-brood coho salmon reared at Sandy Hatchery, Oregon.

Treatment Group	Density (kg/m^3)	Percent Yield	Adults per pond	Adult per m^3	Adults per lpm
Low	11.7	1.64	910	13.06	33.87
Medium	21.8	1.83	1962	28.15	36.50
High	41.9	2.07	4664	66.63	42.32

Table 5. Conditions at release for 1975-brood coho salmon reared at Capilano Hatchery, British Columbia.

Group	Number of Fish	Average size (g)	Total kg	Density (kg/m^3)	Load (kg/lpm)
Low	29,290	15.6	875	7.06	0.52
Medium Low	74,552	19.0	1416	11.42	0.84
Medium High	82,102	19.1	1568	12.65	0.93
High	101,176	14.4	1457	11.75	0.87

Table 6. Catch and escapement of 1975-brood coho salmon reared at Capilano Hatchery, British Columbia.

Group	Tag Code	Jacks Fishery No.	Jacks Fishery %	Jacks Hatchery No.	Jacks Hatchery %	Adults Fishery No.	Adults Fishery %	Adults Hatchery No.	Adults Hatchery %	Total[a] No.	Total[a] %
Low	02 16 17	25	0.17	601	3.2	4839	26.1	1000	5.4	6465	22.1
Medium Low	02 16 18	10	0.05	528	2.8	3243	17.0	755	4.0	4536	6.1
Medium High	02 16 19	15	0.06	496	2.0	4695	18.9	912	3.7	6118	7.4
High	02 16 20	5	0.02	254	1.1	3689	15.9	669	2.9	4617	4.6

[a]Includes jacks.

1977- and 1978-brood fish. Also, there was a problem with establishing accurate population numbers for the experimental raceways. Labelled "discrepancy errors" by the authors, different numbers of fish were reported by the authors. This jeopardized efforts to determine accurate mortality rates as well as verify the marked to unmarked ratios. The authors assumed the populations at release were the "calculated numbers" for purposes of treatment group comparisons. How they determined that these figures were more accurate than those obtained from marked to unmarked fish ratios is unclear. These numbers are given in Sandercock and Stone (1979) and are not the same as those from the recovery tables in Sandercock and Stone (1981). We have used the "calculated" numbers from Sandercock and Stone (1979) for this analysis.

The results of the study are given in Tables 6 and 7. The small number of treatment groups precluded the use of regression analysis and the lack of replicates prevented the use of analysis of variance for establishing statistical significance. Consequently, a graphic analysis was conducted. A linear relationship between number of fish per group (or density) and percent survival was found (Fig. 1). No mortality rates for the juveniles were given, so this aspect of the analysis was not done.

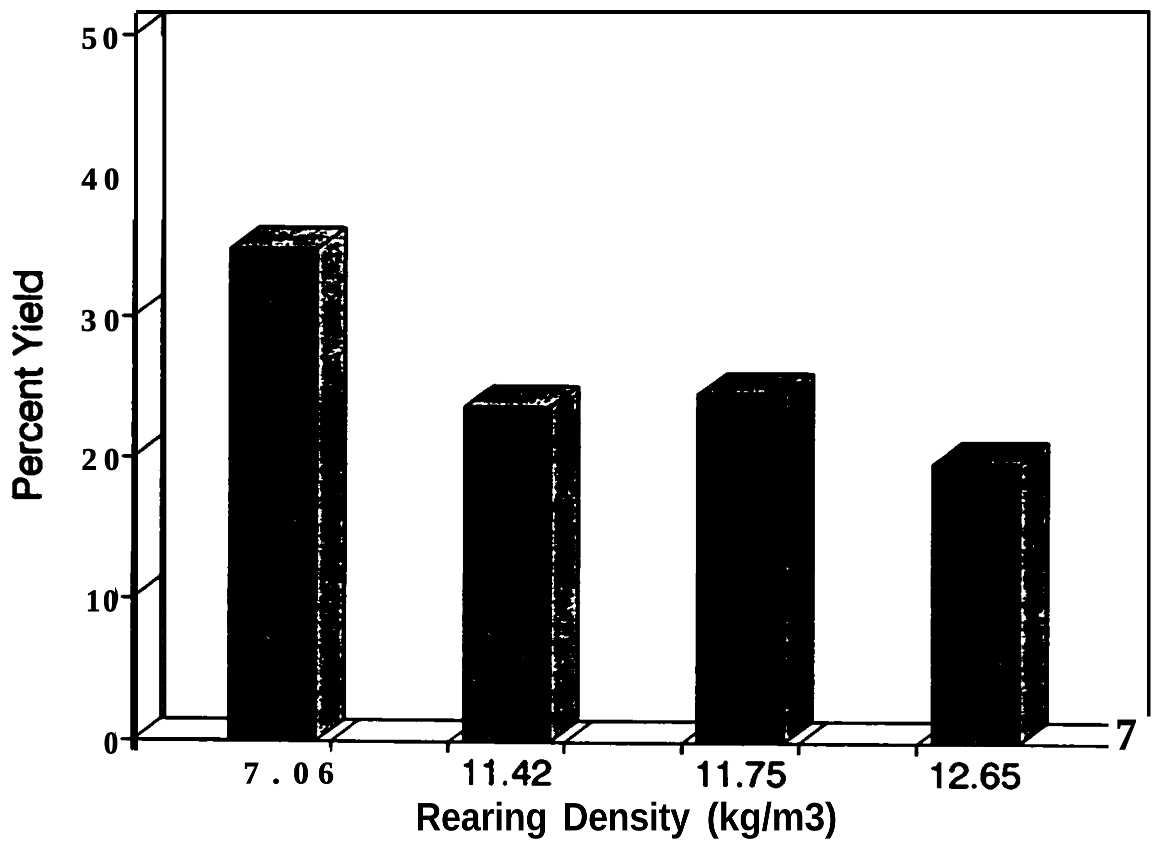
This experiment at Capilano Hatchery stimulated a growing interest in rearing density as a factor in the survival of hatchery salmonids. The density study was continued for two more brood years at Capilano Hatchery in 1977 and 1978 (Fagerlund et al., 1983; Fagerlund et al., 1989). These experiments seemed to be expanded versions of the 1975-brood experiment.

Table 7. Comparison of production between treatment groups of 1975 brood coho salmon reared at Capilano Hatchery, British Columbia

Treatment Group	Density (kg/m^3)	Percent Yield	Adults per pond	Adults per m^3	Adults per lpm
Low	7.06	22.1	5839	47.09	3.48
Medium Low	11.42	6.1	3998	32.25	2.38
Medium High	12.65	7.4	5607	45.22	3.34
High	11.75	4.6	4358	35.15	2.59

Fig. 1. Relationship between rearing density and percent yield for coho salmon reared at Capllano Hatchery, British Columbia.

Capilano Coho Salmon



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The conditions at release for these two brood years are presented in Table 8.

The experiment with 1977-brood fish was relatively simple. Different numbers of fish were placed in four separate raceways to create four rearing densities. Average fish weight was different at release in all four treatments. In contrast, the 1978-brood experiment seemed to have an overly complex design, including a size at release experiment as well as a density experiment. As a consequence, the relationship between density and fish site or mortalities tended to become obscured. Experiments, such as that of Bllton et al. (1981), where only time and site at release were examined, provided a much clearer demonstration of the relationship between size and adult survival.

Recoveries from both broods was relatively high. reaching almost 30% in some instances (Tables 9 and 10). Calculation of overall percent survivals for the 1978-brood was done by assuming that the three size classes were present equally in the raceways. Data on the average population sizes and size distributions within the populations were not available. Using this approach, we could estimate the average size and the density of these ponds. With this assumption we could also derive a percent survival for the entire group (Table 10).

The results of the 1977-brood experlment suggested an inverse relationship between percent yield and density (or load). although regression analysis showed no significant relationship at the **95%** confidence level. No significant relationship was found between adults per pond and rearing density. With the 1978-brood experiment, regression analysis showed a significant relationship between adult yield per pond and rearing density, but not with percent yield and rearing density.

Table 8. Conditions at release for 1977- and 1978-brood coho salmon reared at Capllano Hatchery, British Columbia.

Brood Year, Group	Number of Fish	Mortality (%)	Average size (g)	Total kg	Density (kg/m^3)	Load[a] (kg/lpm)
1977						
Low	56,638	-	17.7	1003	8.09	0.60
Medium Low	75.780		16.6	1258	10.15	0.75
Medium High	84,387		15.4	1307	10.54	0.78
High	104,551	-	13.8	1443	11.64	0.86
1978						
Low[b]	49,410	1.2	13.6	679	5.48	0.40
small			10.5			
medium			13.9			
large			18.0			
Medium[b]	70,313	1.2	13.1	921	7.43	**0.55**
small			11.1			
medium			13.9			
large			17.2			
High[b]	78,195	1.9	12.7	993	8.01	0.59
small			9.4			
medium			12.s			
large			16.2			
Low	51,329	0.6	13.2	678	5.46	0.40
Medium	63,105	0.5	12.3	776	6.26	0.46
High	91,811	0.7	12.5	1148	9.26	0.68

[a] **Flow** was estimated at 28 liters per second.
[b] Weights are only approximate. **The** values given assume that equal proportions of small, medium, and large fish are present in the ponds. Measured weights are given for groups segregated by size but these represent only 30,000 fish from the entire population. **All** calculations of density and load have this error included.

Table 9. Catch and escapement for 1977- and 1978-brood coho salmon reared at Capilano Hatchery, British Columbia. All hatchery and fishery numbers include jacks.

Brood Year, Group	Tag Code	Fishery No.	Fishery %	Hatchery No.	Hatchery %	Total No.	Total %
1977							
Low	02 21 23	4933	8.71	2973	5.25	7906	13.96
Medium Low	02 20 41	7017	9.26	3941	5.20	10958	14.46
Medium High	02 16 49	5603	6.64	3232	3.83	8835	10.47
High	02 16 50	6712	6.42	3638	3.48	10350	9.90
1978[a]							
Low							
small	02 17 01	1063	10.63	279	2.79	1342	13.42
medium	02 17 02	1793	17.53	365	3.57	2158	21.10
large	02 17 03	1946	19.71	368	3.73	2314	23.44
Medium							
small	02 17 04	936	9.79	222	2.32	1158	12.12
medium	02 17 05	2589	26.37	382	3.89	2971	30.26
large	02 17 06	3295	32.57	447	4.42	3742	36.99
High							
small	02 17 07	997	9.75	339	3.31	1336	13.06
medium	02 17 08	1637	17.37	431	4.57	2068	21.94
large	02 17 09	1612	14.81	387	3.55	1999	18.36
Low	02 21 26	7905	15.40	2264	4.41	10168	19.81
Medium	02 19 24	10356	16.41	2486	3.94	12842	20.35
High	02 20 58	13652	14.87	3498	3.81	17187	18.72

[a]Values for percent survival from density groups split into small, medium, and larg groups were given in Fagerlund et al. (1983; 1989). No values for the numbers of f released per group was provided.

Table 10. Comparison of production between treatment groups of 1977- and **1978-brood** coho salmon reared at Capllano Hatchery, British Columbia.

Brood Year, Treatment Group	Density (kg/m^3)	Percent Yield[a]	Adults per pond	Adults per m^3	Adults per lpm
1977					
Low	8.09	14.0	7906	63.77	4.71
Medium Low	10.1s	14.5	10,958	88.38	6.52
Medium High	10.54	10.5	8835	71.26	5.26
High	11.64	9.9	10,350	84.08	6.20
1978					
Low[b]	5.48	19.3	9599	77.43	5.71
Medium[b]	7.43	26.5	18,765	151.40	11.17
High[b]	8.01	17.8	13,833	111.60	8.23
Low	5.46	19.8	10,168	82.02	6.05
Medium	6.26	20.4	12,842	103.58	7.64
High	9.26	18.7	17,187	138.63	10.23

[a] Includes jacks (_ 1.0% of the run).
[b] Calculated by assumption that three sizes of fish are present in equal proportions in the ponds.

In 1979-1982, a series of density studies were conducted at Eagle Creek National Fish Hatchery in Estacada, Oregon (Holway, 1980, 1981, 1982). The purpose of the experiment was to compare adult returns from density studies at Eagle Creek National Fish Hatchery with those at Capllano Hatchery. In particular, density factors (Piper et al., 1982) would be compared. One of the major differences in technique at the two hatcheries was pond splitting. At Capllano Hatchery, only one pond-split occurred when the fish were ponded from the rearing tanks in June of the first production year. Fish were started at a very low density and gradually increased the density to a maximum at release without splitting or handling the fish again. Because of limited space and water supply in the summer, fish at Eagle Creek National Fish Hatchery were reduced in density three times before release. Consequently, maximum densities were reached four times at Eagle Creek Hatchery instead of twice as in the Canadian procedure.

Another difference between the two hatcheries was to include density levels 50% higher at Eagle Creek than at Capllano Hatchery. Conditions at release for the three brood-years of experimental releases are shown in Table 11.

Although there were several unpublished progress reports on the development of the experiment (Holway, 1980, 1981, 1982), the results of the experiments were not tabulated. We obtained final recoveries from the Pacific Marine Fisheries Council database (Mark Lewis, personal communication). A formal write-up on the experiment would have been of much greater help in interpreting the results. Recoveries are shown in Table 12.

Because of the small number of treatment groups and the lack of replicates, the 1979-brood could only be analyzed by graphic analysis. An inverse relationship was found between rearing density and percent yield (Fig.

Table 11. Conditions at release for 1979-1981 broods of coho salmon reared at Eagle Creek National Fish Hatchery, Oregon.

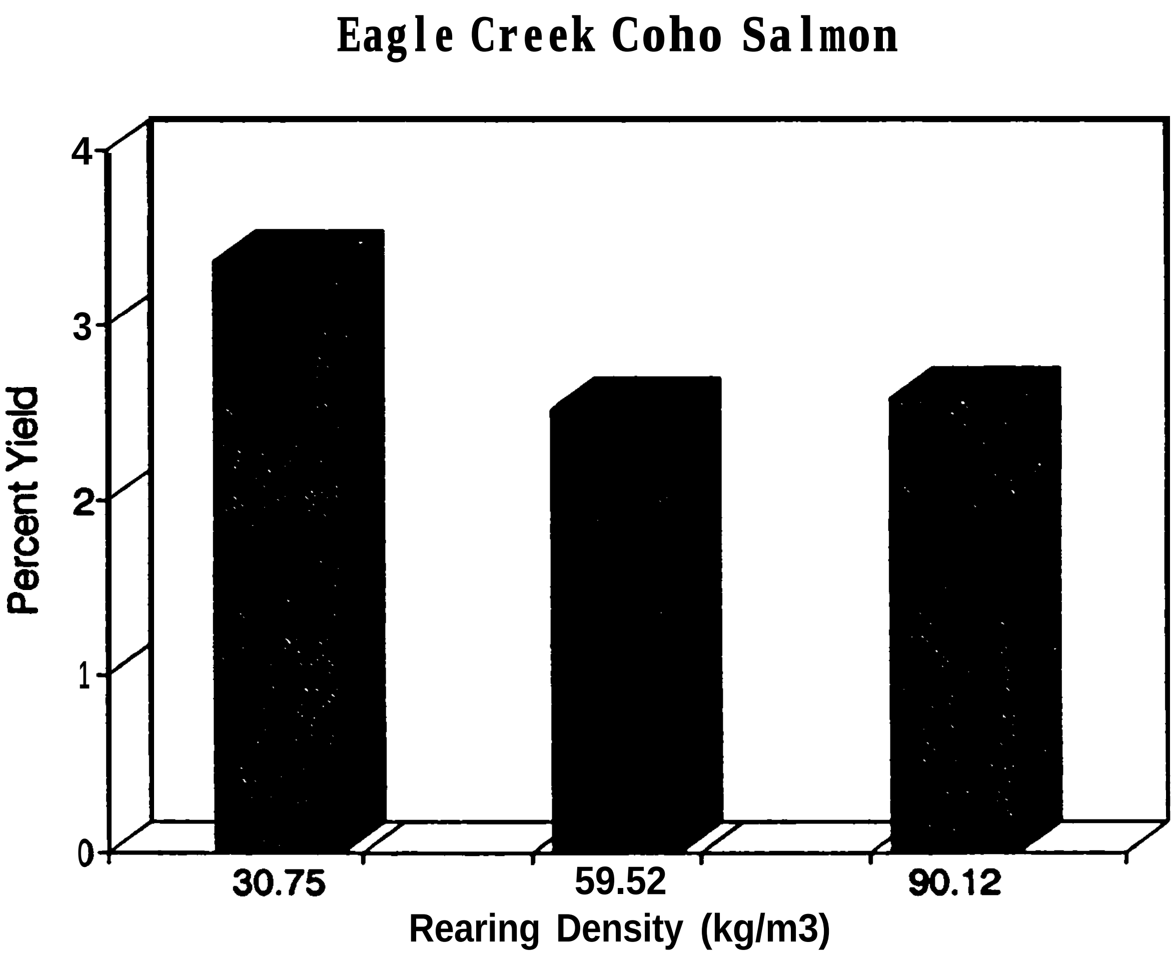
Brood Year, Group	Number of Fish	Mortality (%)[a]	Average size (g)	Total kg	Density (kg/m^3)	Load (kg/lpm)
1979						
Low	43,568	6.5	32.0	1393	30.75	0.74
Medium	83,740	5.4	32.2	2696	59.52	1.42
High	126,785	21.4	32.3	4082	90.12	2.16
1980						
Low	19,105	6.7	32.2	615	13.58	0.32
	20,041	15.7	34.7	695	15.33	0.37
Medium	42,640	2.1	31.5	1344	29.68	0.71
	42,412	1.9	28.7	1218	26.89	0.64
High	66,628	2.6	28.0	1857	40.99	0.98
	66,269	2.2	27.4	1867	41.22	0.99
1981						
Low	21,243		34.1	725	16.01	0.38
	21,663		34.1	740	16.33	0.39
Medium	40,910	-	31.5	1290	28.47	0.68
	42,082		32.7	1374	30.34	0.73
High	65,045		31.3	2037	44.96	1.08
	62,343		31.3	1952	43.09	1.03

[a] In the 1979-brood, furunculosis infested the high density group before the second pond split. Fish from the low density groups of the 1980-brood contracted cold water disease just before release. No mortality rates were available for the 1981 brood.

Table 12. Catch and escapement for 1979-1981 broods of coho salmon reared at Eagle Creek National Fish Hatchery, Oregon.

Brood Year, Group	Tag Code	Jacks Fishery No.	%	Jacks Hatchery No.	%	Adults Fishery No.	%	Adults Hatchery No.	%	Total No.	%
1979											
Low	05 08 27	23	0.05	-	-	1329	3.05	114	0.26	1466	3.37
Medium	05 08 28	13	0.02	-	-	1900	2.28	200	0.24	2113	**2.52**
High	05 08 26	45	0.04	-		2931	2.31	299	0.24	3275	2.58
1980											
Low	05 10 3s	0	0	3	0.02	231	1.21	36	0.19	270	1.42
	05 10 36	0	0	2	0.01	182	1.01	18	0.10	202	1.12
Medium	05 10 37	0	0	6	0.02	481	1.20	74	0.18	**561**	1.40
	OS 10 38	0	0	6	0.02	429	1.11	76	0.20	511	1.32
High	05 10 39	23	0.04	14	0.02	664	1.03	100	0.16	801	1.2s
	05 10 40	0	0	2	0.003	641	1.03	117	0.19	760	1.22
1981											
Low	05 11 38	1	0.01	8	0.04	166	0.82	80	0.40	255	1.26
	05 11 37	1	0.01	5	0.02	215	1.21	73	0.35	294	1.40
Medium	05 11 36	2	0.01	8	0.02	303	0.77	104	0.27	417	1.06
	05 11 35	0	0	9	0.02	285	0.70	96	0.23	390	0.95
High	05 11 34	0	0	11	0.02	375	0.60	127	0.20	513	0.82
	05 11 33	2	0.003	20	0.03	487	0.81	145	0.24	**654**	1.08

Fig. 2. Relationship between rearing density and percent yield for 1979-brood coho salmon reared at Eagle Creek National Fish Hatchery.



Eagle Creek Coho Salmon
Percent Yield
0
1
2
3
4
30.75
59.52
90.12
Rearing Density (kg/m3)

2), although percent yields for the middle and high density groups were similar. A linear relationship was also found between rearing density and adult yield per raceway (Fig. 3).

In the 1980- and 1981-brood experiments, experimental groups were replicated and recoveries were analyzed by analysis of variance (Table 13). In both brood years, the relationship between rearing density and percent yield was not significant. However, the relationship between rearing density and adult yield per raceway was significant for both years.

Beginning in 1980, coho salmon were reared at six densities for three consecutive brood years at two Washington Department of Fisheries hatcheries, Cowlitz Hatchery and Washougal Hatchery (Hopley et al., 1991). The intent of the study at these production-based facilities was to determine if rearing densities affected post-release survival. Conditions at release are shown in Table 14.

The experimental design and execution was good in most aspects. There were minor problems with developing a "planned flow regime" and in the capture of returning jacks at the Washougal facility. Also, data on mortalities and coded wire tags were not provided. Raceway dimensions and rearing periods were different at each site, but methods for handling the fish were similar.

The authors used a linear modelllng approach for the analysis of their percent yields, incorporating brood-year, facility, and release time into their model. They could find no significant improvement of R^2 values when pond densities or loading variable were included. We found no significant relationship by regression analysis between rearing density and percent yield or yield per raceway (Tables 15 and 16). Replicated treatment groups would have been preferable in order to use a stronger analysis of variance approach.

Fig. 3. Relationship between rearing density and yield per raceway for 1979-brood coho salmon reared at Eagle Creek National Fish Hatchery, Oregon.

Eagle Creek Coho Salmon

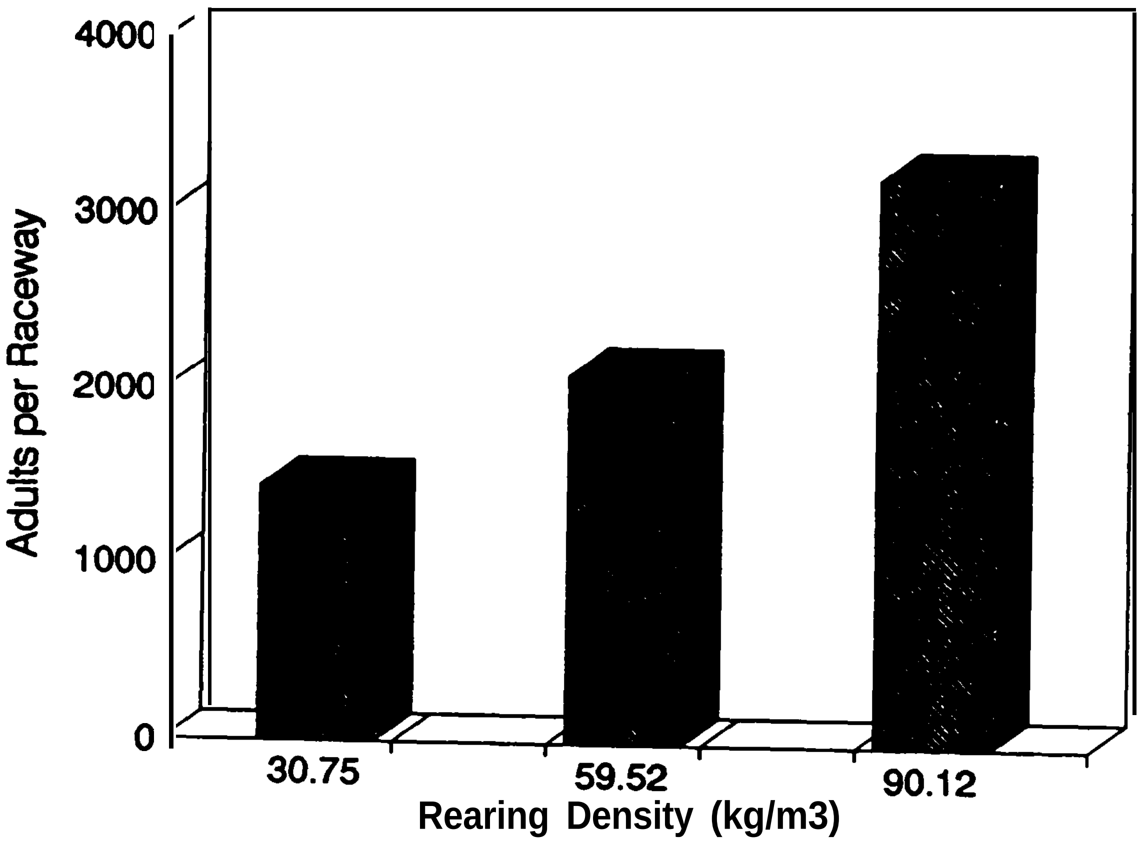


Table 13. Comparison of production between treatment groups of 1979-81 broods of coho salmon reared at Eagle Creek National Hatchery, Oregon.

Brood Year, Group	Density (kg/m^3)	Percent Yield	Adults per pond	Adults per m^3	Adults per lpm
1979					
Low	30.75	3.37	1443	31.85	0.76
Medium	59.52	2.52	2100	46.36	1.11
High	90.12	2.58	3230	71.30	1.71
1980					
Low	13.58	1.42	267	5.94	0.14
	15.33	1.12	200	4.42	0.11
Medium	29.68	1.40	555	12.25	0.29
	26.89	1.32	505	11.15	0.27
High	40.99	1.25	764	16.87	0.40
	41.22	1.22	758	16.73	0.40
1981					
Low	16.01	1.26	246	5.43	0.13
	16.33	1.40	288	6.36	0.15
Medium	28.47	1.06	407	8.98	0.22
	30.34	0.95	381	8.41	0.20
High	44.96	0.82	502	11.08	0.27
	43.09	1.08	632	13.95	0.33

Table 14. Conditions at release for 1980-82 broods of coho salmon reared at Cowlitz and Washougal Hatcheries, Washington.

Hatchery, Brood year	Number of Fish	Average size (g)	Total kg	Density (kg/m^3)	Load[a] (kg/lpm)
Cowlitz Hatchery					
1980	480,645	22.7	10,911	24.07	1.42
	368,900	28.4	10,477	23.11	1.51
	459,690	23.9	10,987	24.24	1.50
	436,991	25.2	11,012	24.29	1.53
	553,380	25.2	13,945	30.76	2.38
	623,675	23.9	14,906	32.88	2.54
1981	352,000	22.7	7,790	17.63	1.09
	421,000	22.7	9,557	21.08	1.41
	452,000	26.7	12,068	26.62	1.71
	441,000	26.7	11,775	25.98	1.78
	535,000	28.4	15,194	33.52	2.00
	607,000	26.7	16,207	35.75	2.70
1982	378,800	25.2	9,546	21.06	1.48
	454,100	25.2	11,443	25.24	1.47
	490,600	23.9	11,725	25.87	1.87
	550,400	26.7	14,696	32.42	2.84
	547,400	25.2	13,795	30.43	2.81
	620,373	26.7	16,564	36.54	3.22
Washougal Hatchery					
1980	41,600	22.7	944	3.14	0.71
	51,315	21.6	1,108	3.69	0.80
	61,543	21.6	1,329	4.42	1.04
	74,647	20.6	1,538	5.12	1.17
	88,158	21.6	1,904	6.34	1.45
	105,091	21.6	2,270	7.55	1.63
1981	40,020	23.9	956	3.18	0.72
	48,641	23.9	1,163	3.87	0.83
	57,530	23.9	1,375	4.58	1.07
	71,330	23.9	1,705	5.67	1.30
	83,218	23.9	1,989	6.62	1.52
	101,264	23.9	2,420	8.05	1.74
1982	39,600	25.2	998	3.32	0.82
	48,300	25.2	1,217	4.05	0.95
	56,746	23.9	1,356	4.51	1.19
	82,600	25.2	2,082	6.93	1.67
	70,500	26.7	1,882	6.26	1.78
	100,900	25.2	2,543	8.46	1.92

Table 15. Catch and escapement for 1980-1982 broods of coho salmon reared at Cowlitz and Washougal Hatcheries, Washington.

Hatchery, Brood Yr	Density (kg/m^3)	Fishery Jack	Fishery Adult	Hatchery Jack	Hatchery Adult	Total No.	Total %
Cowlitz Hatchery							
1980	24.07	12	604	100	153	869	1.66
	23.11	36	827	143	186	1192	2.31
	24.24	38	753	126	187	1109	2.15
	24.29	22	890	165	203	1280	2.41
	30.76	20	796	115	206	1137	2.17
	32.88	21	624	68	153	866	1.72
1981	17.63	72	640	84	199	995	1.91
	21.08	118	673	91	171	1053	2.03
	26.62	36	792	125	289	1242	2.39
	25.98	79	734	104	227	1144	2.21
	33.52	27	663	117	235	1042	2.03
	35.75	11	739	79	241	1070	2.04
1982	21.06		544	16	99	666	1.29
	25.24	3:	501	17	120	670	1.30
	25.87	6	634	18	162	820	1.60
	32.42	26	626	22	117	791	1.54
	30.43	13	460	20	120	613	1.21
	36.54	1	648	23	146	818	1.57
Washougal Hatchery							
1980	3.14	8	311	5	50	374	0.93
	3.69	15	296	7	53	371	0.77
	4.42	20	536	6	96	658	1.30
	5.12	12	448	2	80	542	1.07
	6.34	7	454	1	70	532	1.04
	7.55	2	355	5	65	428	0.85
1981	3.18	0	248	1	54	303	0.76
	3.87	0	167	0	42	209	0.43
	4.58	0	234	0	45	279	0.56
	5.67	0	208	0	49	257	0.50
	6.62		164	0	50	214	0.41
	8.05	8	289	0	59	348	0.67
1982	3.32	2	800	4	102	908	2.32
	4.05	5	866	4	127	1002	2.10
	4.51	3	1035	7	143	1118	2.27
	6.93	2	740	0	140	882	1.67
	6.26	0	839	7	119	958	1.83
	8.46	2	947	7	120	1076	2.05

Table 16. Comparison of production between treatment groups of 1980-1982 broods of coho salmon reared at Cowlitz and Washougal Hatcheries, Washington.

Hatchery, Brood year	Density (kg/m^3)	Percent Yield	Adults per pond	Adults per m^3	Adults per lpm
Cowlitz Hatchery					
1980	24.07	1.66	757	1.67	0.10
	23.11	2.31	1013	2.24	0.15
	24.24	2.15	940	2.08	0.13
	24.29	2.41	1093	2.41	0.15
	30.76	2.17	1002	2.21	0.17
	32.88	1.72	777	1.72	0.13
1981	17.63	1.91	839	1.85	0.12
	21.08	2.03	844	1.86	0.13
	26.62	2.39	1081	2.39	0.15
	25.98	2.21	961	2.12	0.15
	33.52	2.03	898	1.98	0.12
	35.75	2.04	980	2.16	0.16
1982	21.06	1.29	643	1.42	0.10
	25.24	1.30	621	1.37	0.09
	25.87	1.60	796	1.76	0.13
	32.42	1.54	743	1.64	0.14
	30.43	1.21	580	1.28	0.12
	36.54	1.57	794	1.75	0.15
Washougal Hatchery					
1980	3.14	0.93	361	1.20	0.27
	3.69	0.77	349	1.16	0.25
	4.42	1.30	632	2.11	0.49
	5.12	1.07	528	1.76	0.40
	6.34	1.04	524	1.75	0.40
	7.55	0.85	420	1.40	0.30
1981	3.18	0.76	302	1.01	0.23
	3.87	0.43	209	0.70	0.15
	4.58	0.56	279	0.93	0.22
	5.67	0.50	259	0.86	0.20
	6.62	0.41	214	0.71	0.16
	8.05	0.67	348	1.16	0.25
1982	3.32	2.32	902	3.01	0.74
	4.05	2.10	993	3.31	0.78
	4.51	2.27	ii78	3.93	1.03
	6.93	1.67	880	2.93	0.71
	6.26	1.83	958	3.19	0.90
	8.46	2.05	1067	3.56	0.81

One area of interest was the authors' use of analysis of scales from returning adults. They postulated two factors which might reduce the growth rate of fish in the hatchery and cause a reduced size of the fish at release. These were increased densities and the disease incidence resulting from the increase in rearing densities. The data from analysis of adult scales showed no size differences among the treatment groups of juveniles that survived to adulthood.

In 1983, a subcommittee of the Clatsop Economic Development Committee (CEDC) implemented a BPA-sponsored project to develop a low-cost community-oriented salmon rearing facility (Hill et al., 1989). The facility was to provide fall chinook and coho salmon for a terminal fishery on Youngs Bay, Oregon. As part of this specific project, a rearing density study with coho salmon was conducted. Conditions were as shown in Table 17.

This experiment was poorly designed to determine the effects of rearing density. The following conditions made it extremely difficult to interpret the return data in terms of rearing density:

1) Pond dimensions, flows and volumes were estimated. No techniques were described for determining the precision or accuracy of their estimates.

2) No diseased fish or mortalities were determined during rearing so the final number of fish released was only estimated. The only estimate of mortalities was in the 1986 release group from pond 1, where an estimated 20,000 fish died.

3) The size of the fish at release varied in the two ponds (Table 17). During the first two years, both densities and loads at release were similar in the two ponds because of the differences in size. On the third year, the size of the fish was estimated to be the same for the two ponds and consequently the density of pond 2 was nearly twice that of pond 1.

Table 17. Conditions at release for 1984-1986 broods of coho salmon reared for CEDC at Astoria, Oregon.

Brood Year	Pond	Number of Fish	Number tagged	Average size (g)	Total kg	Density (kg/m^3)	Load (kg/lpm)
1982							
	1	93,431	26,631	47.6	4450	1.18	1.96
	2	207,943	26,609	27.8	5773	1.39	1.53
1983							
	1	98,543	25,574	33.8	3328	0.88	1.47
	2	203,683	24,690	27.8	5655	1.36	1.49
1984							
	1	120,651”	27,643	36.2	4366	1.15	1.92
	2	263,126	45,583	36.2	9523	2.29	2.52

[a]This value was assumed after subtracting an estimated 20,000 mortalities.

4) A strategy for volitional release of the fish was used "where the retaining screens are removed and pond levels maintained at or near full capacity, allowing outmigration to occur when such an activity is naturally triggered". The release periods varied from a few days to several weeks, so the time of release was not held constant.

5) Most of the data on returns were incomplete at the time of the report. Also, the distribution of the fish between tag codes was not provided in several instances. For complete data on these returns, one would have to utilize the PMFC database. We have not done this at the present time.

The lack of replicate groups precluded the use of analysis of variance for interpretation of the data. Similarly, the small number of treatment groups did not permit the establishment of a relationship between rearing density and percent yield or adult yield by regression analysis. Consequently, we turned to graphic analysis.

Recoveries from the three years of releases are shown in Table 18. Fish from 1982 and 1983 broods reared in pond 1 survived in greater numbers than those reared in pond 2 (Table 18 and Fig. 4A). The same relationship is reflected in the percent yield (Fig. 4B). These results are probably due to the increased size of the fish in pond 1 because the densities and loads were not very different in those two years.

With 1984-brood fish, pond 1 had a severe disease outbreak which killed an estimated 20,000 fish. Percent yield from the fish in pond 1 was about twice that of pond 2, although the numbers of recovered adults was about equal (Table 18). No difference in size between the two ponds was noted for this release year.

From the confused design and large number of uncontrolled variables, we were unable to conclude anything about the relationship between rearing

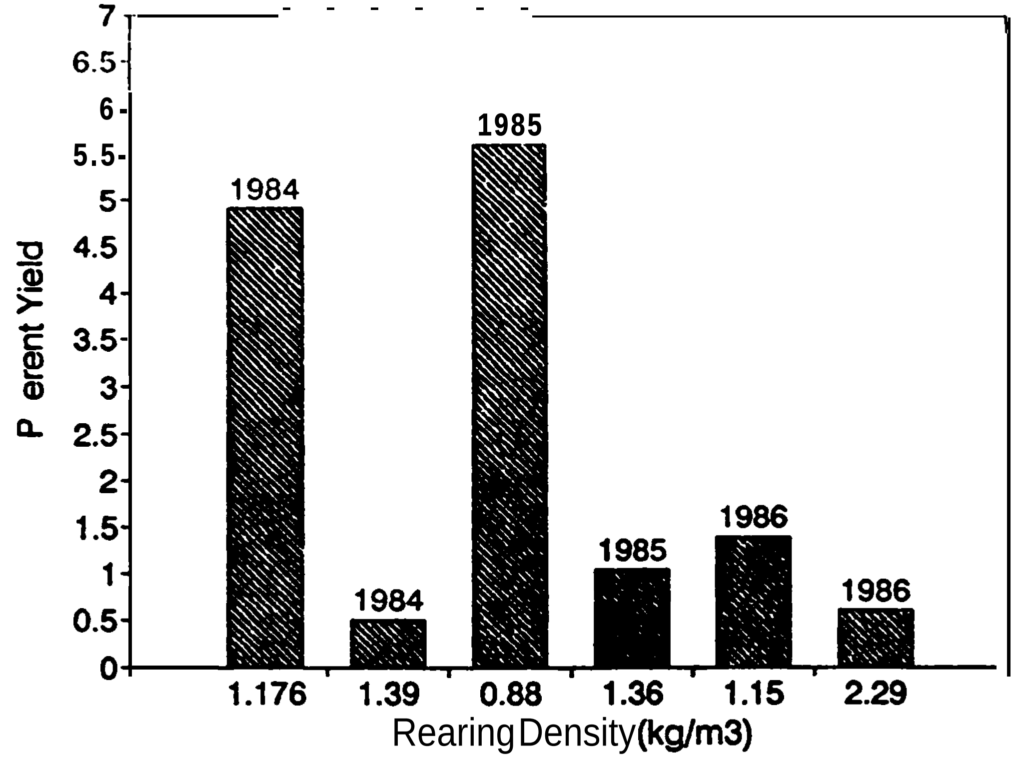
Table 18. Catch and escapement for 1982-1984 broods of coho salmon reared at the CEDC facility at Astoria, Oregon.

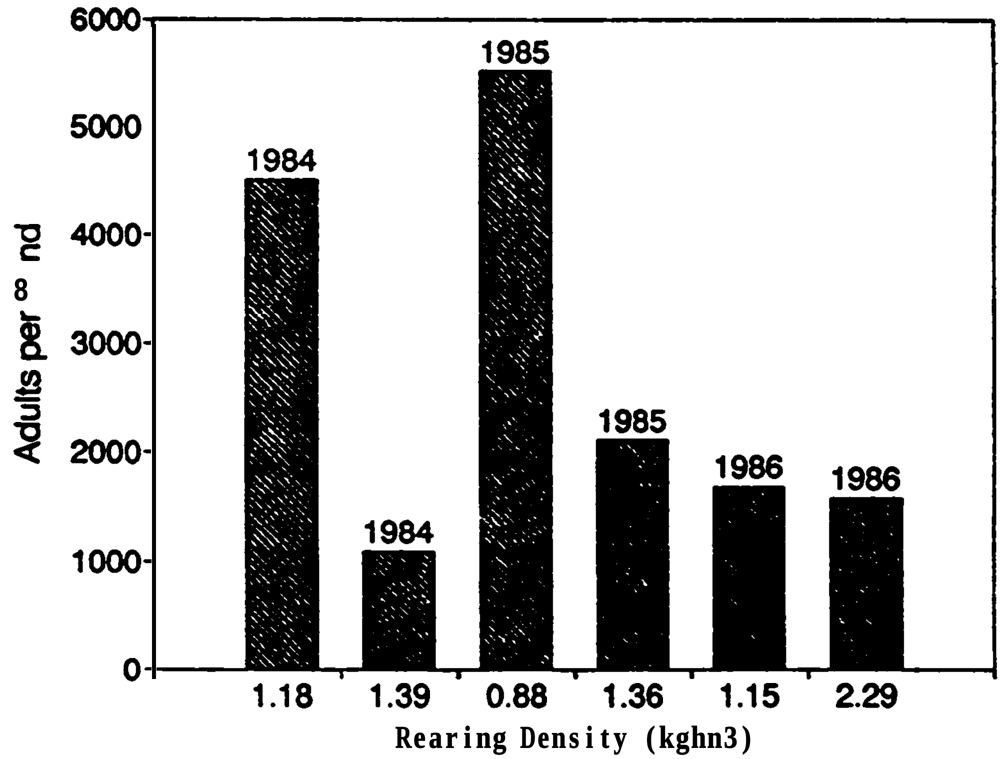
Brood Year	Pond	Tag Code	Fishery No.	Fishery %	Hatchery No.	Hatchery %	Total No.	Total %
1982	1	07 31 41	4150	4.83	68[a]	0.07	4578	4.90
	2	07 31 42	1094	0.53	8[a]	0.004	1102	0.53
1983[b]	1	07 33 44	-	-	-	-	5518	5.60
	2	07 33 43	-	-	-	-	2218	1.04
1984[b]	1	07 38 50-2	-	-	-	-	1689	1.40
	2	07 38	43-5	-	-	-	-	1579 0.60

[a]Jacks only reported.
[b]The authors reported that 7788 coded-wire tagged 1982-brood coho salmon were recovered by the fishery and 349 returned to the hatchery. The distribution by tag code was not reported. They also reported that 3954 1984-brood fish were captured by the fishery and 5 returned to the hatchery. Again, the distribution by tag codes was not provided. These numbers were not consistent with the numbers reported by brood year in their tables.

Figure 4. Relationship between approximate rearing density and adults per pond or percent yield for coho salmon reared at the CEDC facility at Astoria, Oregon.

CEDC Coho Salmon





density and percent yield or adult yield from these experiments. The comparison between groups shown in Table 19 is provided for continuity with the other studies.

In 1981 and 1982, density studies were conducted at Quinsam River Salmon Hatchery, British Columbia. The intent was to look at density-related effects, both in adult recoveries and in juvenile physiological parameters. The conditions for release for both brood years are shown in Table 20. In both years, an effort was made to keep size and weight between density groups at constant levels, but these efforts were only "moderately effective". In addition, both broods were stricken with two periods of disease. With the 1981-brood, furunculosis occurred in the summer of 1982 and the spring of 1983. The 1982 brood was affected in the summer of 1983 with furunculosis and with cold water disease in the spring of 1984. The incidence of cold water disease was found by the authors to be positively correlated with density.

In both brood years, fish were sorted into small, medium, and large groups for experiments with the effects of size at release. This made the density experiment much more complicated to interpret. No information was provided on the average size of the fish in the ponds at the various densities, so it was necessary to assume that the three size groups were present in equal numbers. This assumption was used throughout the calculations. The authors calculated their rearing densities based on the numbers of fish originally ponded. Because of the mortalities in the ponds during rearing (which reached as high as 25%), the numbers at release when maximum rearing densities were reached do not necessarily reflect the numbers originally ponded. We recalculated rearing densities using the above assumption and population numbers corrected for mortalities.

Table 19. Comparison of production between treatment groups of 1982-1984 broods of coho salmon reared at the CEDC facility at Astoria, Oregon.

Brood Year	Pond	Density[a] (kg/m^3)	Percent yield	Yield per pond	Yield per m^3	Yield per lpm
1982	1	1.18	4.90	4578	1.22	2.02
	2	1.39	0.53	1102	0.29	0.29
1983[b]	1	0.88	5.60	5518	1.46	2.43
	2	1.36	1.04	2218	0.59	0.59
1984[b]	1	1.15	1.40	1689	0.45	0.74
	2	2.29	0.60	1579	0.42	0.42

[a] Densities were calculated from approximate rearing dimensions and assumed depth. Actual rearing volumes were not known.

Table 20. Conditions at release for 1981- and 1982-brood coho salmon reared at Quinsam River Salmon Hatchery, British Columbia.

Brood Year, Group	Number of Fish	Mortality (%)	Average size (g)	Total kg	Density (kg/m³)	Load[a] (kg/lpm)
1981						
Low	71,796	1.6	25.9	1860	14.99	0.81
Medium Low	81,743	8.7	22.7	1856	14.97	0.81
Medium High	101,848	13.3	23.5	2393	19.30	1.04
High	91,252	24.8	23.2	2117	17.08	0.92
1982						
Low	50,284	3.0	21.9	1101	8.88	0.48
Low	53,492	5.8	22.7	1214	9.79	0.53
Medium	67,240	12.4	19.8	1331	10.74	0.58
Medium	76,479	7.9	23.2	1774	14.31	0.77
High	80,032	19.0	21.1	1689	13.62	0.73
High	82,815	18.6	20.7	1714	13.83	00.75

Our findings indicated no significant relationship between final rearing densities and percent yield or between final rearing density and numbers of adults per pond for either of the two brood years. We did find a significant negative relationship between mean fish weights and percent yield for the 1981-brood coho salmon (Tables 21 and 23). The bigger the smolts were at release, the less likely they were to survive. This is contrary to the findings of numerous other authors (Johnson, 1961; Bilton et al., 1982). With the 1982-brood, no significant relationship was found (Tables 22 and 24). With only two brood years that show opposite effects, one cannot determine the relationship between size and percent yield. It was noted, however, that the number of jacks increased with increasing smolt size. Final results are summarized in Table 25.

In 1981 and 1982, juvenile coho salmon were reared in a paired three-way factorial design of density and load at Willard National Fish Hatchery, Washington (Banks, 1992). This experiment was nicely designed. Because of the replication, data could be analyzed by analysis of variance and standard errors could be assigned to the recovery of adults. Incidence of disease and physiological effects of the treatments were evaluated during the rearing period. Conditions at release for both brood years are shown in Table 26.

Bacterial kidney disease was detected and treated in both brood years. Cold water disease was'present and treated in the 1981-brood. A conscientious effort was made to verify statistically the occurrence and effects of diseases.

Post-release survival was assessed by marking and tagging about 25,000 fish per raceway just after initial stocking in the rearing ponds. No coded-wire tag data or population sampling data were presented, however (Banks,

Table 21. Data at release for density study with 1981-brood coho salmon reared at Quinsam River Salmon Hatchery, British Columbia.

Group, Size	Tag Code	Number Tagged	Tag Retention	Length (cm)	Weight (g)
Low					
small	02 19 63	9282	0.93	12.8 ± 0.6	21.3 ± 3.3
medium	02 20 07	9329	0.93	13.6 ± 0.6	25.5 ± 3.5
large	02 20 08	9584	0.93	14.4 ± 0.9	29.7 ± 5.9
Medium Low					
small	08 21 16	4003	0.95	12.6 ± 0.7	19.5 ± 3.1
small	08 21 17	4001	0.95	12.6 ± 0.7	20.3 ± 3.5
small	08 21 18	4018	0.95	12.4 ± 0.7	19.5 ± 3.2
medium	08 21 55	3890	0.95	12.8 ± 0.6	20.9 ± 2.8
medium	08 21 56	3707	0.95	13.2 ± 0.7	23.0 ± 3.9
medium	08 21 57	3751	0.95	13.2 ± 0.7	22.7 ± 3.3
large	08 21 58	4074	0.95	13.7 ± 0.7	25.3 ± 4.2
large	08 21 59	4106	0.95	13.8 ± 0.7	25.9 ± 4.4
large	08 21 60	4010	0.95	13.9 ± 0.8	27.1 ± 5.0
Medium High					
small	02 20 09	9405	0.95	12.5 ± 0.8	20.1 ± 3.8
medium	02 20 10	9471	0.95	13.3 ± 0.8	24.0 ± 4.6
large	02 20 11	9860	0.95	13.7 ± 1.0	27.3 ± 7.0
High					
small	02 19 60	8281	0.87	12.7 ± 0.8	20.5 ± 3.9
medium	02 17 62	8229	0.87	13.1 ± 0.8	23.1 ± 4.4
large	02 19 62	8093	0.87	13.6 ± 0.8	25.5 ± 5.0

Table 22. Data at release for a density study with 1982-brood coho salmon reared at Quinsam River Salmon Hatchery, British Columbia.

Group, Size	Tag Code	Number Tagged	Tag Retention	Length (cm)	Weight (g)
Low					
small	08 22 38	9686	0.97	12.3 ± 0.6	18.5 ± 2.9
medium	08 22 39	9636	0.97	12.8 ± 0.6	21.1 ± 3.5
large	08 22 40	9637	0.97	13.4 ± 0.8	24.9 ± 5.1
Low					
small	08 22 29	9401	0.96	12.2 ± 0.7	18.5 ± 3.1
medium	08 22 30	9672	0.96	13.0 ± 0.8	22.5 ± 4.0
large	08 22 31	9419	0.96	13.6 ± 0.8	26.4 ± 5.3
Medium					
small	08 22 32	9153	0.93	11.8 ± 0.7	16.1 ± 3.2
medium	08 22 33	9111	0.93	12.4 ± 0.8	18.6 ± 4.2
large	08 22 34	9122	0.93	12.9 ± 0.8	21.2 ± 4.2
Medium					
small	08 22 41	9800	0.98	12.4 ± 0.7	20.0 ± 3.2
medium	08 22 42	9784	0.98	12.8 ± 0.6	21.9 ± 3.1
large	08 22 43	9830	0.98	13.3 ± 0.8	25.1 ± 4.6
High					
small	08 22 35	8731	0.89	12.1 ± 0.9	18.3 ± 3.3
medium	08 22 36	8686	0.89	12.5 ± 0.6	20.3 ± 3.1
large	08 22 37	8778	0.89	13.0 ± 0.8	23.0 ± 4.0
High					
small	08 22 44	9843	0.99	12.2 ± 0.5	18.2 ± 2.5
medium	08 22 45	9795	0.99	12.5 ± 0.5	19.5 ± 2.8
large	08 22 46	9817	0.99	13.1 ± 0.7	22.4 ± 4.1

Table 23. Catch and escapement for 1981-brood coho salmon reared at Quinsam River Salmon Hatchery, British Columbia.

Group, Size	Tag Code	Jacks		Adults				Total	
				Fishery		Hatchery			
		No.	%	No.	%	No.	%	No.	%
Low									
small	02 19 63	11	0.12	390	4.20	226	2.44	627	6.76
medium	02 20 07	22	0.24	392	4.20	210	2.25	624	6.67
large	02 20 08	50	0.52	331	3.45	136	1.42	51ii	5.39
Medium Low									
small	08 2 16	3	0.08	435	10.87	170	4.25	608	15.19
small	08 2 17	0	0.00	311	7.77	148	3.70	459	11.47
small	08 2 18	5	0.12	350	8.71	189	4.70	544	13.54
medium	08 2 55	3	0.08	227	5.84	121	3.11	351	9.02
medium	08 2 56	16	0.43	239	6.45	151	4.07	406	10.95
medium	08 2 57	24	0.64	328	8.74	125	3.33	477	12.72
large	08 2 58	20	0.49	251	6.16	98	2.41	369	9.06
large	08 2 59	24	0.59	265	6.45	112	2.73	401	9.77
large	08 2 60	25	0.62	276	6.88	155	3.87	456	11.37
Medium High									
small	02 20 09	10	0.11	503	5.35	214	2.28	726	7.73
medium	02 20 10	13	0.14	430	4.54	157	1.66	600	6.34
large	02 20 11	35	0.36	310	3.14	111	1.13	456	4.63
High									
small	02 19 60	10	0.12	306	3.70	186	2.25	502	6.06
medium	02 17 62	15	0.18	277	3.37	113	1.37	405	4.92
large	02 19 62	25	0.31	252	3.11	101	1.25	378	4.67

Table 24. Catch and escapement for 1982-brood coho salmon reared at Quinsam River Salmon Hatchery, British Columbia.

Group, Size	Tag Code	Jacks No.	Jacks %	Adults Fishery No.	Adults Fishery %	Adults Hatchery No.	Adults Hatchery %	Total No.	Total %
Low									
small	08 22 38	66	0.68	846	8.73	204	2.11	1116	11.51
medium	08 22 39	126	1.31	725	7.52	222	2.30	1073	11.14
large	08 22 40	326	3.38	803	8.33	171	1.77	1300	13.49
Low									
small	08 22 29	86	0.92	933	9.92	265	2.82	1284	13.66
medium	08 22 30	187	1.93	986	10.19	224	2.32	1397	14.44
large	08 22 31	476	5.05	749	7.95	189	2.01	1414	15.01
Medium									
small	08 22 32	31	0.34	604	6.60	157	1.72	792	8.65
medium	08 22 33	73	0.80	626	6.87	134	1.47	833	9.14
large	08 22 34	178	1.95	563	6.17	146	1.60	887	9.72
Medium									
small	08 22 41	70	0.71	721	7.36	220	2.25	1011	10.32
medium	08 22 42	127	1.30	772	7.89	201	2.05	1100	11.24
large	08 22 43	228	2.32	705	7.17	148	1.51	1081	11.00
High									
small	08 22 35	45	0.52	658	7.54	178	2.04	881	10.09
medium	08 22 36	54	0.62	722	8.31	147	1.69	923	10.63
large	08 22 37	158	1.80	745	8.49	161	1.83	1064	12.12
High									
small	08 22 44	30	0.31	653	6.63	153	1.55	836	8.49
medium	08 22 45	46	0.47	694	7.09	158	1.61	898	9.17
large	08 22 46	126	1.28	565	5.76	127	1.29	818	8.33

Table 25. Comparison of production between treatment groups of 1981- and 1982 broods of coho salmon reared at Quinsam River Salmon Hatchery, British Columbia. Values for calculated results are based on the assumption that the three size classes of fish are present in the ponds in equal numbers.

Brood Year, Group	Density (kg/m^3)	Percent Yield	Adults per pond	Adult per m^3	Adults per lpm
1981					
Low	14.99	6.27	1685	13.59	0.73
Medium Low	14.97	11.45	3951	31.87	1.72
Medium High	19.30	6.23	1725	13.91	0.75
High	17.08	5.22	1235	9.96	0.54
1982					
Low	8.88	12.04	2971	23.96	1.29
Low	9.79	14.37	3346	26.99	1.45
Medium	10.74	9.17	2230	17.99	0.97
Medium	14.31	10.85	2767	22.32	1.20
High	13.62	10.95	2611	21.06	1.14
High	13.83	8.66	2350	18.95	1.02

Table 26. Conditions at release for 1981- and 1982-brood coho salmon reared at Willard National Fish Hatchery, Washington.

Brood Year, Flow (lpm)	Number of fish	Average size (g)	Total kg[a]	Total kg[b]	Density (kg/m^3)	Load (kg/lpm)
1981						
757	25,000	22.9	537	520	14.8	0.71
	50,000	24.2	1158	1124	32.0	1.53
	75,000	23.2	1605	1557	44.3	2.12
1514	25,000	22.2	530	502	14.3	0.35
	50,000	23.9	1120	1082	30.8	0.74
	75,000	23.0	1620	1574	44.8	1.07
2271	25,000	23.0	545	517	14.7	0.24
	50,000	22.9	1190	1051	29.9	0.48
	75,000	23.9	1681	1620	46.1	0.74
1982						
757	25,000	23.7	484	471	13.4	0.64
	50,000	24.6	1037	1005	28.6	1.37
	75.000	24.0	1347	1307	37.2	1.78
1514	25,000	23.8	500	485	13.8	0.33
	50,000	24.9	1075	1047	29.8	0.71
	75,000	24.5	1378	1332	37.9	0.91
2271	25,000	22.3	500	474	13.5	0.22
	50,000	25.1	977	949	27.0	0.43
	75,000	24.1	1453	1405	40.0	0.64

[a]Calculated from values given in Banks (1992) for load.
[b]Calculated from values given in Banks (1992) for density, assuming that raceway volume is 35.1 m^3. Densities and loads in the present table are calculated from this value.

1992). Raceway load was found to have no effect on growth or in-hatchery survival of the juveniles.

Nearly 60% of all the recoveries of tags were from adults that returned to the hatchery. Only two of the fish that returned to the hatchery were jacks (Table 27). Significant relationships both between rearing density and percent yield and between rearing density and adults per pond were found (Table 28). Specifically, "adult yield increased by 3.4 fish for each increase of 1,000 fingerlings stocked". The author then stated that "the optimum fingerling production level at Willard Hatchery is at least equal to or in excess of 75,000 fish per raceway". The author concluded that "the increased cost of rearing fish at this level is small in comparison to annual expenditures for operation, maintenance, and administration, which are not related to levels of production intensity".

Lowest density groups were found to produce the largest adults. No effects of rearing density on sex ratios, catch:escapement ratios, or catch distributions were found.

Table 27. Catch and escapement for 1981 and 1982 broods of coho salmon reared at Willard National Fish Hatchery, Washington.

Flow (lpm)	Number of fish	Percent Recovery of Adults[a] 1981-brood	1982-brood
757	25,000	0.43 ± 0.01	0.84 ± 0.08
	50,000	0.41 ± 0.02	0.65 ± 0.08
	75,000	0.40 ± 0.08	0.62 ± 0.09
1514	25,000	0.42 ± 0.02	0.59 ± 0.13
	50,000	0.40 ± 0.02	0.59 ± 0.11
	75,000	0.30 ± 0.00	0.53 ± 0.01
2271	25,000	0.56 ± 0.13	0.71 ± 0.01
	50,000	0.43 ± 0.00	0.46 ± 0.01
	75,000	0.41 ± 0.04	0.65 ± 0.00

[a]Recovery numbers include fishery catch and hatchery returns.

Table 28. Comparison of production between treatment groups of 1981 and 1982 broods of coho salmon reared at Willard National Fish Hatchery, Washington.

Brood year, flow (lpm)	Number of fish	Percent Yield	Adults per pond	Adult per m^3	Adults per lpm
1981					
757	25,000	0.43 ± 0.01	101 ± 4	2.88	0.13
	50,000	0.41 ± 0.02	194 ± 11	5.53	0.26
	75,000	0.40 ± 0.08	277 ± 59	7.89	0.37
1514	25,000	0.42 ± 0.02	98 ± 22	2.79	0.07
	50,000	0.40 ± 0.02	186 ± 7	5.30	0.12
	75,000	0.30 ± 0.00	214 ± 4	6.10	0.14
2271	25,000	0.56 ± 0.13	131 ± 32	3.73	0.06
	50,000	0.43 ± 0.00	201 ± 1	5.73	0.09
	75,000	0.41 ± 0.04	286 ± 30	8.51	0.13
1982					
757	25,000	0.84 ± 0.08	173 ± 12	4.93	0.23
	50,000	0.65 ± 0.08	273 ± 31	7.78	0.36
	75,000	0.62 ± 0.09	346 ± 49	9.86	0.46
1514	25,000	0.59 ± 0.13	135 ± 32	3.85	0.09
	50,000	0.59 ± 0.11	255 ± 45	7.26	0.17
	75,000	0.53 ± 0.01	297 ± 5	8.46	0.20
2271	25,000	0.71 ± 0.01	146 ± 4	4.16	0.06
	50,000	0.46 ± 0.01	180 ± 4	5.13	0.08
	75,000	0.65 ± 0.00	391 ± 1	11.14	0.17

Chinook Salmon

One of the earliest of the density studies using 1975- and 1976-brood spring chinook salmon was conducted at Cowlitz Hatchery (Hopley, unpublished). The intent of the research was to determine optimum loading rates during rearing as well as the economic costs per unit density. The conditions prior to release are shown in Table 29.

This experiment was well designed and executed. Experimental densities were replicated, flow rates were held constant, mortality rates were low and disease incidence was almost nonexistent. Mortality rates, data on coded-wire tagging and tag retention were not presented in the manuscript. Escapement and recovery data was presented in a combined form, such that no age class differentiations could be achieved.

Data for total percent recoveries of the 1975 and 1976 broods were analyzed by analysis of variance (Table 30). At a 95% confidence level, the relationship between density and percent yield for the 1975-brood was significant. The relationship for the 1976-brood was not. When the brood years were combined, the relationship was significant. Alternatively, because the mean densities were not particularly close between brood years, the data was also analyzed by regression analysis. Using a regression analysis, a significant negative relationship between density and total percent survival was found.

Table 29. Conditions at release for 1975- and 1976-brood spring chinook salmon reared at Cowlitz Hatchery, Washington.

Brood Year, Group	Number of Fish	Average size (g)	Total kg	Density (kg/m^3)	Load (kg/lpm)
1975					
Low	28,746	133.5	3838	6.78	0.50
	27,967		3734	6.59	0.49
Medium	61,782	122.7	7581	13.38	1.00
	61,658		7565	13.36	1.00
High	88.051	119.5	10,519	18.57	1.39
	88.691		10,596	18.71	1.40
1976					
Low	28,227	90.8	2563	4.53	0.34
	27,776		2522	4.45	0.33
Medium	56,964	100.9	5747	10.15	0.76
	58,262		5878	10.38	0.78
High	87,966	113.5	9984	17.63	1.32
	89,433		10,151	17.92	1.34

Table 30. Comparison of production between treatment groups for 1975- and 1976-brood spring chinook salmon reared at Cowlitz Hatchery, Washington.

Brood Year, Group	Density (kg/m^3)	Percent Yield[a]	Adults per pond[b]	Adults per m^3	Adults per lpm
1975					
Low	6.78	1.78	499	0.88	0.07
	6.59	1.96	548	0.97	0.07
Medium	13.38	1.46	905	1.60	0.12
	13.36	1.34	827	1.46	0.11
High	18.57	0.84	738	1.29	0.10
	18.71	0.99	879	1.55	0.12
1976					
Low	4.53	1.66	468	0.83	0.06
	4.45	1.81	504	0.89	0.07
Medium	10.15	1.93	1092	1.93	0.14
	10.38	1.78	1036	1.83	0.14
High	17.63	1.63	1435	2.53	0.19
	17.92	0.93	831	1.47	0.114

[a]No data available for recoveries of different year classes.
[b]Calculated from percent yield and number of juveniles per pond.

We also ran analysis of variance for the relationship between density and adult yield per pond for each brood year. At a 95% confidence level, fish from the 1975-brood showed a significant relationship between density and adults per pond, while those from the 1976-brood did not. Combined, they showed a significant relationship. Regression analysis also indicated a significant positive relationship between density and adults per pond.

In 1979 and 1980, a density experiment was conducted at Capilano Hatchery, British Columbia, using fall chinook salmon. Variable numbers of fry were ponded into 3 Burrow's ponds in February. Groups of 75,000 fish from the 1979 brood from each pond were tagged in late May of 1980. For 1980-brood fish, tagging occurred in April or early May of 1981. However, in 1981, two samples of about 40,000 fish from each pond that were larger or smaller than the mean length were marked with coded-wire tags. Thus, both rearing density and size at release were examined for effects on survival to adulthood. Conditions at release for both brood-years are given in Table 31.

Before release of the fish, samples were taken to estimate population numbers by calculating the ratios between tagged- and untagged fish (Table 32). We have assumed, with the authors, that this estimate most closely approximates the population size. The differences observed between the initial and final population estimates may represent either error in the estimates or losses due to unrecorded mortality.

Table 31. Conditions at release for 1979- and 1980-broods of fall chinook salmon reared at Capilano Hatchery, British Columbia.

Brood Year, Group	Number of Fish	Mortality (%)	Average size (g)	Total kg	Density[a] (kg/m^3)	Load[b] (kg/lpm)
1979						
Low	212,713	0.55	6.11	1300	10.48	0.54
Medium	340,435	0.68	5.98	2036	16.42	0.85
High	398,940	0.32	5.69	2270	18.31	0.95
1980						
Low	171,219	0.37	7.76	1329	10.72	0.55
Medium	272,310	0.48	7.83	2132	17.20	0.89
High	378,422	0.45	7.62	2884	23.26	1.20

[a]Volume of the ponds was never stated. It is assumed that it is the same as that for Capilano coho salmon described in Fagerlund et al. (1983), that is, 5.6 m x 24.6 m x 0.9 m = 123.98 m^3.
[b]Flow is assumed to be 40 L/second, or 2400 L/minute, for all ponds.

Table 32. Data at release for 1979- and 1980-broods of fall chinook salmon reared at Capilano Hatchery, British Columbia.

Brood Year, Group		Tag Code	Length (cm)	Weight (g)
1979				
Low		02 18 32	8.51 ± 0.68	6.11 ± 1.49
Medium		02 18 31	8.40 ± 0.66	5.98 ± 1.44
High		02 18 30	8.24 ± 0.72	5.69 ± 1.53
1980				
Low	small	02 21 51	8.60 ± 0.42	6.52 ± 1.03
	large	02 21 50	9.54 ± 0.38	8.84 ± 1.27
Medium	small	02 21 53	8.61 ± 0.37	6.52 ± 0.95
	large	02 21 52	9.54 ± 0.35	8.92 ± 1.19
High	small	02 19 40	8.52 ± 0.47	6.89 ± 1.03
	large	02 19 41	9.50 ± 0.35	8.72 ± 1.13

Yields of fish by year-class are shown in Table 33, presented as fish returning per 100,000 released. The actual numbers of fish captured could not be determined from the data given, because the exact number of fish in the large- and small-size groups of the 1981-release were not given. However, it is possible to calculate the total return for each raceway if it is assumed that there were equal numbers of large- and small-size fish in the raceways. Results from these calculations are provided in Table 34, together with the percent returns for the individual tag codes.

The lack of replicates for the groups precluded the use of analysis of variance for detecting significant differences between groups. Instead, we used regression analysis to determine if significant relationships existed between density and percent survival and between density and number of adults surviving. No significant relationships were detected, although the number of groups was small. When we examined the results by graphic analysis, results suggested that the percent recovery decreased as the rearing density increased, while the numbers of fish surviving increased as the density increased. Survival between the years was significantly different, with more fish surviving from the 1981-release. This may have been partly due to the increased size of fish released in 1981, but it is more likely that ocean conditions between years affected the survival of juveniles.

Fagerlund et al. (1987) say little about the relationship between density and survival in their technical report. They

Table 33. Catch and escapement of 1979- and 1980-brood fall chinook salmon reared at Capilano Hatchery, British Columbia. Numbers given are recoveries per 100,000 released[a].

Brood Year, Group	Fishery[b]		Hatchery		Total		Percent
	Jacks	Adults	Jacks	Adults	Jacks	Adults	Yield
1979							
Low	279	334	49	54	328	388	0.72
Medium	246	328	34	24	280	352	0.63
High	198	352	44	31	242	383	0.63
1980							
Low							
small	730	943	34	74	764	1017	1.78
large	1219	1390	96	174	1315	1464	2.88
Medium							
small	565	683	23	75	588	758	1.35
large	1194	1375	165	156	1359	1531	2.89
High							
small	542	646	13	87	555	733	1.29
large	916	1382	150	128	1066	1510	2.58

[a]Experimental groups of the 1980-brood were divided into small and large populations for tagging. The number of tagged fish was not recorded, so that the number of fish recovered could not be calculated for each tag group (Fagerlund et al., 1987).

[b]Fishery includes Canadian sport and commercial catch plus Alaskan (U.S.) catch.

Table 34. Comparison of production between treatment groups for 1979- and 1980-brood fall chinook salmon reared at Capilano Hatchery, British Columbia.

Brood Year, Group	Density (kg/m^3)	Percent Yield[a]	Adults per pond	Adults per m^3	Adults per lpm
1979					
Low	10.48	0.72	1451	11.7	0.60
Medium	16.42	0.63	2171	17.5	0.90
High	18.31	0.63	2206	17.8	0.92
1980					
Low	10.72	2.33	3688	29.7	1.54
small		1.78			
large		2.88			
Medium	17.20	2.12	5177	41.3	2.13
small		1.35			
large		2.89			
High	23.26	1.93	6540	52.8	2.73
small		1.29			
large		2.58			

[a]Calculation of percent yield for the pond assumes that small and large populations are present in equal numbers.

appeared to be more concerned about the changes in physiology and body composition of fish in the hatchery in relation to stress from rearing density. They do remark in their conclusions that "increasing the density reduced the overall return rate" and that small fish were affected more than the larger fish.

Beginning with the 1981-brood year, a five-year density study with fall chinook salmon was carried out at Elk River Fish Hatchery, Port Orford, Oregon. The objectives of the study were well-defined, but, unfortunately, the experiment was never summarized. Much of the information required for analysis of the results is still raw data and not readily available. Data presented in annual reports for the study are summarized here. The fish were reared in modified Burrow's ponds at levels of approximately 25,000, 35,000, and 45,000 fish per pond. Release data is presented in Table 35.

In an Oregon Department of Fish and Wildlife memorandum, dated 11 August 1982, replicated pairs of each density group were described. However, the same coded-wire tag code was used for each of the replicates. This effectively negated the utility of the replicate pond in providing estimates of error. In each year subsequently, only single ponds were used for each group. Return data for the releases are given in Table 36 and 37.

Because of the lack of replicates and the small number of ponds, data could not be analyzed statistically within a single rearing year. The large variation in percent survival (from 4.26% to 0.25%) also precluded simple averaging and tests of

Table 35. Conditions at release for 1981-1985 broods of fall chinook salmon reared at Elk River Hatchery, Oregon.

Brood Year, Group	Number of Fish	Flow (lpm)	Average size (g)	Total kg	Density (kg/m^3)	Load (kg/lpm)
1981[a]						
Low	26,046	1817	32.01	834	7.48	0.46
Medium	36,909	1842	32.90	1214	10.89	0.66
High	46,828	1827	31.44	1472	13.20	0.81
1982						
Low	27,350	1688	47.29	1293	11.59	0.77
Medium	35,030	1696	45.40	1590	14.26	0.94
High	45,990	1734	47.79	2198	19.71	1.27
1983						
Low	26,778	1930	46.33	1241	11.13	0.64
Medium	38,083	2044	45.86	1746	15.66	0.85
High	48,555	2203	44.51	2161	19.38	0.98
1984						
Low	27,221	1665	41.98	1143	10.25	0.69
Medium	38,645	1726	39.43	1524	13.67	0.88
High	47.221	1635	41.59	1964	17.61	1.20
1985						
Low	26,842	1741	35.75	960	8.61	0.55
Medium	37,308	1703	33.88	1264	11.34	0.74
High	46,755	1749	31.75	1484	13.31	0.85

[a] Values represent the averages from paired ponds. Each pair had only a single tag code.

Table 36. Catch and escapement for 1981-1985 broods of fall chinook salmon reared at Elk River Hatchery, Oregon.

Brood Year, Group	Tag Code	Jacks Fishery No.	Jacks Fishery %	Jacks Hatchery No.	Jacks Hatchery %	Adults Fishery No.	Adults Fishery %	Adults Hatchery No.	Adults Hatchery %	Total No.	Total %
1981[a]											
Low	07 26 05	0	0	10	0.04	144	0.52	23	0.08	177	0.64
Medium	07 26 04	3	0.01	18	0.06	102	0.36	26	0.09	149	0.53
High	07 26 03	1	0.003	1	0.003	54	0.20	13	0.04	69	0.25
1982											
Low	07 29 15	0	0	4	0.01	105	0.39	11	0.04	120	0.44
Medium	07 29 14	0	0	7	0.03	110	0.43	7	0.02	124	0.48
High	07 27 22	0	0	5	0.02	48	0.18	4	0.01	57	0.21
1983											
Low	07 29 17	32	0.12	56	0.21	979	3.72	55	0.21	1122	4.26
Medium	07 29 16	24	0.09	45	0.17	960	3.64	74	0.29	1103	4.19
High	07 29 18	22	0.08	57	0.21	727	2.73	66	0.25	872	3.27
1984											
Low	07 29 19	5	0.02	19	0.07	421	1.58	66	0.24	521	1.95
Medium	07 29 20	7	0.03	28	0.11	365	1.38	46	0.28	654	2.46
High	07 29 21	12	0.04	22	0.08	313	1.15	36	0.14	666	2.45
1985											
Low	07 29 22	21	0.09	64	0.26	743	3.02	54	0.22	882	3.59
Medium	07 29 24	13	0.05	40	0.16	550	2.16	57	0.23	660	2.60
High	07 29 23	3	0.01	14	0.06	426	1.67	60	0.23	503	1.97

[a]Values represent the sum from paired ponds. Each pair had only a single tag code.

Table 37. Comparison of production between treatment groups of 1981-1985 broods of fall chinook salmon reared at Elk River Hatchery, Oregon.

Brood Year, Group	Density (kg/m^3)	Percent Yield	Percent mortality	Adults per pond	Adults per m^3	Adults per lpm
1981[a]						
Low	7.48	0.64	1.68	177	1.59	0.10
Medium	10.89	0.53	2.49	149	1.34	0.08
High	13.20	0.25	1.66	69	0.62	0.38
1982						
Low	11.59	0.44	1.87	120	1.08	0.07
Medium	14.26	0.48	1.57	124	1.11	0.07
High	19.71	0.21	1.98	57	0.51	0.03
1983						
Low	11.13	4.26	0.92	1122	10.06	0.58
Medium	15.66	4.19	0.73	1103	9.89	0.54
High	19.38	3.27	1.03	872	7.82	0.40
1984						
Low	10.25	1.95	1.30	521	4.67	0.31
Medium	13.67	2.48	1.77	654	5.87	0.38
High	17.61	2.45	1.64	666	5.97	0.41
1985						
Low	8.61	3.59	0.91	882	7.91	0.51
Medium	11.34	2.60	0.86	660	5.92	0.39
High	13.31	1.97	1.16	503	4.51	0.29

[a]Values in this brood year come from paired ponds. Each pair had only a single tag code. The adults per pond represents the sum of recoveries from the two ponds. Other values are calculated from this number.

means. Instead, we normalized the data by setting percent yield of the medium density groups equal to 100 and comparing the percent yield of the low- and high density groups relative to the medium density group. By this means, we could show that percent yield of the low density group was 112.8% that of the medium density group, and that of the high density group was 65.6% that of the medium density group (Table 38, Figure 5).

In a similar analysis, numbers of returning adults and jacks per pond were normalized (Table 38, Figure 6). Numbers of returning fish in the medium density groups for each brood-year were assumed to be 100. Returning fish from the low- and high density groups were then compared to this value. Fish per pond from the low density group returned at 104.8% that of the medium density group, while fish per pond from the high density group were only 69.9% that of the medium density group.

We concluded from these analyses that there was an inverse relationship between density and percent survival. Numbers of fish returning per pond were similar in the two lower groups, but were less in the high density group. It is interesting that the effect of high density rearing seems to be more severe when overall average survival was low.

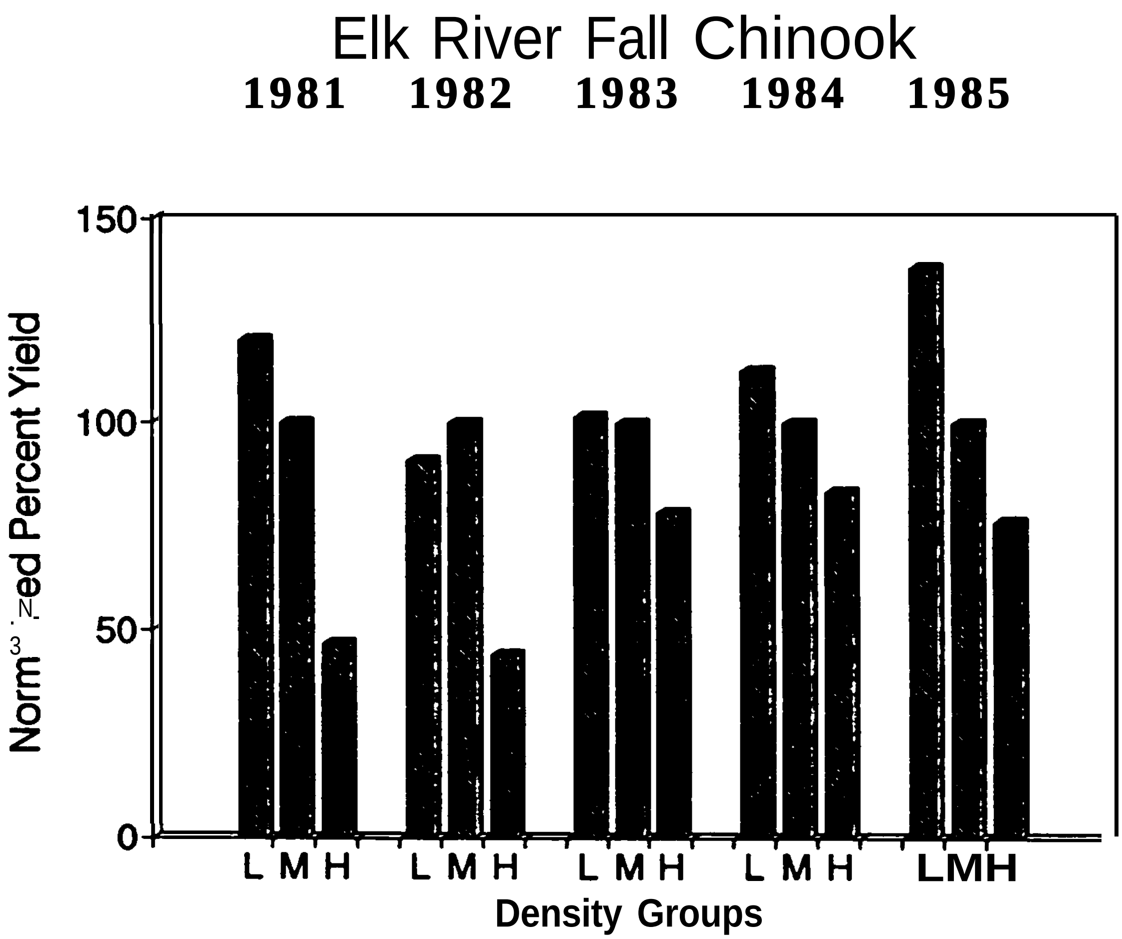
In 1982, the Fishery Restoration and Enhancement Division of the Alaska Department of Fish and Game conducted a density study at Deer Mountain Hatchery, using Unuk River spring chinook salmon (Denton 1988). This facility is located within Ketchikan, and is owned by the City of Ketchikan. Final conditions before release

Table 38. Percent yield and adults per pond normalized for recoveries of 1981-1985 broods of fall chinook salmon reared at Elk River Hatchery, Oregon. Medium density groups are set equal to 100 for each brood year.

Brood Year, Group	Density (kg/m^3)	Percent Yield	Normalized values	Adults per pond	Normalized values
1981[a]					
Low	7.48	0.64	120.3	167	112.1
Medium	10.89	0.53	100.0	149	100.0
High	13.20	0.25	46.6	69	46.3
1982					
Low	11.59	0.44	91.1	120	96.8
Medium	14.26	0.48	100.0	124	100.0
High	19.71	0.21	44.1	57	46.0
1983					
Low	11.13	4.26	101.7	1122	101.7
Medium	15.66	4.19	100.0	1103	100.0
High	19.38	3.27	78.1	872	78.1
1984					
Low	10.25	1.95	113.0	521	79.7
Medium	13.67	2.48	100.0	654	100.0
High	17.61	2.45	83.3	666	101.8
1985					
Low	8.61	3.59	138.1	882	133.6
Medium	11.34	2.60	100.0	660	100.0
High	13.31	1.97	75.9	503	76.2
Average for 5 years					
Low			112.8		104.8
Medium			100.0		100.0
High			65.6		69.9

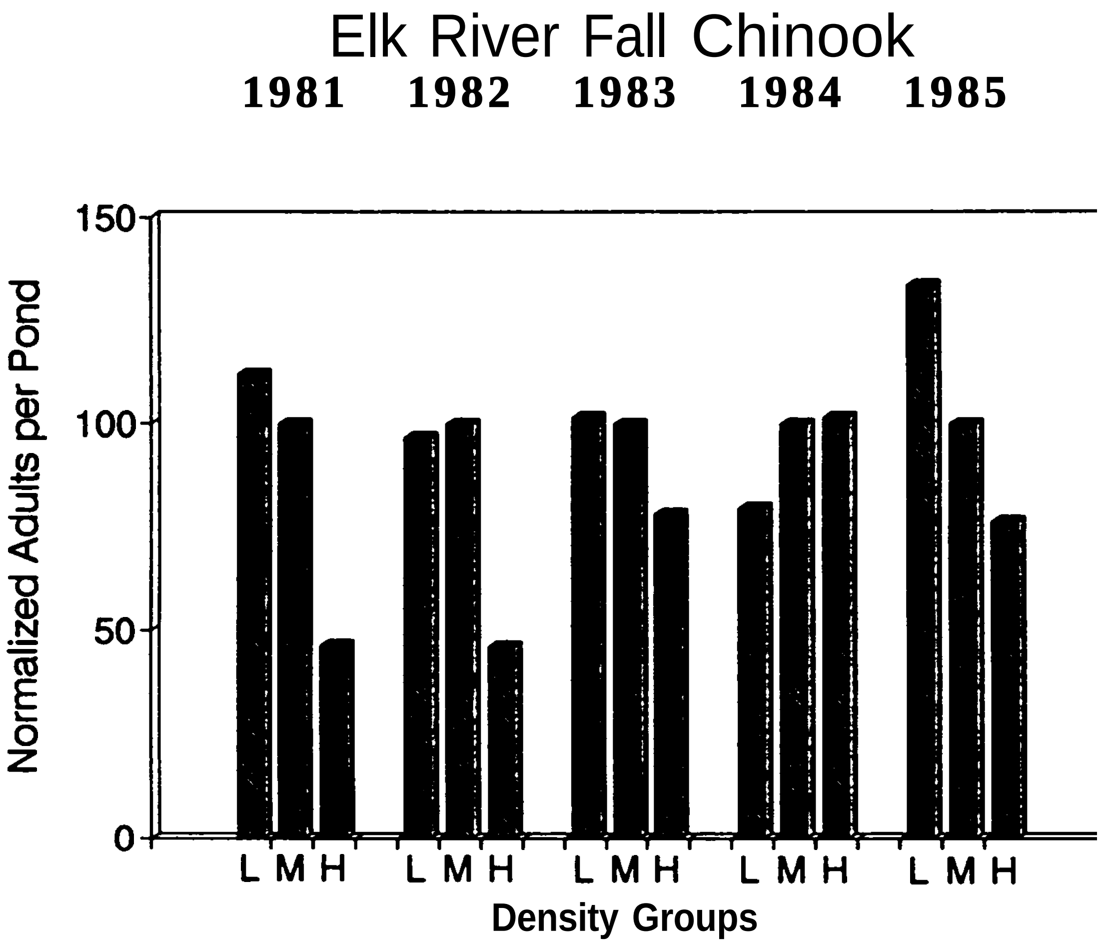
[a] Values in this brood year come from paired ponds. Each pair had only a single tag code. The adults per pond represents the sum of recoveries from the two ponds. Other values are calculated from this number.

Figure 5. Relationship between rearing density and normalized percent yield for 1981-1985 broods of fall chinook salmon reared at Elk River Hatchery.



Elk River Fall Chinook
1981 1982 1983 1984 1985
150
100
50
0
Norm 3 ·N- ed Percent Yield
L M H L M H L M H L M H LMH
Density Groups

Figure 6. Relationship between rearing density and normalized adult yield per pond for 1981-1985 brood of fall chinook salmon reared at Elk River Hatchery.



Elk River Fall Chinook
1981
1982
1983
1984
1985
Normalized Adults per Pond
150
100
50
0
L M H
L M H
L M H
L M H
L M H
Density Groups

are shown in Table 39, while catch and escapement data for the three treatment groups are given in Table 40.

This experiment was designed and executed well. It is unfortunate that it was incomplete in several aspects:

1) No mortalities, flows, coded-wire tagging data or tag retention rates were provided.

2) More treatment groups over several release-years would provide better insight into optimum rearing densities, as well as the effects of ocean conditions on the survival at the various rearing densities.

The report was brief but suggestive. Because the treatment groups were not replicated in any manner, we could not use analysis of variance and regression analysis for examining the data. By graphic analysis, results suggested that percent yield was inversely related to the rearing density and load (Table 41; Fig. 7). The number of adults returning to the facility was relatively independent of the number of fish per raceway except at the highest rearing density and load (Fig. 8).

In 1978, a study was conducted at Little Port Walter on Baranof Island using wild spring chinook from the Unuk River, near Ketchikan (Martin and Wertheimer, 1989). The paper of Martin and Wertheimer (1989) was one of the first published studies to correlate chinook rearing densities with adult returns. The intent of this experiment was to determine the operating cost per returning adult, assuming that the feeding costs varied with rearing density while the facility costs remained fixed. Release conditions were as shown in Table 42.

Table 39. Conditions at release for 1981-brood spring chinook salmon reared at Deer Mountain Hatchery, Alaska.

Group	Number of Fish	Number tagged	Average size (g)	Total kg	Density (kg/m^3)	Load (kg/lpm)
Low	8,529	8,341	17.7	151	6.9	0.21
Medium	16,863	15,784	16.6	280	12.8	0.39
High	39,1460	15,882	17.8	697	32.0	0.97

Table 40. Catch and escapement for 1981-brood spring chinook salmon reared at Deer Mountain Hatchery, Alaska.

Group	Fishery at age:					Hatchery at age:					Total at age:					Percent
	2	3	4	5	6	2	3	4	5	6	2	3	4	5	6	Yield
Low	0	0	129	63	23	2	32	81	190	21	2	32	210	253	44	6.34
Medium	0	0	89	99	17	6	17	100	213	14	6	17	189	312	31	3.29
High	0	0	67	16	7	7	5	58	157	23	7	5	125	173	30	0.87

Table 41. Comparison of production between treatment groups of 1981-brood spring chinook salmon reared at Deer Mountain Hatchery, Alaska.

Group	Density (kg/m^3)	Percent Yield	Adults per pond	Adults per m^3	Adults per lpm
Low	6.9	5.94	507	23.21	0.71
Medium	12.8	3.15	532	24.36	0.74
High	32.0	0.84	328	15.02	0.46

Table 42. Conditions at release for 1978-brood spring chinook salmon reared at Little Port Walter, Alaska. Size is given as mean weights ± standard errors.

Size, Density	Number of Fish	Average size (g)	Total kg	Density (kg/m^3)	Load (kg/lpm)
Small (mean wt = 10 g)					
Low	11,000	10.1 ± 0.08	111	9.81	0.41
	22,700	10.2 ± 0.08	232	10.22	0.41
Medium	31.200	10.3 ± 0.04	321	14.19	0.66
	42,400	9.9 ± 0.06	420	18.53	0.85
High	28,000	9.7 ± 0.14	272	23.97	1.12
Large (mean wt = 30 g)					
Low	4,800	31.2 ± 1.25	150	6.61	0.30
Medium	8,100	31.8 ± 0.50	258	11.37	0.55
High[a]	8,400	28.2 ± 0.40	237	20.91	0.93

[a]The high density population was accidently killed and replaced with the population from one of the replicated medium density groups.

Figure 7. Relationship between rearing density and percent yield for 1981-brood spring chinook salmon reared at Deer Mountain Hatchery, Alaska.

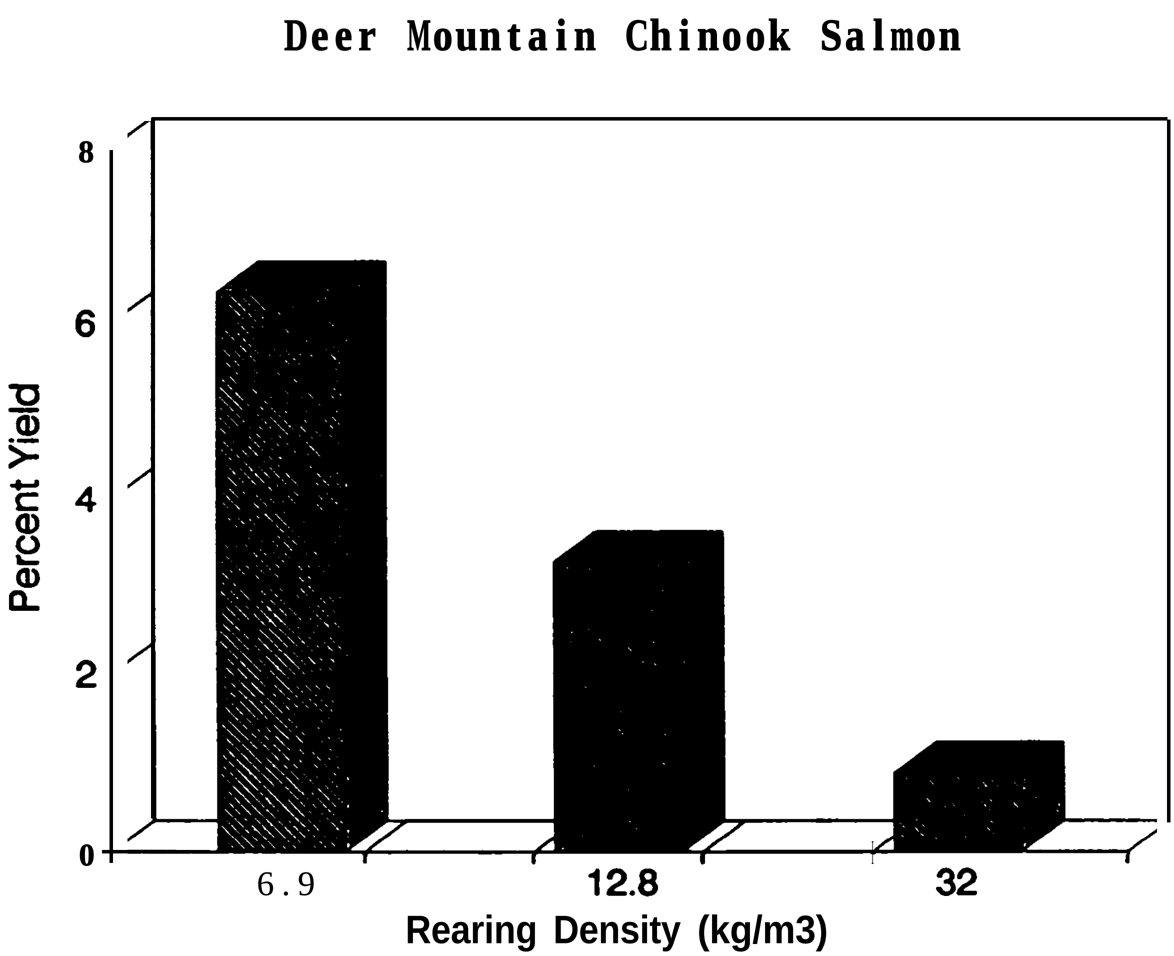
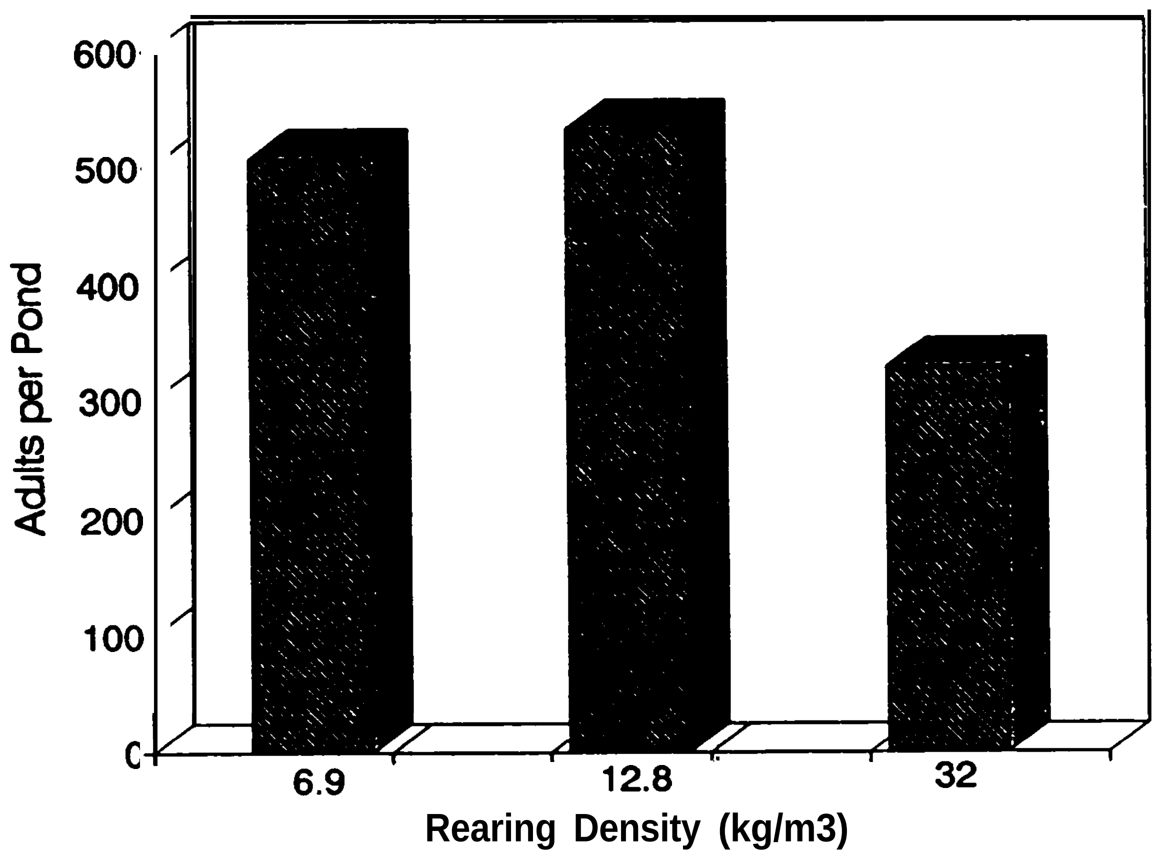

Deer Mountain Chinook Salmon
Percent Yield
0
2
4
6
8
6.9
12.8
32
Rearing Density (kg/m3)

Figure 8. Relationship between rearing density and yield per pond for 1981-brood spring chinook salmon reared at Deer Mountain Hatchery, Alaska.

Deer Mountain Chinook Salmon



This study was carried out for only a single year. There were creditable efforts to establish mortalities, growth rates, and timing of release. The authors did a good job of pointing out the complexities of the trade-off between density and size on the age-classes, percent return, and economic efficiency.

In the results presented, there were some inconsistencies between the authors' Table 1 and Figure 4. The number of fish per raceway calculated from their Table 1 was very different from the numbers of adults provided in their Figure 4. No coded-wire tag data was given and all recovery numbers were incomplete at the publication date. We based our analyses on the corrected form of Table 1 and consequently have no final recovery numbers (Table 43). In addition, this study had a small number of non-replicated groups. Regression analysis of the relationship of density to adult yield showed no significance, probably due to the small number of groups. Graphic analysis suggested that there was a relationship between rearing density and percent yield (Fig. 9) but no relationship between rearing density and adult yield per pond (Fig. 10).

In the years of 1982-1985, four broods of spring chinook salmon were reared in a paired "three-way factorial design" of density and load at Carson National Fish Hatchery, Washington (Banks, 1993). We chose to work with the author's numbers for density and load, using his density rates to calculate the total kilograms of fish per raceway (Table 44).

This experiment and its design were very similar to that of Willard National Fish Hatchery, Washington (Banks, 1992). Like

Table 43. Comparison of production for treatment groups of 1978-brood spring chinook salmon reared at Little Port Walter, Alaska.

Size, Density	Density (kg/m^3)	Percent Yield	Adults per pond	Adult per m^3	Adults per lpm
Small (mean wt = 10 g)					
Low	9.81	1.39	153	13.50	0.56
	10.22	1.39	315	13.91	0.56
Medium	14.19	1.03	321	14.17	0.66
	18.53	0.91	385	16.99	0.78
High	23.97	0.74	206	18.18	0.85
Large (mean wt = 30 g)					
Low	6.61	3.00	144	6.36	0.29
Medium	11.37	2.37	192	8.48	0.41
High[a]	20.91	2.19	184	16.24	0.72

[a]The high density population was accidently killed and replaced with the population from one of the replicated medium density groups.

Figure 9. Relationship between rearing density and percent yield for 1978-brood spring chinook salmon reared at Little Port Walter, Alaska

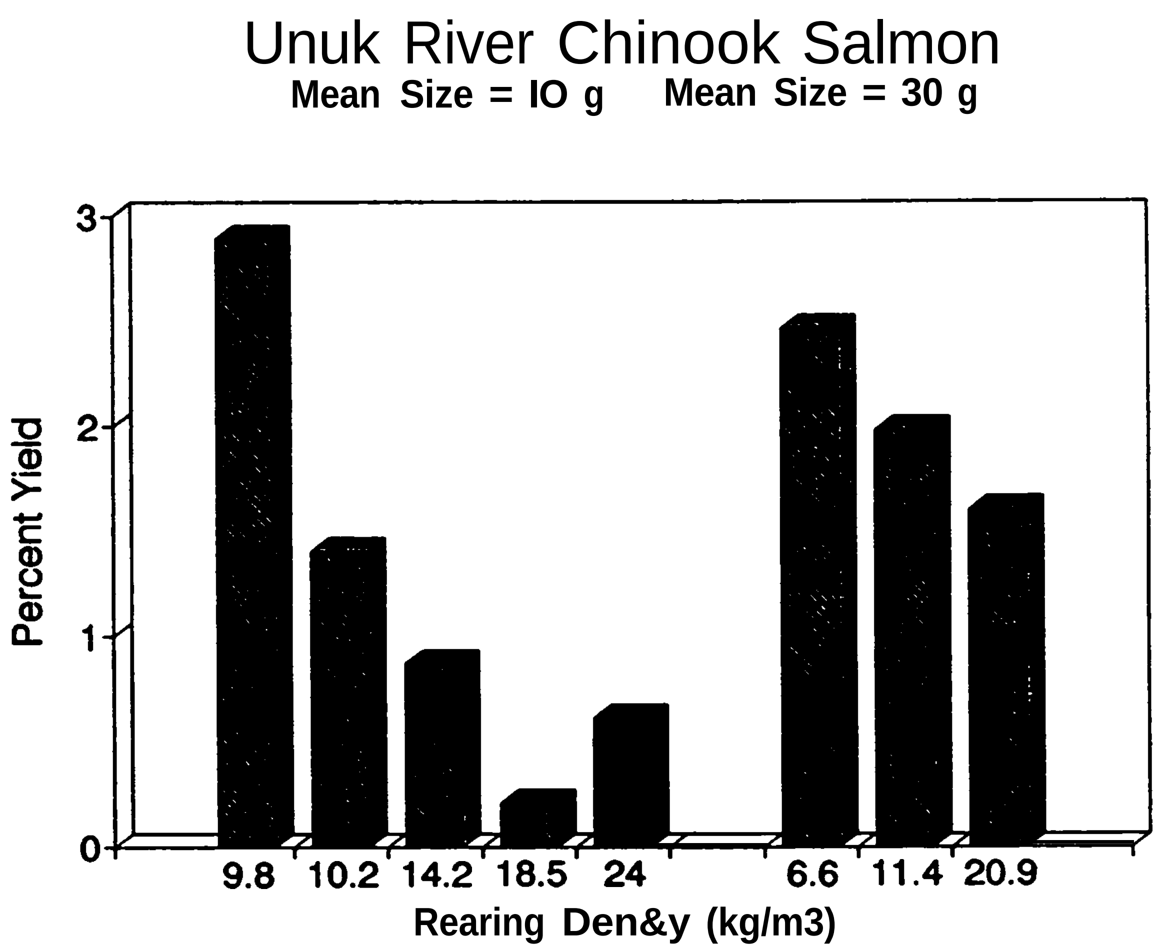

Unuk River Chinook Salmon
Mean Size = IO g
Mean Size = 30 g
Percent Yield
0
1
2
3
9.8
10.2
14.2
18.5
24
6.6
11.4
20.9
Rearing Den&y (kg/m3)

Figure **10. Relationship between rearing density and adult yield per pond for 1978-brood spring chinook salmon reared at Little Port Walter, Alaska.**

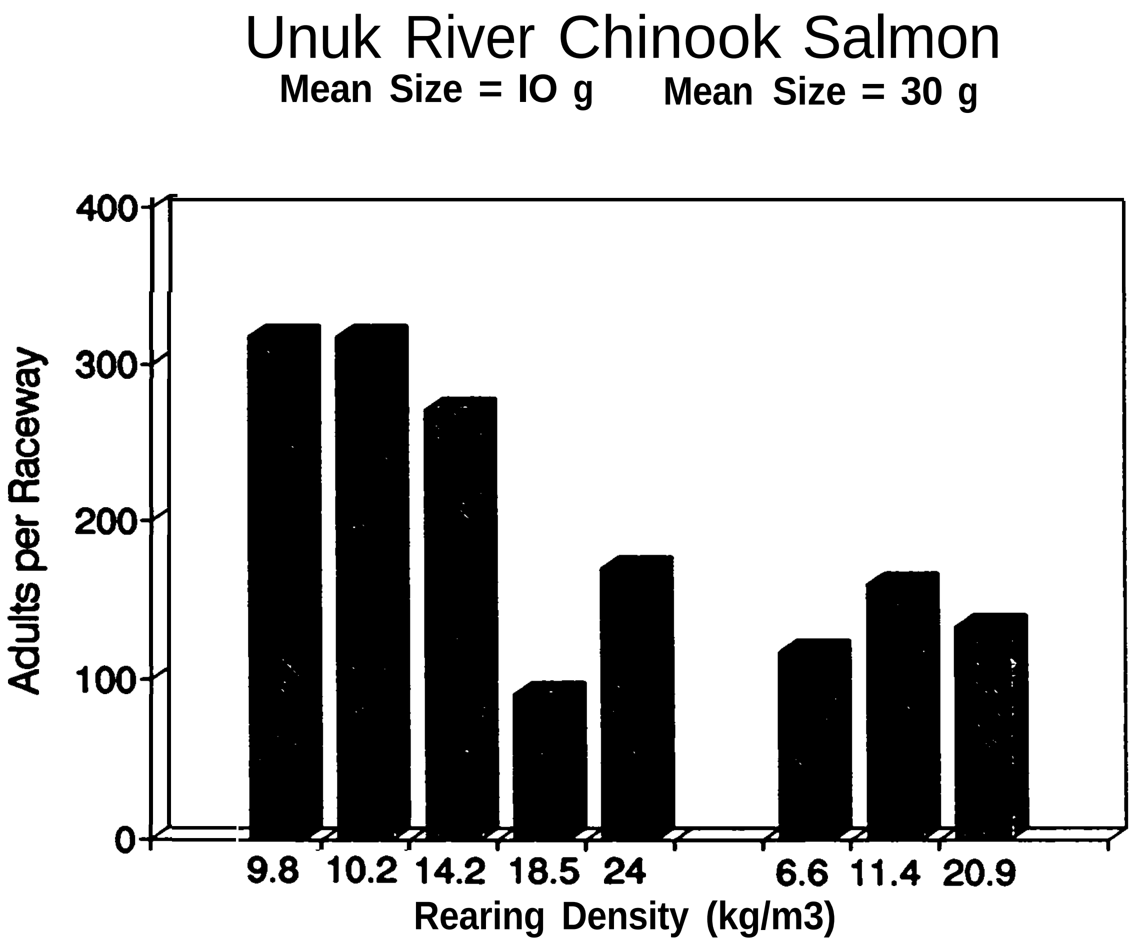

Unuk River Chinook Salmon
Mean Size = IO g
Mean Size = 30 g
Adults per Raceway
400
300
200
100
0
9.8
10.2
14.2
18.5
24
6.6
11.4
20.9
Rearing Density (kg/m3)

Table 44. Conditions at release for 1982-1985 broods of spring chinook salmon reared at Carson National Fish Hatchery, Washington.

Brood Year, Flow (lpm)	Number of fish	Weight (kg)	Total kg	Density (kg/m^3)	Load (kg/lpm)
1982					
757	20,000	26.3	520	15.2	0.69
	40,000	25.4	1009	29.5	1.33
	60,000	25.2	1450	42.4	1.92
1514	20,000	25.1	489	14.3	0.32
	40,000	25.5	995	29.1	0.66
	60,000	24.8	1460	42.7	0.97
2271	20,000	25.5	499	14.6	0.22
	40,000	23.9	944	27.6	0.42
	60,000	25.6	1460	44.2	0.67
1983					
757	20,000	26.8	335	9.8	0.45
	40,000	26.8	674	19.7	0.89
	60,000	27.1	862	25.2	1.29
1514	20,000	24.2	400	11.7	0.27
	40,000	26.9	831	24.3	0.55
	60,000	26.6	1173	34.3	0.77
2271	20,000	26.6	455	13.3	0.20
	40,000	25.7	862	25.2	0.38
	60,000	26.9	1122	32.8	0.50
1984					
757	20,000	23.5	414	12.1	0.54
	40,000	23.1	770	22.5	1.01
	60,000	23.5	1125	32.9	1.49
1514	20,000	22.8	397	11.6	0.28
	40,000	23.5	845	24.7	0.56
	60,000	23.2	1146	33.5	0.76
2271	20,000	23.4	441	12.9	0.19
	40,000	22.7	814	23.8	0.36
	60,000	23.5	1200	35.1	0.53

Table 44. Conditions at release for 1982-1985 broods of spring chinook salmon reared at Carson National Fish Hatchery, Washington (continued).

Brood Year, Flow (lpm)	Number of fish	Weight (kg)	Total kg	Density (kg/m^3)	Load (kg/lpm)
1985					
757	20,000	25.5	499	14.6	0.66
	40,000	25.3	1002	29.3	1.33
	60,000	24.5	1457	42.6	1.92
1514	20,000	26.3	520	15.2	0.35
	40,000	25.1	1002	29.3	0.66
	60,000	25.1	1488	43.5	0.98
2271	20,000	25.6	503	14.7	0.22
	40,000	25.4	1012	29.6	0.45
	60,000	25.4	1505	44.0	0.67

the Willard experiment, this one was well set up. Analysis of variance could be performed and standard errors could be assigned to adult recoveries. We chose to stay with the author's analyses for determining results. They included the following:

1) Fingerling mortality from bacterial kidney disease (BKD), particularly in the 1983- and 1984-brood years, was related to increased rearing density and decreased flow. The author noted that his pathological analyses of disease incidence did not show this relationship Exact mortality and disease counts were not given in the paper.

2) Increased density resulted in lower percent survival, while increased flow appeared to yield higher percent survival (Table 45). Differences between survival rates of different broods were attributed to annual variations in ocean conditions.

3) With increased density, no significant differences were found in adults per raceway within the 1982- and 1985-brood years. A significant decrease in adults per raceway was found within the 1983- and 1984-brood years (Table 45).

4) Lengths, sex ratios, and age compositions did not show any treatment effects for hatchery returns.

With these results, the author recommended that the usual practice of rearing 40,000 fish per raceway at a flow of 1,514 liters per minute be reduced, for reasons of economics, incidence of disease, water quality, and production potential, to 20,000 fish per raceway at 1514 liters per minute.

Table 45. Comparison of production for treatment groups of 1982-1985 broods of spring chinook salmon reared at Carson National Fish Hatchery, Washington.

Brood Year, Flow (lpm)	Density (kg/m^3)	Percent Yield	Adults per pond	Adults per m^3	Adults per lpm
1982					
757	15.2	0.43 ± 0.05	86 ± 11	2.51	0.11
	29.5	0.39 ± 0.08	153 ± 32	4.47	0.20
	42.4	0.13 ± 0.03	73 + 15	2.13	0.10
1514	14.3	0.54 ± 0.09	108 ± 20	3.16	0.07
	29.1	0.28 ± 0.06	109 ± 24	3.19	0.07
	42.7	0.25 ± 0.08	147 ± 46	4.29	0.10
2271	14.6	0.64 ± 0.07	127 ± 12	3.71	0.06
	27.6	0.32 ± 0.04	126 ± 14	3.68	0.06
	44.2	0.28 ± 0.03	167 ± 3	4.88	0.07
1983					
757	9.8	0.82 ± 0.13	103 ± 19	3.01	0.14
	19.7	0.45 ± 0.03	112 ± 4	3.27	0.15
	25.2	0.18 ± 0.01	57 ± 0	1.67	0.08
1514	11.7	0.67 ± 0.03	111 ± 2	3.25	0.07
	24.3	0.29 ± 0.01	88 ± 9	2.57	0.06
	34.3	0.16 ± 0.00	72 ± 2	2.11	0.05
2271	13.3	0.76 ± 0.03	130 ± 15	3.80	0.06
	25.2	0.44 ± 0.08	147 ± 26	4.29	0.07
	32.8	0.25 ± 0.02	106 ± 8	3.09	0.05
1984					
757	12.1	0.08 ± 0.01	14 ± 3	0.41	0.02
	22.5	0.01 ± 0.00	4 ± 1	0.17	0.005
	32.9	0.01 ± 0.00	3 ± 1	0.09	0.004
1514	11.6	0.07 ± 0.01	12 ± 2	0.35	0.008
	24.7	0.02 ± 0.00	9 ± 1	0.26	0.006
	33.5	0.01 ± 0.01	7 ± 3	0.20	0.005
2271	12.9	0.07 ± 0.01	14 ± 2	0.41	0.006
	23.8	0.02 ± 0.01	6 ± 3	0.18	0.003
	35.1	0.01 ± 0.00	3 ± 1	0.09	0.001

Table 45 (continued). Comparison of production for treatment groups of 1982-1985 broods of spring chinook salmon reared at Carson National Fish Hatchery, Washington.

Brood Year, Flow (lpm)	Density (kg/m^3)	Percent Yield	Adults per pond	Adults per m^3	Adults per lpm
1985					
757	14.6	0.42 ± 0.06	82 ± 12	2.39	0.11
	29.3	0.12 ± 0.01	48 ± 2	0.17	0.06
	42.6	0.09 ± 0.01	53 ± 7	1.55	0.07
1514	15.2	0.36 ± 0.05	72 ± 10	2.11	0.05
	29.3	0.19 ± 0.06	76 ± 25	2.22	0.05
	43.5	0.08 ± 0.01	47 ± 4	1.37	0.03
2271	14.7	0.45 ± 0.08	89 ± 16	2.60	0.04
	29.6	0.15 ± 0.03	61 ± 13	1.78	0.03
	44.0	0.18 ± 0.00	106 ± 1	3.09	0.05

Summary

Results from the density studies using 17 brood years of coho salmon and 10 brood years of chinook salmon are shown in Figures 47 and 48, respectively. The values in these tables represent the relationship between rearing density and percent yield or adults per pond. They are the quantitative results of analysis of variance and regression analyses or the qualitative result of graphic evaluations.

As in many areas of fisheries, the results are not as defined as one would desire. Both tables are replete with O's, representing no relationship between rearing density and percent yield or adult yield per pond. Nevertheless, some conclusions can be reached. The relationships between rearing density and percent yield shown in Tables 46 and 47 are either absent or negative. No positive relationships were seen with either chinook or coho salmon. Conversely, the relationship between rearing density and adult yield per pond is usually either absent or positive, indicating that more adults can be produced in ponds of higher density. Only two studies, both with chinook salmon, found a positive relationship between rearing density and adult yield per pond.

From these studies, we have reached the following conclusions:

1) There is usually an inverse relationship between percent yield and rearing density, although this relationship may be

Table 46. Summary of density experiments on coho salmon

Hatchery	Brood Year	Relationship of Density to: Percent yield	Adults per pond	Reference
Sandy	1975	0	+	Hemmingsen et al., unpubl.
Capilano	1975		0	F.K. Sandercock and E.T. Stone, unpubl. (1979, 1981) Fagerlund et al., (1981, 1983, 1987)
	1977		0	
	1978	0	+	
Eagle Creek	1979		+	J.E. Holway, unpubl. (1980-2)
	1980	0	+	
	1981	0	+	
Washougal	1980	0	0	Hopley et al., (1991)
	1981	0	0	
	1982	0	0	
Cowlitz	1980	0	0	Hopley et al., (1991)
	1981	0	0	
	1982	0	0	
Clatsop Economic Development	1982	N/A	N/A	Hill et al., (1989)
	1983	N/A	N/A	
	1984	N/A	N/A	
Quinsam	1981	0	0	Fagerlund et al., (1984, 1989)
	1982	0	0	
Willard	1981		+	J.L. Banks, (1986, 1992)
	1982		+	
	Total	17	17	
	Negative Relationship	5	0	
	Positive Relationship	0	7	
	No Relationship	12	10	

Table 47. Summary of density experiments on chinook salmon.

Hatchery	Brood Year	Relationship of Density to: Percent yield	Adults per pond	Reference
Cowlitz	1975		+	C.W. Hopley, unpublished
	1976	0	0	
Deer Mountain	1977	-	0	C. Denton, unpublished (1988)
Little Port Walter	1978	-	0	R.M. Martin and A. Wertheimer (1989)
Capilano	1979	0	0	Fagerlund et al., (1987)
	1980	0	0	
Elk River	1981	-		Nicholas et al., (1983-1986, 1988)
	1982	-		
	1983	-		
	1984	-	+	
	1985	-		
Carson	1982	-	0	J. Banks, (1993)
	1983	-	0	
	1984	-	0	
	1985	-	0	
	Total	15	15	
Negative Relationship		12	4	
Positive Relationship		0	2	
No Relationship		3	9	

masked for reasons discussed later. The relationship is most strongly expressed in chinook salmon.

2) There is often a positive relationship between rearing density and adult yield per pond. The relationship is most strongly expressed in coho salmon.

3) In both species, juvenile mortalities tended to increase with rearing density, often threatening the interpretation of the experimental results. However, this parameter was not always provided in the reports.

Other analyses may be useful to managers, depending upon the limiting conditions at the hatchery. If brood stock is abundant but rearing space is limiting, adults/m^3 may be the parameter of interest. Similarly, if water supply is the limiting factor, adults/lpm may be the most useful parameter. We have limited our analyses to the two parameters reported in Tables 46 and 47 because these are the usual parameters of concern to hatchery managers.

We recommend that managers consider the goals of their hatchery carefully in view of these suggested relationships. In some studies, similar numbers of adults survived regardless of the rearing density of the juveniles. In such cases, it makes little sense to expend extra time and money to rear juveniles that are destined not to survive. In other instances, percent yield decreased with increased rearing density but the number of adults captured by the fishery or returning to the hatchery increased. In these cases, the loss in percent survival may be compensated by the extra adults.

The lack of a demonstration of a relationship between rearing density and percent yield in some of the studies reported probably results chiefly from two factors. First, the number of groups tested was often small so that attainment of statistical significance was difficult. We have tried to alleviate this problem somewhat by using qualitative graphic analyses to determine if the relationship was present.

Secondly, in the experimental design of some studies, density levels within a brood year were not sufficiently different to permit detection of significant changes in survival. For example, densities at Quinsam River Fish Hatchery ranged from 15 to 19 kg/m^3 and 9 to 14 kg/m^3 for the 1981- and 1982-broods, respectively. No significant relationship between density and survival was determined in either instance. On the other hand, coho from the 1981- and 1982-broods at Willard National Fish Hatchery were reared at densities ranging from 500 to 1500 kg/m^3, a threefold increase in levels. Results from these studies showed a clear relationship between rearing density and percent yield.

A third possible factor was that ocean conditions influenced the relationship. Effects of high rearing density may not be expressed if ocean conditions are favorable, but, in years of poor upwellings, the effects of elevated rearing may be detrimental to survival.

The magnitude of the rearing density in kg/m^3 was not a factor in determining the relationship. Eagle Creek Hatchery raised coho salmon at some of the highest rearing densities of all the studies, yet the study demonstrated a negative relationship between rearing density and percent yield. Washougal Hatchery, on the other hand, reared coho salmon at some of the lowest rearing densities and found no relationship.

Each hatchery persents unique characteristics which influence the relationship between rearing density and percent yield or adult yield per pond. The best way to determine the correct relationships is to conduct density experiments at each facility, realizing that unknown conditions may even then affect the results. We recommend that special attention be placed on the following areas when conducting these experiments:

1) The rearing densities tested should be widely separated so there is a likelyhood of achieving statistical differences between groups.

2) The experimental groups should be replicated so that analysis of variance can be used for testing differences statistically.

3) Only one variable at a time should be tested. When other variables are introduced, they often obscure the results.

4) Careful records should be kept of pond sizes, water flows, mortalities, fish sizes, and population numbers. These are the critical data needed for comparing the results of density studies.

5) Releases of all groups should take place at the same time. Volitional releases are not appropriate because rearing density may affect migration timing.

We offer the uniform style of tables in this review as a possible model for future studies. We hope that this review may provide a beginning for a database of density studies that may help us understand this complex aspect of hatchery rearing.

FISH CULTURE AND WATER QUALITY

Methods and Materials

Fish Culture

Spring chinook salmon adults were collected at the Dexter holding ponds below the Dexter Dam 15 miles east of Eugene. The adults were hauled to Willamette Hatchery in Oakridge, Oregon, and were held in a 300 foot long by 15 feet wide excavated rock and earth pond supplied with water from Salmon Creek at a flow of about 10,600 liters per minute. Approximately 1600 adults were held throughout the summer. Spawning occurred from September through October and each egg-take was incubated separately. Juveniles released in the summer and fall of their first year came from the earliest egg-takes. The fish used for this project were derived from later spawning populations in order not to exceed the size required for release. These fish were ponded in groups by hatching dates.

Juvenile fish were taken randomly from different egg-take groups and marked with adipose-fin clips and coded-wire tags. At the time of tagging (from 1 July 1991 to 31 July 1991) they were introduced into experimental raceways. Because of the complexity of the experimental design, the letters A through G are used to designate the different test groups (Table 48). Subscripts represent replicates. Ideal conditions for each raceway are given in Table 49.

Table 48. Designations and pond number for experimental ponds at Willamette Hatchery.

Designation	Pond	Characteristics
A_1	7	Normal density, no oxygen supplementation
A_2	17	Replicate
B_1	6	Half density, no oxygen supplementation
B_2	16	Replicate
C_1	8	Normal density, oxygen supplementation
C2	18	Replicate
D_1	9	Triple density, oxygen supplementation
D_2	19	Replicate
E_1	30N	Michigan system, first pass, oxygen added
E_2	30s	Replicate
F_1	20N	Michigan system, second pass, oxygen added
F_2	20s	Replicate
G_1	10s	Michigan system, third pass, oxygen added
G2	10N	Replicate

Table 49. Ideal characteristics of experimental ponds at Willamette Hatchery[a].

Group	Number of fish	Final pounds	Inflow gpm	Load pounds/gpm	Pond volume ft^3	Density pounds/ft^3
A	36,000	3,600	500	7.2	3,700	0.970
B	18,000	1,800	500	3.6	3,700	0.486
C	36,000	3,600	500	7.2	3,700	0.970
D	108,000	10,800	500	21.6	3,700	2.919
E,F,G	54,000	5,400	750	7.2	1,850	2.919

[a] Characteristics given are approximate and should be compared with experimental numbers provided in the Results section.

When required, oxygen was added to the raceways through sealed contact columns (Westers et. al., 1988). Modifications of the design to fit site-specific requirements were determined before experimental rearing began (Fish Factory, 1990). No packing media or dispersion plates were used in the columns. In raceways with supplemental oxygen, dissolved oxygen in the raceway effluent was maintained at 100% of saturation. Oxygen flow into the contact column was increased or decreased manually using a Brooks rotometer.

Flows of oxygen into the water supply of the various raceways were adjusted weekly to maintain 100% saturation of oxygen at the outflow in all groups except groups A (controls) and groups B. In order to adjust the oxygen flows to provide saturated levels of oxygen at the outflow, maximum oxygen demand during the day was determined and the oxygen flow was adjusted to that level of demand. These adjustments could not maintain a constant dissolved oxygen concentrations at the outflow but could ensure that the fish were receiving, on the average, oxygen at levels at or above saturation.

Fish were fed BioMoist Feed from Bioproducts, Inc., or Oregon Moist Pellet from Moore-Clark Company. Feed was weighed daily for each pond and recorded with the cumulative amount of food per pond on a daily feed sheet. Fish growth was programmed to meet production goals based on historical monthly weight gains.

Mortalities of both tagged and untagged fish were enumerated and recorded weekly for each pond when the ponds were cleaned. Cumulative mortalities were used to estimate population sizes each month.

Water temperatures were recorded on a Taylor thermograph. Precipitation was recorded by a National Oceanic and Atmospheric Administration weather observation station located at the hatchery.

Sample counts to determine fish per pound for the single pass systems were taken at the end of each month by crowding the fish. One percent of the population was sampled in each raceway. In the Michigan ponds, grab samples from various compartments were taken until 1% of the population was sampled. During the sampling on 25 February 1993 (before release), the location in the raceway of each sample was recorded to determine if fish size was different in various locations in the raceways. In Michigan ponds, the cells defined by the baffles were numbered from 1 to 6, beginning at the upstream end, and the cell location for each sample was recorded.

Growth of the fish was calculated from pond counts in three different ways (Ricker 1975):

$$\text{Absolute Change} = w_2 - w_1$$

$$\text{Relative Change} = (w_2 - w_1)/ w_1$$

$$\text{Instantaneous Rate} = \log_e w_2 - \log_e w_1$$

where

w_2 = The weight at the end of the time period.

w_1 = The weight at the beginning of the time period.

Food conversions were calculated from the change in biomass of the raceway and the amount of food fed. The change in the biomass was calculated as:

$$\text{Delta B} = ((N_1 - M)/S_2) - (N_1/S_1)$$

where

Delta B = The change in the biomass.

N_1 = The number of fish in the pond at the start.

M = The observed mortalities.

S_2 = The sample count at the end of the month in number of fish per kg.

S_1 = The sample count at the beginning of the month in number of fish per kg.

The conversion rate each month was then calculated as:

$$\text{Conversion Rate} = \text{Delta B /kg food.}$$

Length frequencies were obtained during tagging, in early October, in mid December and in late February. Fork lengths from samples of about 200 fish were recorded.

Numbers of fish per raceway at release were calculated from measurements of fish per pound and the total pounds of fish in a raceway. Total pounds of fish in a raceway were determined from water displacement when fish were loaded into liberation trucks. The numbers estimated at release were then compared with population numbers estimated from monthly inventories.

Blood hematocrit levels were determined by standard methods in March just before liberation.

In addition to the fish raised at Willamette Hatchery, 382,024 spring chinook salmon were reared at the Dexter holding ponds to ensure that mitigation goals for the hatchery were attained. These fish were also marked with coded wire tags and adipose fin clips. Samples for water quality analyses were taken periodically. At release, total numbers were estimated by the methods described above.

Water Chemistry

Water samples were collected weekly between 12:15 and 13:00. At that time, initial feeding of the fish was completed and one exchange of water had taken place without the presence of human activities. The water samples were taken in the same order: inflow into Group E, outflow from Group E, outflow from Group F, outflow from Group G, outflow from Group D, outflow from Group C, outflow from Group A, outflow from Group B, inflow from an indoor rearing trough set up to record water temperatures.

Dissolved gases were measured using a Common Sensing model TBO-F Total Dissolved Gas and Oxygen Monitor. Dissolved oxygen in parts per million was calculated by the following formulas:

Dissolved Oxygen (ppm) = pO_2 * beta • 31.9988 * 1000/(760* 22.414)

where beta = exp(-58.3877 🖃 ☎🖱🗄📬🖱🗀🖮✆ • (100/(273.15 + ^{o}C))) + (23.8439 * (ln(^{o}C+273.15))))

The pH was measured at the sample site using an Orion pH meter model SA230 and an Orion combination pH electrode.

Alkalinity analysis was done by the titration method in Clesceri et al. (1989). An end point of 4.5 pH units was determined potentiometrically using the Orion pH meter.

Samples of 600 ml water were filtered through Whatman 934-AH filters, dried at 103-105^{o}C and weighed using a Cahn DTL electrobalance to determine suspended solids (Clesceri et al. 1989).

Ammonia analysis was done using the phenate method (Clesceri et al. 1989). The samples and standards were read at 630 nm using a Milton Roy Spectronic 21 spectrophotometer or a Shimadzu Model W-1201 spectrophotometer.

A Royce System VI water quality monitoring system was installed in 1992 to record the diel changes in dissolved oxygen, temperature, and pH. Dissoved oxygen probes were placed at the inflow and outflow of ponds designated A2, B2, C2, D2, El, F1, and G1. Temperature probes were installed with the dissolved oxygen probes. A pH probe was installed at the inflow of pond C2 to measure the pH of incoming water supplied to ponds A2, B2, C2, and D2. A series of pH probes were placed at the outflow of ponds A2, B2, C2, and D2. In the Michigan ponds, pH probes were placed at the inflows for ponds El, F1,and G1 and at the outflow of pond G1. In these ponds, no differences in pH were observed between the outflow of a pond and the inflow of the pond directly below it. Data was collected and stored at three different time resolutions: 6 minute intervals, 30 minute intervals and 60 minute intervals. This data was also condensed and stored for intervals of 48 hours, 10 days and 30 days.

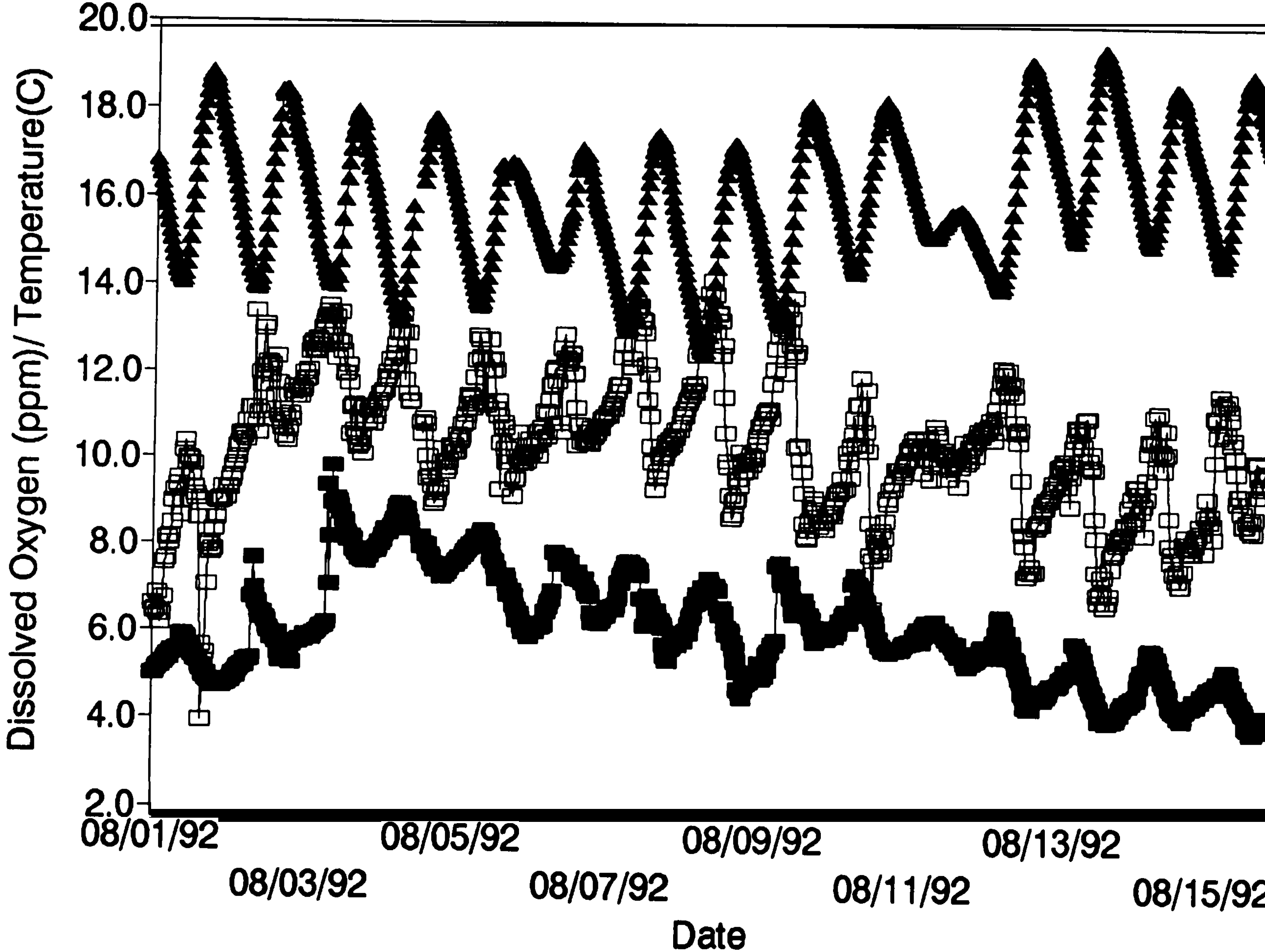
Results and Discussion

Dissolved Oxygen

In 1992-1993, variations in dissolved oxygen concentrations over a 24-hour period was followed with the Royce continuous monitoring system. Examples of this variation are shown in Figs. 11, 12, and 13. In August, dissolved oxygen levels in groups A2 and D2 varied inversely with temperature (Fig. 11), reflecting changes in metabolic activity with temperature. Temperatures reached maxima in the raceways near 1800 hours, resulting in the lowest dissolved oxygen concentrations at that time. The average dissolved oxygen level in the effluent of the raceway A2 without oxygen supplementation did not attain saturation and remained in the range of 5-8 ppm. In contrast, the dissolved oxygen concentration in the effluent of raceway D2 with oxygen supplementation averaged 9-12 ppm. Because of the high density of fish in raceway D2, dissolved oxygen concentrations reached lows of 3.9 ppm for short periods during pond cleaning. If a minimum dissolved oxygen concentration of 5 ppm during rearing is to be maintained at all times, modifications in the pond cleaning procedures should be addressed.

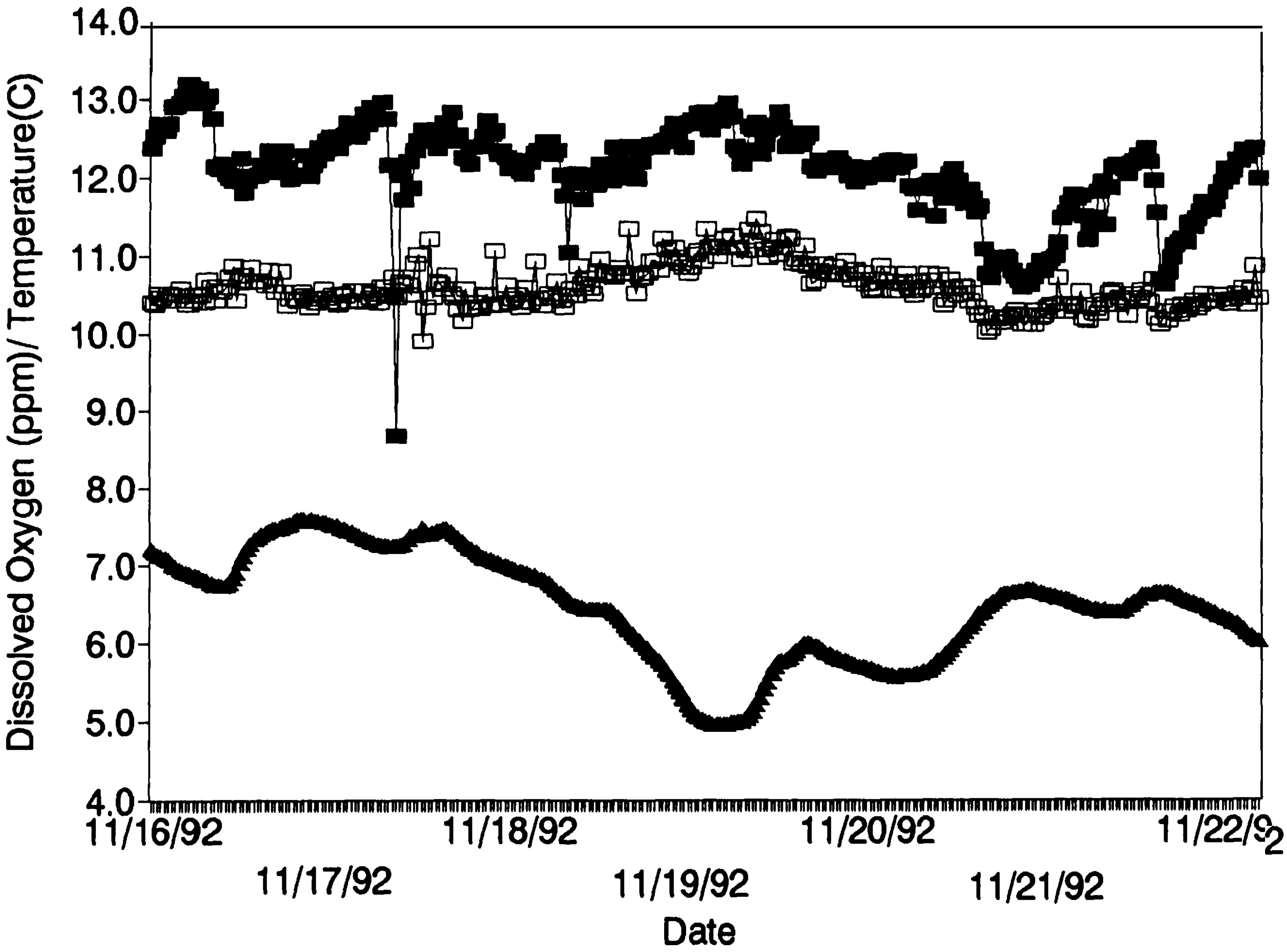
In November (Fig. 12), when temperatures varied irregularly from 5-8^{o}C, the dissolved oxygen concentrations in the effluent of ponds A2 and D2 did not show the diel fluctuation present in August at higher temperatures. Dissolved oxygen levels

Figure 11. Die1 changes in oxygen concentrations at the outflow of ponds A2 (-a-) and D2 (-■-) from 01 August 1992 to 16 August 1992. Temperatures at the inflow are also shown (-▲-).



Dissolved Oxygen (ppm)/ Temperature(C)
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
08/01/92
08/03/92
08/05/92
08/07/92
08/09/92
08/11/92
08/13/92
08/15/92
Date

Figure 12. Die1 changes in oxygen concentrations at the outflow of ponds A2 (-□-) and D2 (-■-) from 05 November 1992 to 30 November 1992. Temperatures at the inflow are also shown (-▲-).



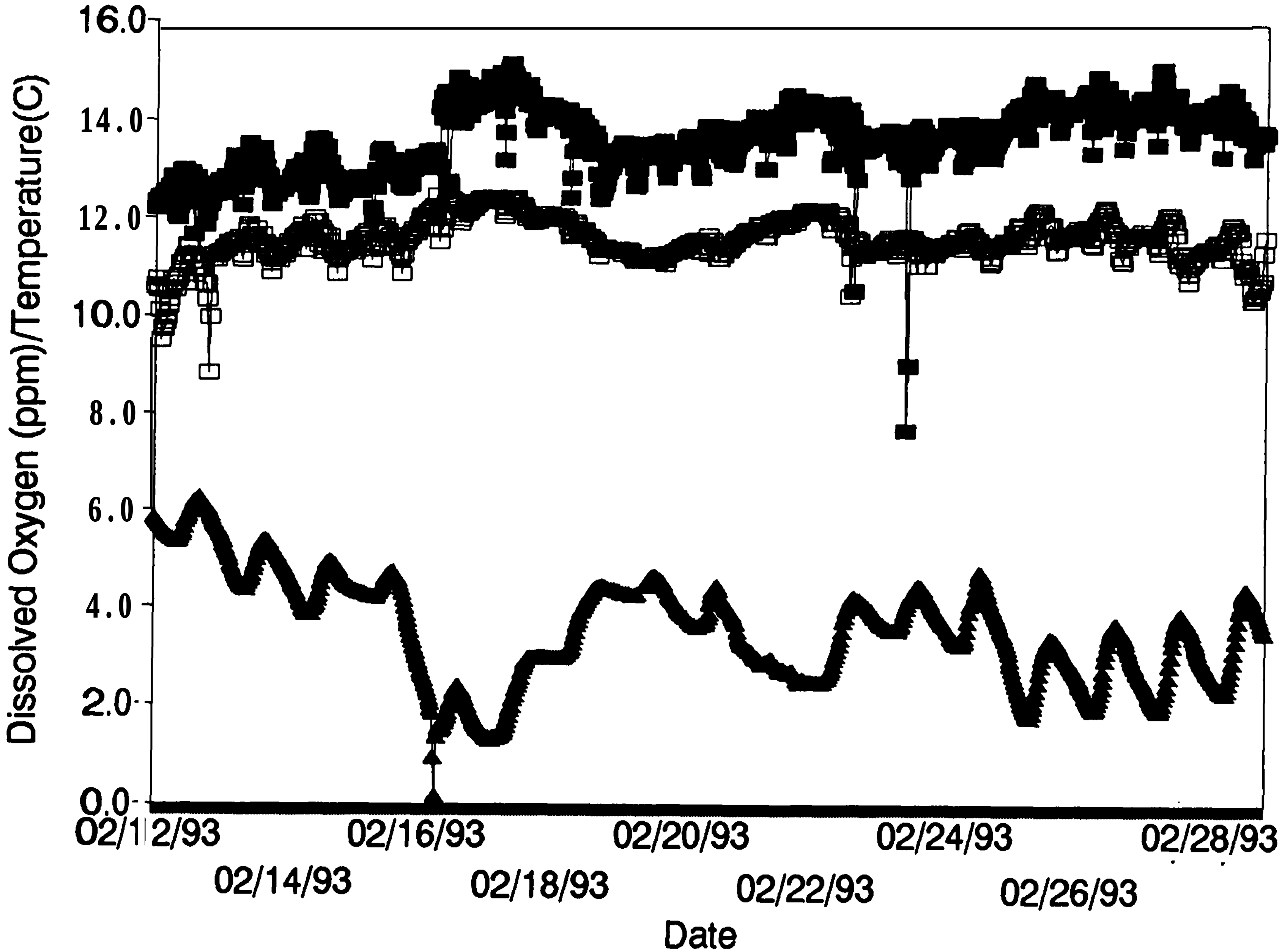
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
Dissolved Oxygen (ppm)/ Temperature(C)
11/16/92
11/17/92
11/18/92
11/19/92
11/20/92
11/21/92
11/22/92
Date

in pond A2 were relatively constant at about 10.5 ppm, while those in pond D2 were slightly higher at 11-13 ppm. Dissolved oxygen concentrations in February for the effluents of the two ponds (Fig. 13) were similar to that in November, except that the temperatures were lower and the dissolved oxygen concentrations slightly higher.

In the Michigan ponds, die1 changes in dissolved oxygen in ponds El and Fl occurred in August (Fig. 14). The magnitude of the changes was greater than in pond D2, especially in ponds Fl and Gl. One of the greatest changes in dissolved oxygen occurred in pond Gl on August 1, when the dissolved oxygen concentration in the effluent varied between 14 ppm and 4 ppm. These large changes resulted from the recycling of the water through the ponds. During the warm part of the day, pond El consumed the maximum amount of oxygen. When the water was pumped into the column at the head of pond Fl the water was enriched in oxygen but not as fully as that at the head of raceway El. A similar enrichment took place at the head of raceway Gl. Consequently, fluctuations tend to be augmented after the third use of water in pond Gl.

In November and February (Figs. 15 and 16), some die1 fluctuation in oxygen concentration in the effluents of the Michigan series of ponds was still evident, although it was reduced by the cooler temperatures. During the coolest water temperatures in February, die1 fluctuation in dissolved oxygen concentration disappeared.

Figure 13. Die1 changes in oxygen concentrations at the outflow of ponds A2 (-□-) and D2 (-■-) from 12 February 1993 to 28 February 1993. Temperatures at the inflow are also shown (-▲-).



16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Dissolved Oxygen (ppm)/Temperature(C)
02/12/93
02/14/93
02/16/93
02/18/93
02/20/93
02/22/93
02/24/93
02/26/93
02/28/93
Date

Figure 14. Diel changes in oxygen concentrations at the outflow of ponds El (-▬-), F1 (-a-) and G1 (-✢-) from 01 August 1992 to 16 August 1992. Temperatures at the inflow are also shown (-

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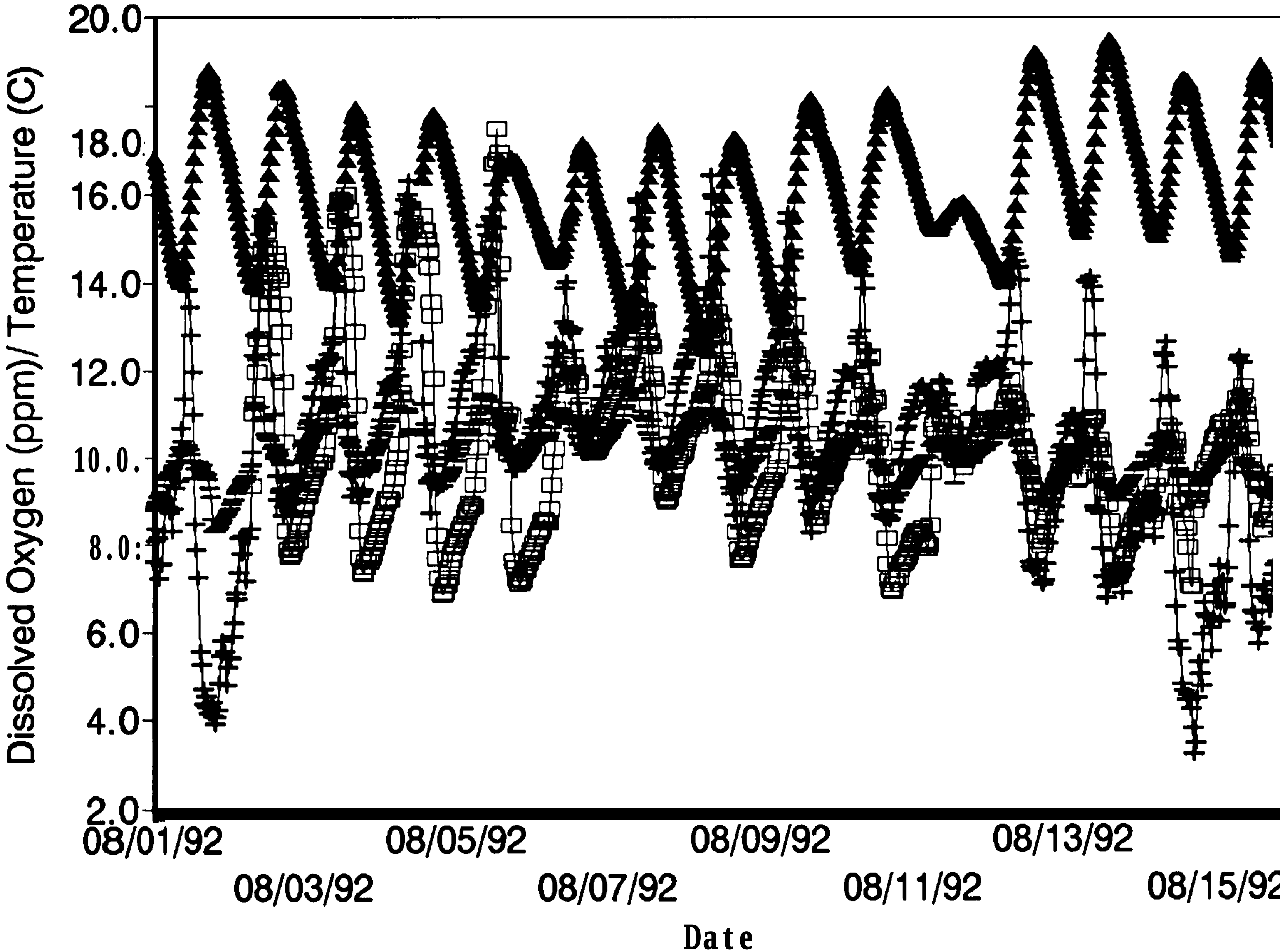
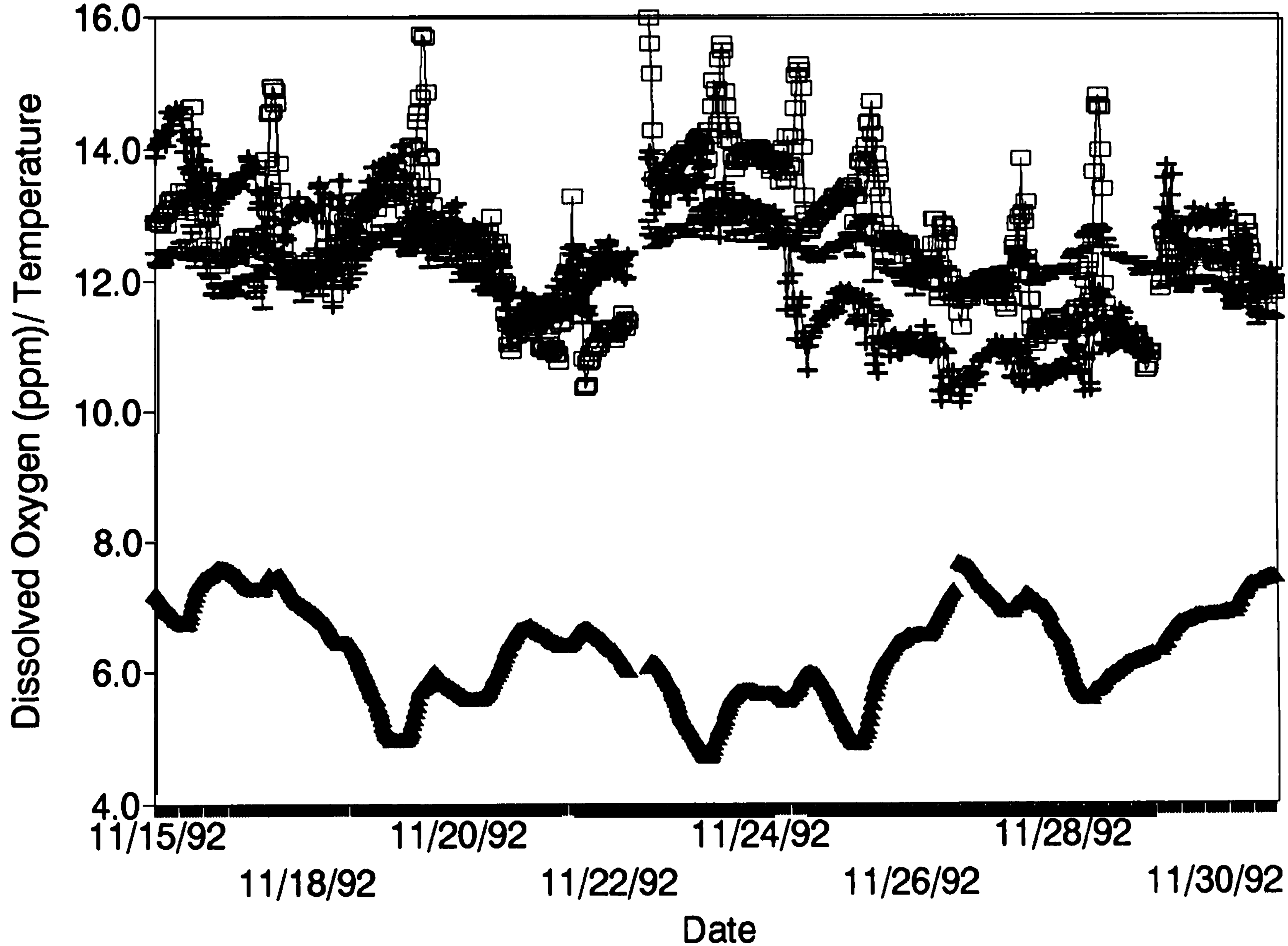


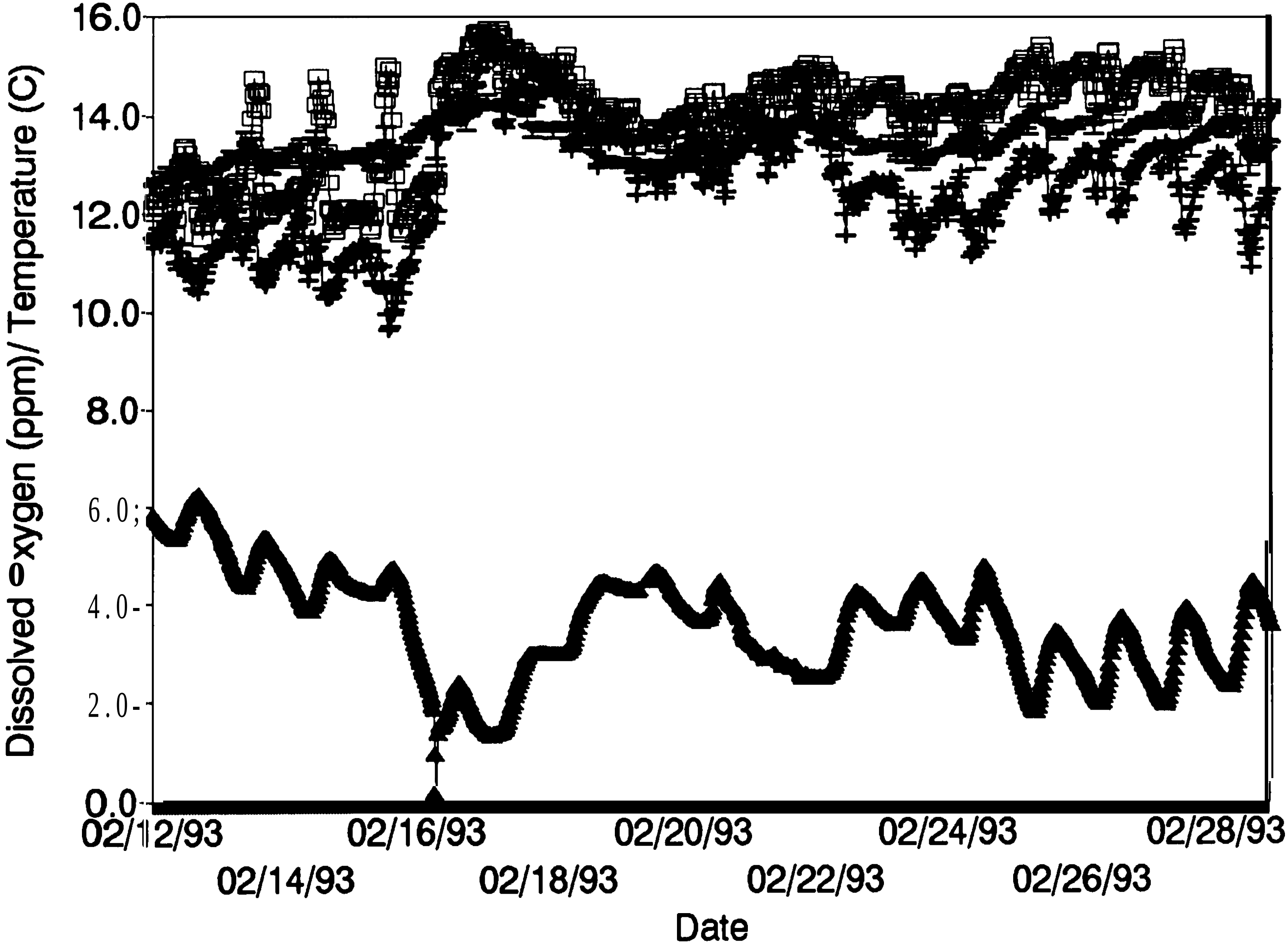
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
Dissolved Oxygen (ppm)/ Temperature (C)
08/01/92
08/03/92
08/05/92
08/07/92
08/09/92
08/11/92
08/13/92
08/15/92
Date

Figure 15. Die1 changes in oxygen concentrations at the outflow of ponds El (-■-), F1 (-a-) and G1 (-+-) from 15 November 1992 to 30 November 1992. Temperatures at the inflow are also shown (-▲-).



16.0
14.0
12.0
10.0
8.0
6.0
4.0
Dissolved Oxygen (ppm)/ Temperature
11/15/92
11/18/92
11/20/92
11/22/92
11/24/92
11/26/92
11/28/92
11/30/92
Date

Figure 16. Die1 changes in oxygen concentrations at the outflow of ponds El (-■-), Fl (-a-) and G1 (-+-) from 12 February 1993 to 28 February 1993. Temperatures at the inflow are also shown (-▲-).



16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Dissolved oxygen (ppm)/ Temperature (C)
02/12/93
02/14/93
02/16/93
02/18/93
02/20/93
02/22/93
02/24/93
02/26/93
02/28/93
Date

For comparison with the measurements for dissolved oxygen in the first two years of this project, dissolved oxygen measurements were made weekly for the various experimental groups as described in Materials and Methods (Appendix A). Oxygen concentrations were derived from temperature and gas pressure measurements (Appendix B). The environment from which the oxygen samples were taken is constantly changing and the values given in Appendix A represent only a single value from a wide range of concentrations. Similar problems with single measurements occur with other metabolic parameters such as carbon dioxide, pH, and ammonia. All show diel changes, as well as changes with temperature, feeding, and activity. Although data on these parameters are provided in this report, it should be kept in mind that these data represent single measurements from continuously changing environments.

Weekly averages of dissolved oxygen concentrations for each experimental pond were also calculated from 30 minute averages from the continuous monitoring system (Table 50). Correlations were observed between the decrease in dissolved oxygen at the outflow and density, load, and total number of fish per raceway (Table 51).

Values for dissolved oxygen, pH, and temperature at 30 minute intervals from July 1992 through March 1993 are provided in the accompanying computer disks. File names for the data sets are:

July 1992	WIJUL92.WK1
August 1992	WIAUG92.WK1

Table 50. Weekly average dissolved oxygen concentrations (ppm) from the inflow (I) and outflow (O) of experimental ponds, as measured by the data monitoring system at Willamette Hatchery, 1992-1993.

	A2		B2		C2		D2		E1		F1		G1	
Date	I	O	I	O	I	O	I	O	I	O	I	O	I	O
08/02/92	8.13	5.58	8.46	7.57	10.87	8.91	13.95	8.85	10.66	9.53	11.50	9.78	13.02	9.54
08/09/92	8.54	6.94	8.78	8.16	10.79	9.14	12.86	11.22	10.52	10.44	11.88	10.63	14.04	11.72
08/16/92	7.43	5.10	7.97	6.39	10.33	8.30	11.54	9.45	9.80	9.80	11.51	9.60	13.36	9.39
08/23/92	6.98	5.85	7.55	7.07	10.29	8.32	10.85	8.15	9.32	10.04	11.76	9.23	13.46	8.11
08/30/92	8.59	7.22	8.90	8.21	10.83	10.06	13.03	9.41	10.68	10.04	13.02	10.32	14.71	10.72
09/06/92	8.47	7.58	9.14	8.06	10.20	8.87	12.36	9.23	10.76	9.23	13.07	10.01	14.22	8.74
09/13/92	8.25	8.81	8.86	8.19	11.26	9.84	13.23	10.10	11.27	9.72	13.44	10.57	14.80	9.98
09/20/92	8.78	8.47	9.38	8.51	12.12	10.13	13.52	9.87	11.55	10.04	13.77	10.99	15.23	10.88
09/27/92	9.70	8.41	9.04	8.66	12.58	10.65	14.21	10.06	11.88	9.88	14.44	11.34	17.02	13.67
10/04/92	9.33	8.50	8.83	8.84	13.24	10.97	14.94	10.60	12.35	10.26	14.75	12.03	16.21	13.12
10/11/92	9.50	9.34	9.96	9.77	13.44	11.70	15.73	12.47	12.57	10.64	15.38	12.99	16.12	13.48
10/18/92	9.91	9.35	10.03	9.98	13.74	11.37	15.64	12.43	12.79	10.73	16.70	12.80	15.75	13.93
10/25/92	9.93	10.06	10.19	9.85	12.56	10.96	14.82	11.56	12.75	10.47	15.32	11.89	15.20	12.52
11/01/92	9.85	9.00	9.37	8.84	13.37	10.78	14.12	11.21	12.02	10.56	13.92	10.65	16.19	11.89
11/08/92	10.80	10.15	10.64	10.41	13.48	11.08	13.15	11.33	11.69	10.80	14.34	11.83	12.61	10.83
11/15/92	10.92	10.43	11.03	10.45	13.95	11.51	13.73	12.18	12.31	11.21	14.92	11.67	11.89	10.98
11/22/92	11.05	10.58	10.76	10.84	14.35	11.73	14.54	12.09	12.90	12.20	15.42	12.55	15.13	12.84
11/29/92	11.23	10.72	10.93	10.63	14.59	11.98	14.13	11.81	13.59	12.36	15.43	12.69	14.84	11.60
12/05/92	10.94	9.95	11.18	10.66	14.29	11.65	13.47	11.32	12.93	11.85	15.18	12.16	14.48	12.29
01/31/93	12.95	12.17	12.78	12.78	15.38	13.13	16.30	13.28	14.53	13.84	15.63	15.06	16.20	13.28
02/07/93	12.45	11.79	12.16	12.17	15.16	12.42	16.10	12.78	14.12	13.16	15.08	13.99	15.64	11.32
02/14/93	11.61	10.94	11.54	12.17	14.60	13.04	15.35	12.63	13.83	12.87	14.46	12.62	15.80	11.49
02/21/93	11.98	11.78	11.93	11.82	14.82	13.30	15.95	13.68	13.92	13.49	15.01	14.08	16.54	13.24
02/28/93	12.13	11.60	11.95	11.70	14.97	13.28	15.28	13.96	13.87	13.55	15.28	14.41	16.51	12.49
03/07/93	12.02	11.68	12.01	11.61	13.13	12.79	14.52	13.38	14.89	12.73	14.56	12.73	15.54	12.59
03/15/93	11.50	10.86	11.23	10.98	13.36	12.33	14.75	12.31	13.31	12.69	13.89	12.25	14.83	12.36

Table 51. Correlation coefficients (R) between the difference in oxygen between inflow and outflow for all experimental raceways and density, load, and total number of fish per raceway. Weekly averages from the continuous monitoring system were used for calculations.

Month	Density	Load	Number of fish per raceway
August	0.478	0.573	0.678
September	0.677	0.898	0.877
October	0.281	0.605	0.496
November	0.325	0.660	0.456
February	0.072	0.400	0.201
March	0.581	0.883	0.791

September 1992	WISEP92.WK1
October 1992	WIOCT92.WK1
November 1992	WINOV92.WK1
December 1992	WIDEC92.WK1
February 1993	WIFEB93.WK1
March 1993	WIMAR93.WK1

Due to a software problem and damage to the computer in shipping, data was not collected from 6 December 1992 through 29 January 1993. Also, oxygen levels at the outflow of ponds F1 and G1 may be artifactually elevated. Suspended solids from the effluent of pond El tended to form a foam by adhering to oxygen enriched bubbles in the contact column. The foam adhered to the pH probe and interfered with measurement of dissolved oxygen. This condition was worsened when fish in the pond upstream were fed.

pH

pH was sampled at weekly intervals throughout the rearing period for spring chinook salmon (Table 52). Data was combined for each group of duplicate ponds. Analysis of variance and Fisher least significant difference tests (Pc 0.05) indicated differences between groups (Fig. 17). pH of the effluent decreased in proportion to the density of fish per pond. Although this is the same pattern seen last year, the magnitude of the changes were less because of higher alkalinity and pH levels of incoming water. The weekly average obtained from the

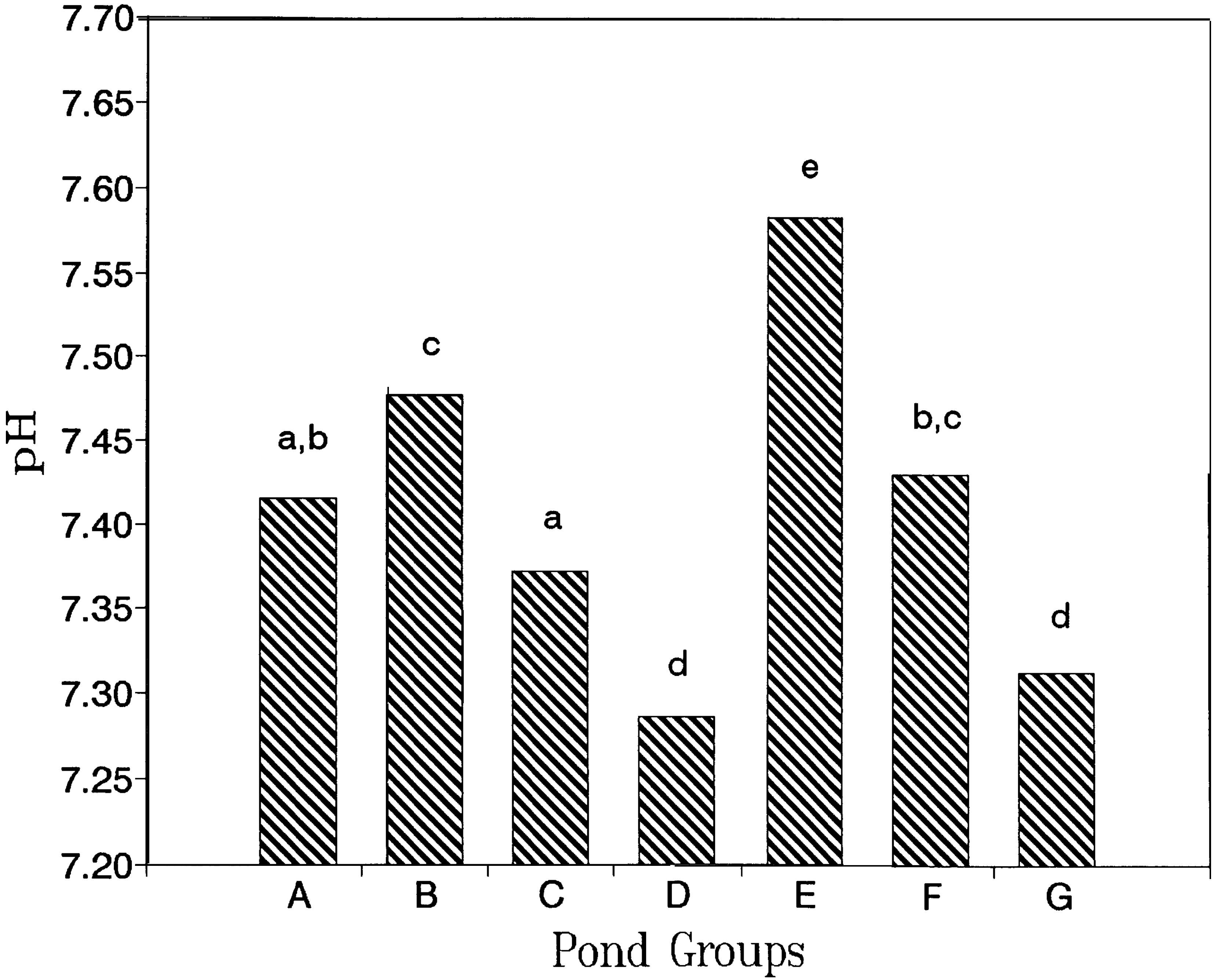
Table 52. pH values at the inflow and outflow of various experimental ponds collected as single samples at Willamette Hatchery, 1992-1993.

Date	Inflow	Inflow	A1	A2	B1	B2	C1	C2	D1	D2	Inflow	Inflow	E1	E2	F1	F2	G1	G2
08/04/92	7.98	-	7.71	-	7.81	-	7.63	-	7.51	-	7.97	-	7.89	-	7.73	-	7.55	-
08/11/92	8.01	-	7.62	-	7.75	-	7.56	-	7.15	-	8.06	-	7.76	-	7.37	-	7.21	-
08/25/92	7.80	-	7.54	-	7.64	-	7.46	-	7.35	-	7.84	-	7.63	-	7.48	-	7.38	-
08/27/92	-	7.87	-	7.63	-	7.69	-	7.58	-	7.41	-	7.99	-	7.88	-	7.63	-	7.47
09/01/92	7.89	-	7.55	-	7.68	-	7.50	-	7.36	-	8.00	-	7.89	-	7.61	-	7.43	-
09/03/92	-	7.90	-	7.66	-	7.74	-	7.63		7.47	-	8.03		7.93		7.73	-	7.56
09/08/92	7.84	-	7.55	-	7.63	-	7.50	-	7.43	-	7.90	-	7.83	-	7.63	-	7.45	-
09/10/92		7.97	-	7.67		7.74	-	7.60		7.46	-	8.00		7.90		7.72	-	7.57
09/15/92	7.93	-	7.47	-	7.57	-	7.40	-	7.30	-	7.99		7.85	-	7.51	-	7.34	-
09/17/92		7.80	-	7.58		7.60	-	7.53		7.46	-	7.86		7.82		7.65	-	7.50
09/22/92	7.80	-	7.58	-	7.63	-	7.56	-	7.40	-	7.84	-	8.81	-	7.67	-	7.47	-
09/24/92	-	7.56	-	7.37	-	7.43	-	7.30	-	7.24	-	7.60		7.57		7.47	-	7.36
10/01/92	7.82	-	7.51	-	7.56	-	7.46	-	7.41	-	7.84	-	7.79	-	7.65	-	7.50	
10/06/92	7.67	-	7.56	-	7.60	-	7.52		7.31	-	7.62	-	7.50		7.42	-	7.32	-
10/08/92	-	7.59	-	7.43	-	7.50	-	7.39	-	7.34	-	7.62	-	7.59	-	7.52	-	7.41
10/13/92	7.58	-	7.33	-	7.42	-	7.29	-	7.19	-	7.93	-	7.53	-	7.29	-	7.13	-
10/15/92	-	7.77	-	7.51	-	7.72	-	7.46	-	7.44	-	7.66	-	7.66	-	7.58	-	7.50
10/20/92	7.51	-	7.39	-	7.44	-	7.36	-	7.32	-	7.50	-	7.54	-	7.47	-	7.36	-
10/22/92	-	7.51	-	7.35	-	7.40	-	7.28	-	7.22	-	7.46	-	7.39	-	7.34	-	7.26
10/27/92	7.57	-	7.48	-	7.51	-	7.42	-	7.38	-	7.58	-	7.54	-	7.48	-	7.38	-
10/29/92	-	7.40	-	7.25	-	7.30	-	7.21	-	7.17	-	7.45	-	7.31	-	7.27	-	7.21
11/03/92	7.45	-	7.36	-	7.40	-	7.34	-	7.32	-	7.58	-	7.48	-	7.41	-	7.33	-
11/05/92	-	7.53	-	7.46	-	7.48	-	7.40	-	7.31	-	7.76	-	7.47	-	7.41	-	7.32
11/10/92	7.56	-	7.41	-	7.49	-	7.36	-	7.25	-	7.62	-	7.48	-	7.34	-	7.20	-

Table 52 (cont). pH values at the inflow and outflow of various experimental ponds collected as single samples at Willamette Hatchery, 1992-1993.

Date	Inflow	Inflow	A1	A2	B1	B2	C1	C2	D1	D2	Inflow	Inflow	E1	E2	F1	F2	G1	G2
11/12/92	-	7.56	-	7.42	-	7.49	-	7.41	-	7.23	-	7.72	-	7.60	-	7.48	-	7.18
11/17/92	7.58	-	7.40	-	7.46	-	7.36	-	7.20	-	7.93	-	7.53	-	7.29	-	7.13	-
11/19/92	-	7.63	-	7.46	-	7.50	-	7.43	-	7.25	-	7.77	-	7.50	-	7.35	-	7.19
11/24/92	7.46	-	7.28	-	7.31	-	7.25	-	7.14	-	7.78	-	7.68	-	7.28	-	7.08	-
12/01/92	7.44	-	7.30	-	7.37	-	7.22	-	7.16	-	7.72	-	7.62	-	7.23	-	7.11	-
12/03/92	-	7.42	-	7.31	-	7.36	-	7.26	-	7.17	-	7.59	-	7.35	-	7.27	-	7.16
12/08/92 7.64	-	7.35		7.40		7.27		7.17		7.71		7.47		7.30		7.18		
12/10/92		7.40		7.30		7.35		7.24		7.15		7.60		7.34		7.24		7.16
12/17/92		7.50		7.41		7.46		7.36		7.29		7.51		7.47		7.37		7.29
12/22/92	7.37		7.26		7.31		7.22		7.15		7.41		7.31		7.21		7.15	
12/24/92		7.45		7.33		7.39		7.30		7.23		7.44		7.43		7.32		7.24
12/29/92	7.48		7.34		7.41		7.30		7.24		7.53		7.46		7.34		7.25	
12/30/92		7.51		7.38		7.44		7.33		7.27		7.55		7.52		7.40		7.31
01/07/93		7.51		7.43		7.48		7.40		7.35		7.60		7.52		7.45		7.37
01/12/93	7.74		7.45		7.69		7.40		7.35		7.58		7.52		7.46		7.36	
01/14/93		7.54		7.42		7.47		7.40		7.35		7.57		7.53		7.46		7.35
01/19/93	7.50		7.39		7.43		7.35		7.31		7.60		7.49		7.43		7.34	
01/21/93		7.38		7.29		7.33		7.26		7.20		7.48		7.40		7.32		7.27
01/26/93	7.43		7.29		7.34		7.27		7.23		7.47		7.43		7.36		7.27	
01/28/93		7.41		7.31		7.35		7.28		7.25		7.49		7.42		7.34		7.36
02/02/93	7.49		7.35		7.40		7.32		7.27		7.57		7.51		7.44		7.32	
02/04/93		7.38		7.30		7.32		7.27		7.23		7.42		7.40		7.35		7.27
02/09/93	7.42		7.27		7.31		7.24		7.20		7.48		7.44		7.35		7.23	
02/11/93		7.37		7.30		7.30		7.26		7.20		7.35		7.35		7.30		7.22
02/16/93	7.62		7.35		7.39		7.34		7.32		7.51		7.49		7.46		7.36	
02/18/93		7.43		7.32		7.35		7.30		7.24		7.35		7.35		7.31		7.24
03/02/93	7.60		7.50		7.53		7.44		7.41		7.69		7.66		7.55		7.43	
03/04/93		7.38		7.30		7.33		7.29		7.24		7.47		7.44		7.37		7.25
03/09/93	7.30		7.20		7.23		7.15		7.12		7.37		7.33		7.26		7.17	

Figure 17. pH at the outflow for various experimental raceways at Willamette Hatchery, 1992-1993. Groups with the same letter above-the bar graph are not significantly different.



7.70
7.65
7.60
7.55
7.50
7.45
7.40
7.35
7.30
7.25
7.20
pH
a,b
c
a
d
e
b,c
d
A
B
C
D
E
F
G
Pond Groups

continuous monitoring system shows the same relationship between pH of effluent water and the number of fish per pond (Table 53). Changes in pH with changes in oxygen concentration in pond D2 are shown for September (Fig. 18) and February (Fig. 19). Die1 cycles of both oxygen and pH can be seen in September, although the correlation between oxygen concentration and pH in the effluent is not as great as one might expect. In February, no die1 cycle in dissolved oxygen was evident, although there was some indication of a die1 change in PH.

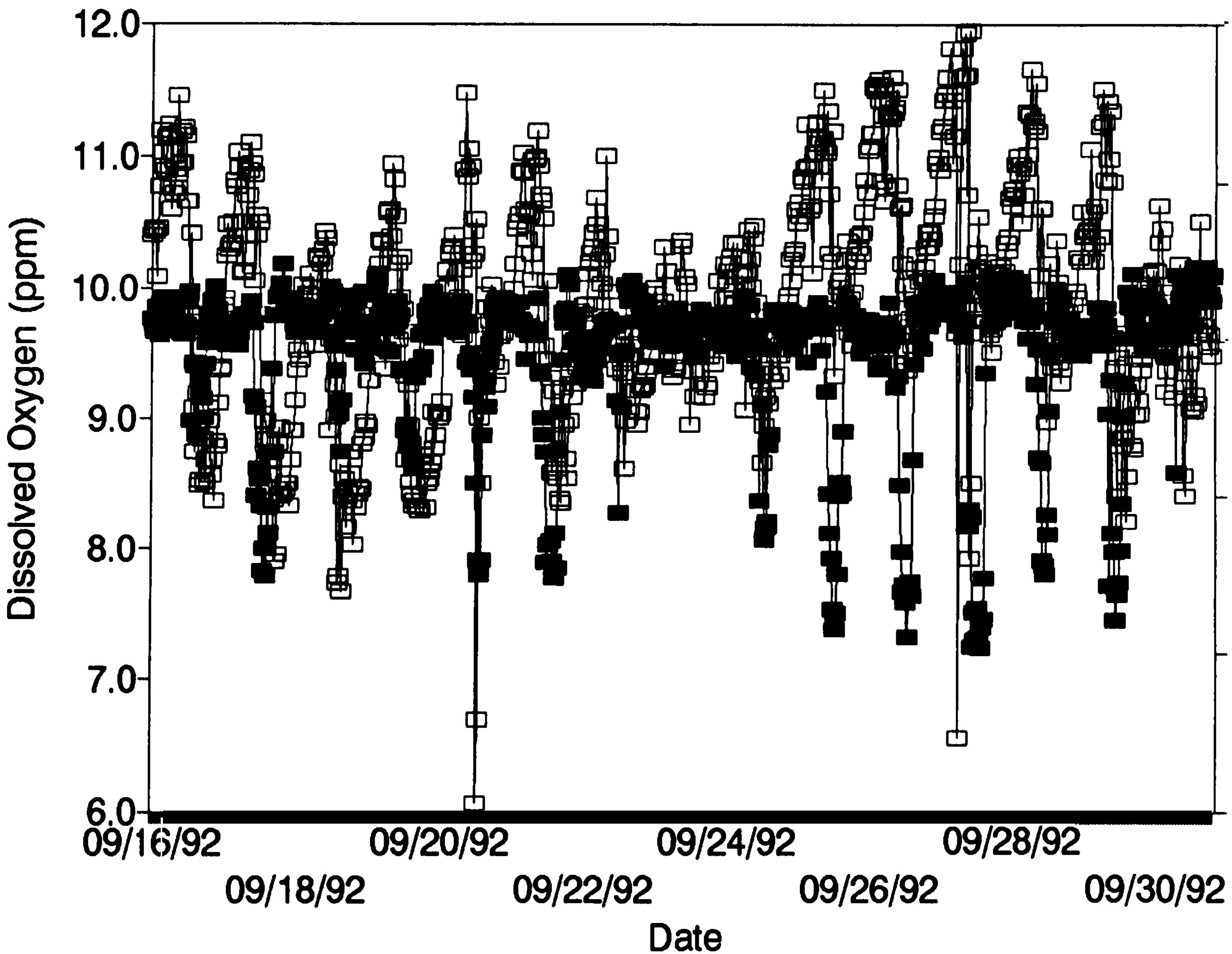
The changes in pH during a 24-hour period do not suggest a simple relationship with other water quality parameters. Similar patterns of pH changes occur in the normal density pond (A2) (Fig. 20) and the initial pond (El) in the Michigan series of ponds (Fig. 21). Load rates for these two ponds are 5.70 and 4.31 pounds fish per gallon per minute, respectively. The conformation of the raceway therefore seems to have little effect on pH changes in effluent water. However, in the second raceway of the series of Michigan ponds (Fl) (Fig. 21), pH was decreased for short intervals at about 1300 hours, then returned to a higher PH. In pond D2, where the load is higher, the decrease in pH is not as great as in pond Fl. This suggests that the inflow to pond Fl has been conditioned in some way to cause this greater decrease in pH.

The complex changes in the water quality of the hatchery pond during a 24-hour cycle shows the limitations of sampling at a single time point during the day. Daily or weekly averages do not indicate the magnitude or duration of fluctuations in water

Table 53. Weekly average pH from the inflow and outflou (0) of experimtd ponds, 8s measured by the data monitoring system at Willamette Hatchery, 1992.1993.

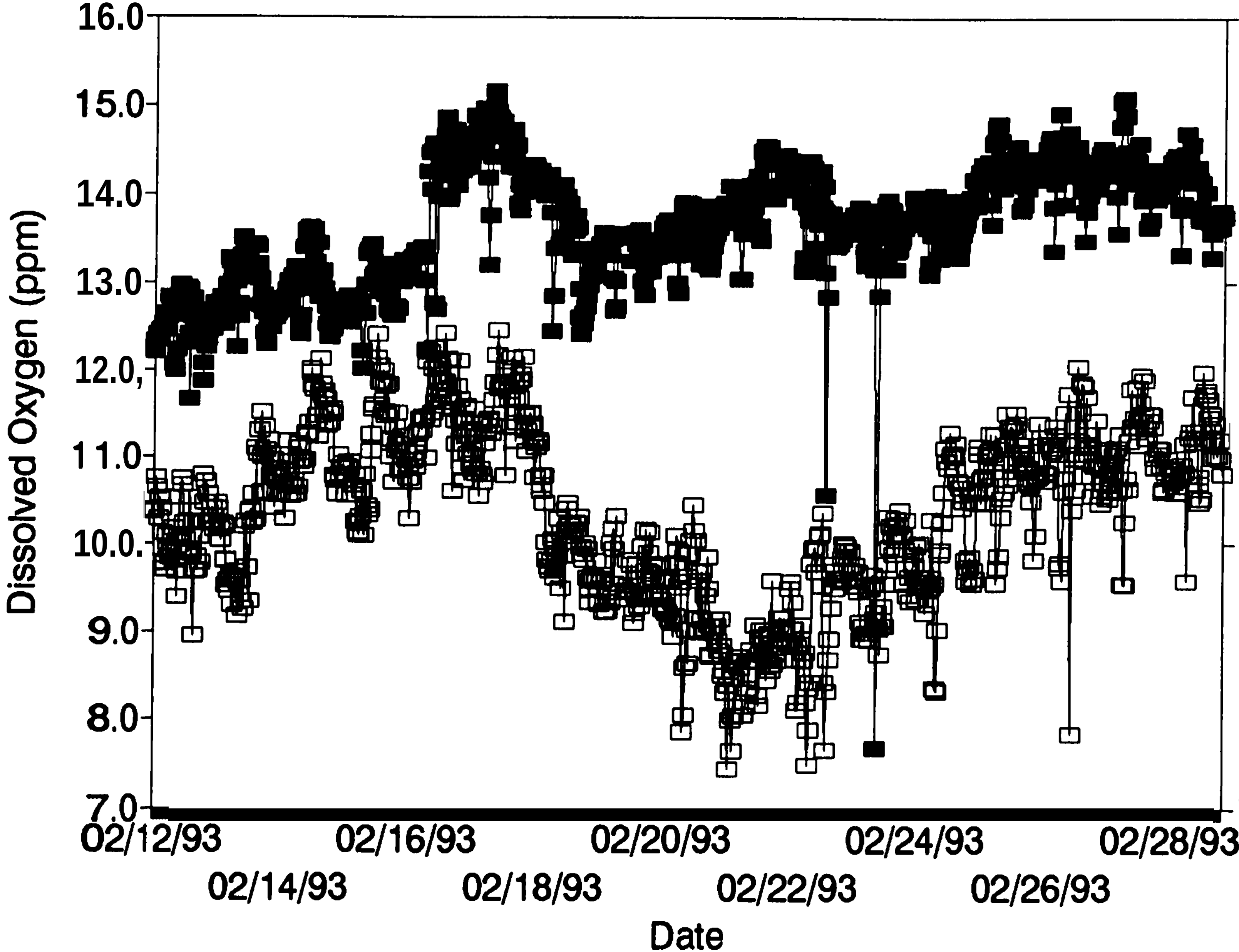
Date	Inflow	A2	B2	C2	D2	Inflow	E1	F1	G1	Temp.
08/02/92	7.58	7.59	7.64	7.61	7.63	7.64	7.58	7.57	7.63	16.6
08/09/92	7.59	7.62	7.65	7.61	7.64	7.67	7.58	7.59	7.61	15.5
08/16/92	7.94	7.93	7.90	7.81	7.50	8.19	7.76	7.61	7.27	16.6
08/23/92	7.92	7.94	7.89	7.79	7.52	8.19	7.76	7.62	7.27	15.1
08/30/92	7.93	7.94	7.90	7.80	7.52	7.99	7.76	7.62	7.28	13.9
09/06/92	7.92	7.94	7.89	7.79	7.53	7.93	7.76	7.62	7.28	13.6
09/13/92	7.75	7.76	7.73	7.70	7.58	7.85	7.67	7.53	7.36	12.3
09/20/92	7.66	7.66	7.65	7.66	7.60	7.80	7.63	7.47	7.40	11.8
09/27/92	7.66	7.66	7.64	7.65	7.59	7.80	7.62	7.46	7.39	11.8
10/04/92	7.65	7.65	7.63	7.59	7.61	7.73	7.58	7.41	7.34	11.1
10/11/92	7.64	7.65	7.63	7.56	7.61	7.69	7.56	7.36	7.31	9.7
10/18/92	7.64	7.65	7.62	7.55	7.60	7.69	7.55	7.37	7.31	8.8
10/25/92	7.64	7.66	7.63	7.56	7.60	7.69	7.56	7.37	7.31	9.3
11/01/92	7.63	7.65	7.62	7.55	7.52	7.69	7.56	7.37	7.31	8.8
11/08/92	7.63	7.65	7.62	7.55	7.46	7.69	7.56	7.37	7.31	7.8
11/15/92	7.62	7.63	7.60	7.53	7.52	7.69	7.54	7.36	7.30	6.1
11/22/92	7.58	7.47	7.42	7.33	7.25	7.68	7.38	7.26	7.17	6.4
11/29/92	7.62	7.45	7.45	7.40	7.27	7.57	7.39	7.26	7.10	6.1
12/05/92	7.62	7.45	7.45	7.40	7.27	7.57	7.39	7.26	7.10	6.0
01/31/93	7.64	7.35	7.37	7.37	7.29	7.51	7.39	7.31	7.30	4.3
02/07/93	7.64	7.34	7.37	7.37	7.29	7.51	7.38	7.29	7.29	5.2
02/14/93	7.56	7.42	7.40	7.37	7.31	7.60	7.36	7.31	7.12	5.5
02/21/93	7.54	7.42	7.38	7.35	7.31	7.60	7.36	7.30	7.10	3.3
02/28/93	7.57	7.43	7.40	7.36	7.31	7.61	7.37	7.28	7.08	3.2
03/07/93	7.57	7.43	7.41	7.38	7.29	7.61	7.37	7.28	7.07	5.2
03/15/93	7.57	7.44	7.42	7.39	7.31	7.62	7.44	7.38	7.31	6.3

Figure 18. Die1 changes in oxygen concentrations (-□-) and pH (-■-) at the outflow of pond D2 from 16 September 1992 to 30 September 1992.



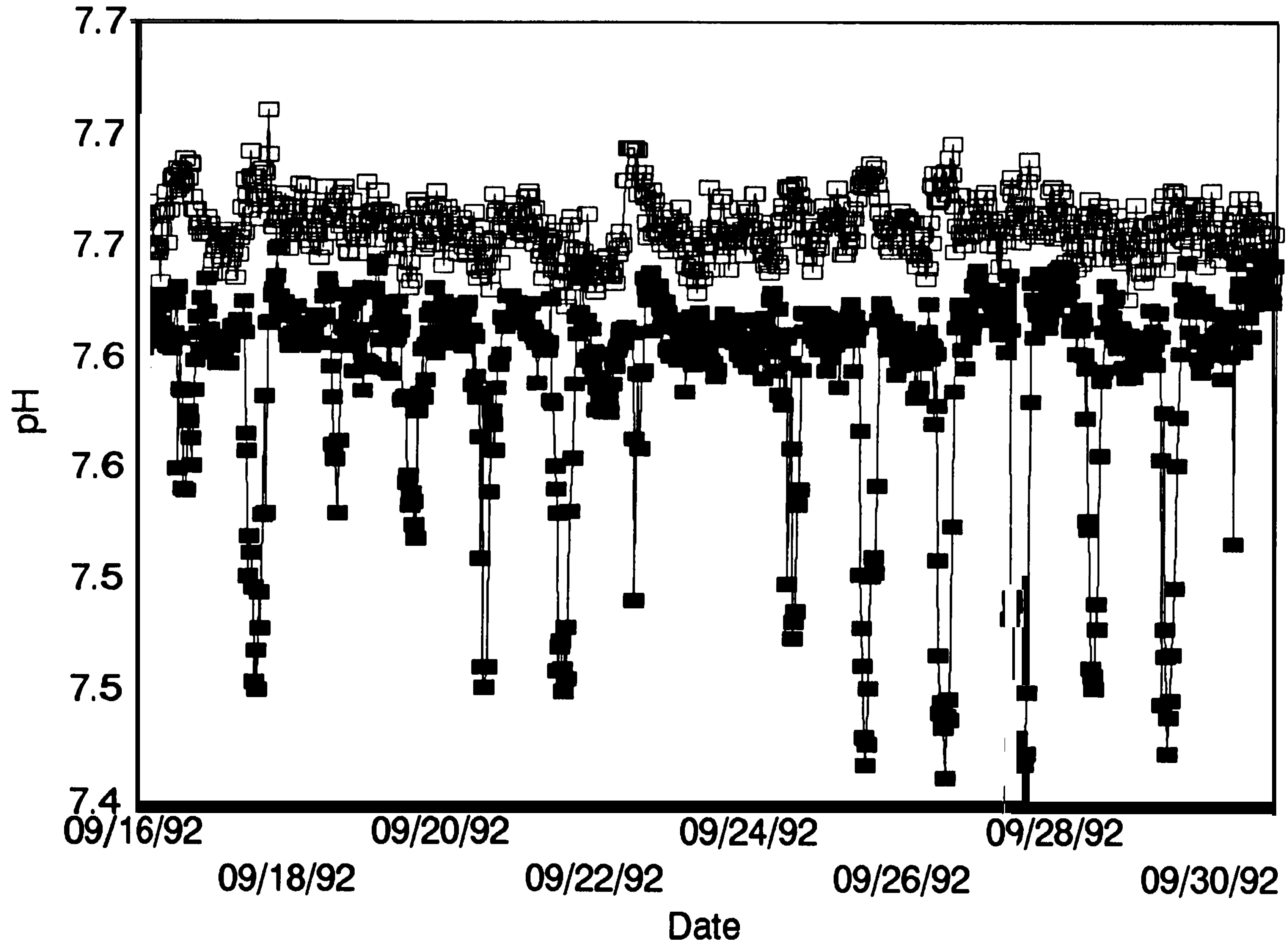
12.0
11.0
10.0
9.0
8.0
7.0
6.0
Dissolved Oxygen (ppm)
7.8
7.7
7.6
7.5
7.4
7.3
pH
09/16/92
09/18/92
09/20/92
09/22/92
09/24/92
09/26/92
09/28/92
09/30/92
Date

Fig. 19. Die1 changes in oxygen concentrations (-■-) and pH (-a-) at the outflow of pond D2 from 12 February 1993 to 28 February 1993.



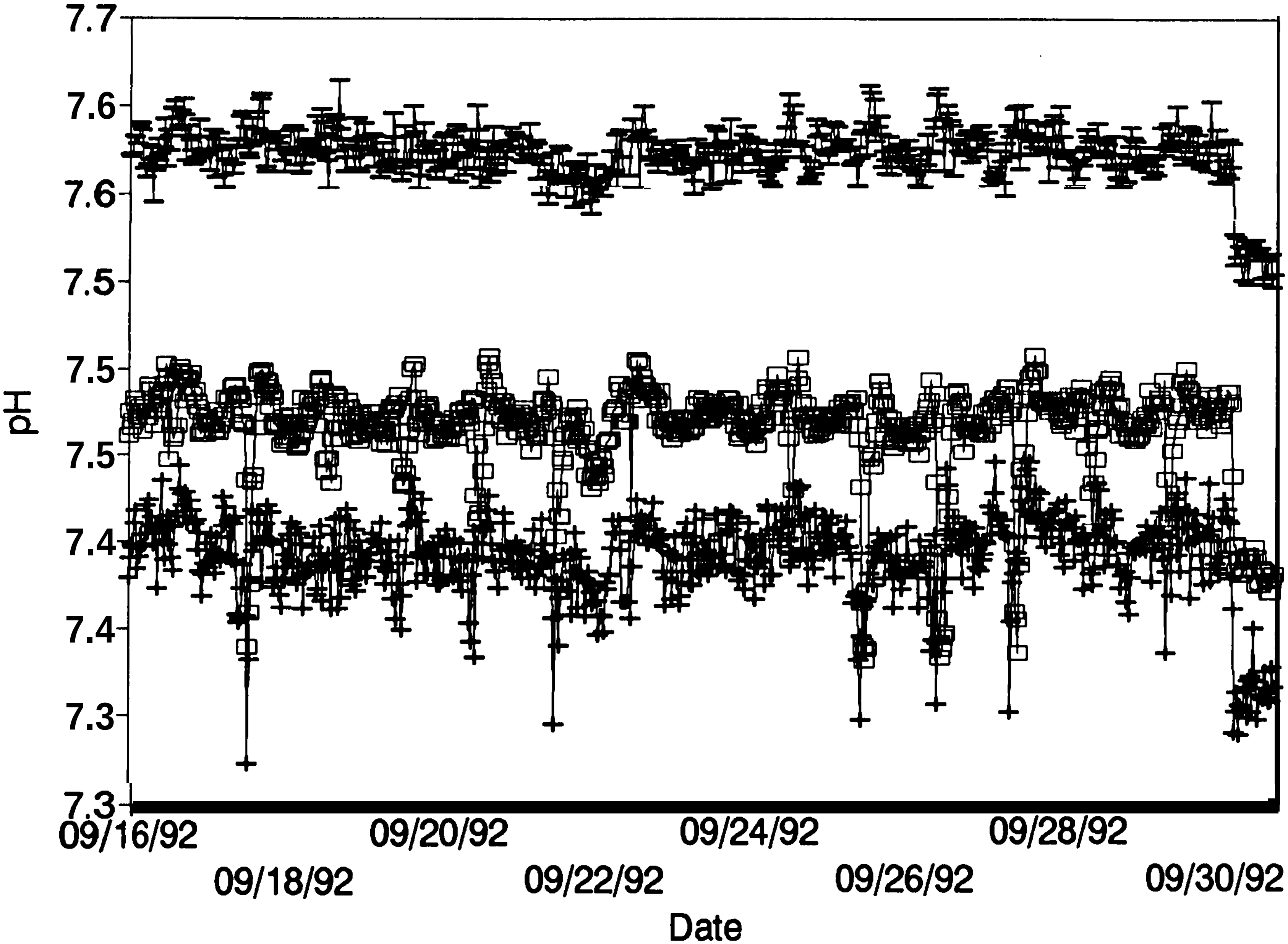
16.0
15.0
14.0
13.0
12.0,
11.0
10.0.
9.0
8.0
7.0
Dissolved Oxygen (ppm)
7.5
7.4
7.3
7.2
pH
02/12/93
02/14/93
02/16/93
02/18/93
02/20/93
02/22/93
02/24/93
02/26/93
02/28/93
Date

Figure 20. Die1 changes in pH at the outflow of ponds A2 (-a-) and D2 (-■-) from 16 September 1992 to 30 September 1992.



7.7
7.7
7.7
7.6
7.6
7.5
7.5
7.4
pH
09/16/92
09/18/92
09/20/92
09/22/92
09/24/92
09/26/92
09/28/92
09/30/92
Date

Figure 21. Die1 changes in pH at the outflow of ponds El (-■-), F1 (-□-) and G1 (-+-) from 16 September 1992 to 30 September 1992.



7.7
7.6
7.6
7.5
7.5
7.5
7.4
7.4
7.3
7.3
pH
09/16/92
09/18/92
09/20/92
09/22/92
09/24/92
09/26/92
09/28/92
09/30/92
Date

quality that may affect the physiology of the fish. As suggested by the review on cyclic changes in oxygen concentration, our knowledge of the effects of these cyclic changes in water quality on the behavior or performance of the fish is not known.

Alkalinity

Changes in alkalinity are important to the present experiment in that they reflect the ability of the surface water to buffer changes in pH resulting from production of metabolic CO_2. Analysis of variance ($P \leq 0.05$) did not show significant differences between alkalinity at the outflows from the different groups in the past two years (Swing and Sheahan 1991; Ewing and Sheahan, 1992) so analyses were reduced to three replicate samples of the incoming water (Table 54). Variations throughout the year were associated with rainfall. As the rainfall increased, alkalinity of the water decreased (correlation coefficient R = -0.553). Rainfall was slightly below normal for the 1991-1992 production season (Table 55).

Ammonia

The data for ammonia production (Table 56) were combined for replicate raceways in each group. Analysis of variance and Fisher least significant difference tests ($P< 0.05$) of the

Table 54. Water alkalinity (as mg $CaCO_3$/L) for the inflowing water at Willamette Hatchery, 1992-93.

Date	Samples 1	2	3	Average	Date	Samples 1	2	3	Average
08/04/92	32.9	32.9	32.3	32.7	12/01/92	24.2	24.2	24.2	24.2
08/11/92	33.9	34.5	34.5	34.3	12/03/92	23.1	23.1	23.1	23.1
08/25/92	34.5	34.5	34.5	34.5	12/08/92	25.7	25.7	25.7	25.7
08/27/92	34.5	34.5	34.5	34.5	12/10/92	24.2	24.2	24.2	24.2
09/01/92	34.5	35.0	35.0	34.8	12/14/92	26.8	26.8	26.3	26.6
09/03/92	35.0	35.5	35.0	35.2	12/22/92	26.8	26.8	26.8	26.8
09/08/92	32.9	32.9	32.9	32.9	12/24/92	27.8	27.3	27.8	27.7
09/10/92	34.5	34.5	34.5	34.5	12/28/92	26.3	26.3	26.3	26.3
09/15/92	35.0	34.5	34.5	34.6	12/30/92	27.3	27.3	27.3	27.3
09/17/92	35.0	34.5	35.0	34.8	01/04/93	28.4	28.4	28.4	28.4
09/22/92	35.0	35.0	35.0	35.0	01/12/93	28.9	28.9	28.9	28.9
09/24/92	33.9	33.4	33.4	33.6	01/14/93	29.4	28.9	28.9	29.1
10/01/92	34.5	35.0	34.5	34.6	01/19/93	29.4	29.4	29.4	29.4
10/06/92	35.0	35.0	35.0	35.0	01/21/93	24.7	24.7	24.7	24.7
10/08/92	36.0	35.5	35.5	35.7	01/26/93	24.7	24.7	24.7	24.7
10/13/92	35.0	35.5	35.0	35.2	01/28/93	25.2	25.2	25.2	25.2
10/15/92	35.5	35.0	35.0	35.2	02/02/93	26.8	26.8	26.8	26.8
10/20/92	35.5	35.0	35.0	35.2	02/04/93	25.7	25.7	25.7	25.7
10/22/92	35.0	35.0	35.0	35.0	02/09/93	24.2	24.2	24.2	24.2
10/27/92	35.5	35.5	35.5	35.5	02/11/93	24.7	24.7	24.7	24.7
10/29/92	33.4	33.9	33.9	33.7	02/16/93	26.3	26.3	26.8	26.4
11/03/92	27.0	26.5	27.0	26.9	02/18/93	27.3	27.3	27.3	27.3
11/05/92	29.7	29.2	29.2	29.3	03/02/93	28.4	28.4	28.4	28.4
11/10/92	29.4	28.9	28.9	29.1	03/04/93	25.7	25.7	25.7	25.7
11/12/92	28.9	28.4	28.9	28.7	03/09/93	21.5	21.5	21.5	21.5
11/17/92	27.8	27.8	27.8	27.8					
11/19/92	27.3	27.3	27.3	27.3					
11/24/92	24.2	24.2	24.2	24.2					

Table 55. Daily rainfall in inches at Willamette Hatchery for the rearing cycle from July 1992 to March 1993.

Day	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
1	0	0	0	0	0.48	0.53	0.16	0	0
2	0	0	0	0.04	0.50	0.96	T	0	0.35
3	0	0	0	0.42	0	0.22	T	0	0.15
4	0	0	0	0.01	0.07	0	0.02	T	0.22
5	0	0	0.08	0	0.24	0	0.03	0	0.25
6	0	0	0	0	0	0.05	0	0.04	0
7	0	0	0	0	0.54	0.31	0	0	0
8	0	0	0	0	0.42	0.29	T	0	0
9	0	0	0	0	0.70	1.16	0	0.09	0
10	0	0	0	0	0.04	1.12	0	0.03	0.25
11	0	0	0	0	0.06	0.07	0	0	0
12	0	0	0	0	0	0.36	0.17	0.17	0
13	0	0	0	0	0	0	0	0.06	0
14	0	0	0	0	0	0.04	T	0	0.09
15	0	0	0	0	0	0.27	T	0	0.70
16	0	0	0	0	0	T	T	0	0.85
17	0	0	0	0.10	0.07	0.73	T	0	0.75
18	0	0	0	0	0.16	0.18	0	T	0.77
19	0	0	0	0	0.48	T	0.60	0.46	0.25
20	0	0	0	0	0.49	0.48	1.30	0.46	0.25
21	0	0	0	0.89	0.39	0.45	0.32	0.53	0
22	0	0	0	0.04	1.45	0.11	0.92	0.76	0
23	0	0	0	0	0.50	T	0	0.05	0.69
24	0	0	0	0	0	0	0.32	0	0.34
25	0	0	0.49	0	0	0	0.06	0	0.25
26	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0.26	0	0	0	0
28	0	0	0	0	0	0.73	T	0	0
29	0	0	0	0.07	0	0.10	0		0
30	0	0	0	1.00	0.09	0.19	0		T
31	0	0		0.62		0.74	0		0

T = Trace amount of precipitation recorded.

Table 56. Unionized ammonia concentrations (µg/L) at the inflow and outflow of ● xperimental ponds at Willamette Hatchery, 1992-1993.

	Inflow	Inflow	A1	A2	B1	B2	C1	C2	D1	D2	Inflow	Inflow	E1	E2	F1	F2	G1	G2
08/04/92	0.02		0.23		0.08		0.12		0.26									
08/08/92		0.01		0.20		0.07		0.10		0.52		0.00		0.07		0.25		0.36
08/11/92	0.03		0.16		0.15		0.13		0.35		0.02		0.07		0.26		0.47	
08/18/92												0.03		0.17		0.45		0.5
08/25/92	0.01		0.26		0.11		0.22		0.56									
08/27/92		0.02		0.29		0.17		0.13		0.62		0.04		0.23		0.42		0.78
09/01/92	0.03		0.16		0.06		0.09		0.56		0.04		0.17		0.36		0.61	
09/03/92		0.04		0.24		0.15		0.14		0.51		0.03		0.29		0.39		0.50
09/08/92	0.01		0.17		0.03		0.11		0.38				0.17		0.31		0.54	
09/10/92		0.01		0.12		0.08		0.06		0.39		0.01		0.26		0.44		0.56
09/15/92	0.02		0.20		0.08		0.12		0.37		0.00		0.09		0.23		0.27	
09/17/92		0.03		0.19		0.14		0.14		0.31		0.03		0.18		0.32		0.51
09/22/92	0.01		0.29		0.16		0.17		0.53		0.03		0.16		0.24		0.47	
09/24/92		0.07		0.21		0.14		0.15		0.34		0.02		0.15		0.26		0.41
09/29/92											0.02		0.16		0.36		0.56	
10/01/92		0.02		0.19		0.12		0.13		0.34		0.02		0.22		0.37		0.62
10/06/92	0.03		0.11		0.06		0.10		0.24									
10/08/92		0.01		0.15		0.09		0.12		0.33		0.01		0.22		0.32		0.44
10/13/92	0.01		0.17		0.12		0.15		0.41		0.03		0.15		0.28		0.40	
10/15/92		0.02		0.14		0.10		0.12		0.41		0.02		0.17		0.23		0.40
10/20/92	0.02		0.09		0.07		0.07		0.28		0.01		0.13		0.40		0.50	
10/22/92		0.03		0.16		0.12		0.15		0.41		0.01		0.17		0.36		0.56
10/27/92	0.03		0.10		0.07		0.10		0.26		0.03		0.12		0.18		0.30	
10/29/92		0.01		0.10		0.07		0.13		0.42		0.01		0.19		0.37		0.50
11/03/92	0.02		0.09		0.03		0.06		0.18		0.00		0.16		0.31		0.37	

Table 56. (Cont.) Unionized ammonia concentrations (µg/L) at the inflow and outflow of experimental ponds at Willamette Hatchery, 1992-1993.

	Inflow	Inflow	A1	A2	B1	B2	C1	C2	D1	D2	Inflow	Inflow	E1	E2	F1	F2	G1	G2
11/05/92		0.00		0.04		0.02		0.04		0.17		0.00		0.10		0.23		0.33
11/10/92	0.02		0.11		0.07		0.14		0.29		0.03		0.08		0.19		0.23	
11/12/92		0.01		0.09		0.07		0.09		0.34		0.01		0.14		0.26		0.39
11/17/92	0.03		0.10		0.08		0.09		0.35		0.03		0.14		0.16		0.32	
11/19/92		0.00		0.04		0.05		0.03		0.11		0.01		0.06		0.13		0.16
11/24/92	0.02		0.06		0.04		0.06		0.14		0.01		0.16		0.20		0.24	
12/01/92	0.00		0.06		0.05		0.09		0.11		0.03		0.06		0.17		0.27	
12/03/92		0.04		0.09		0.06		0.10		0.16		0.04		0.11		0.20		0.24
12/08/92	0.01		0.05		0.06		0.07		0.13		0.01		0.08		0.12		0.32	
12/10/92		0.05		0.11		0.08		0.08		0.19		0.01		0.08		0.14		0.23
12/15/92											0.01		0.08		0.14		0.23	
12/17/92		0.02		0.07		0.06		0.05		0.11		0.01		0.06		0.15		0.17
12/22/92	0.03		0.07		0.04		0.08		0.18									
12/24/92		0.00		0.08		0.02		0.06		0.16		0.02		0.08		0.16		0.27
12/28/92	0.03		0.10		0.06		0.09		0.18		0.03		0.08		0.14		0.25	
12/30/92		0.04		0.10		0.06		0.09		0.24		0.01		0.08		0.19		0.24
01/05/93											0.04		0.10		0.21		0.26	
01/12/93	0.00		0.04		0.03		0.03		0.11									
01/14/93		0.01		0.05		0.02		0.03		0.07		0.01		0.03		0.10		0.15
01/19/93	0.01		0.03		0.04		0.03		0.09		0.02		0.05		0.12		0.13	
01/21/93		0.04		0.09		0.06		0.09		0.26		0.05		0.10		0.12		0.21
01/26/93	0.02		0.04		0.03		0.06		0.19		0.00		0.04		0.09		0.13	
01/28/93		0.04		0.12		0.07		0.11		0.17		0.04		0.16		0.23		0.31
02/02/93	0.03		0.12		0.04		0.15		0.20		0.01		0.05		0.11		0.16	
02/04/93		0.03		0.12		0.04		0.08		0.22		0.01		0.08		0.15		0.19

Table 56. (Cont.) Unionized ammonia concentrations (µg/L) at the inflow and outflow of ● xperimental ponds at Willamette Hatchery, 1992-1993.

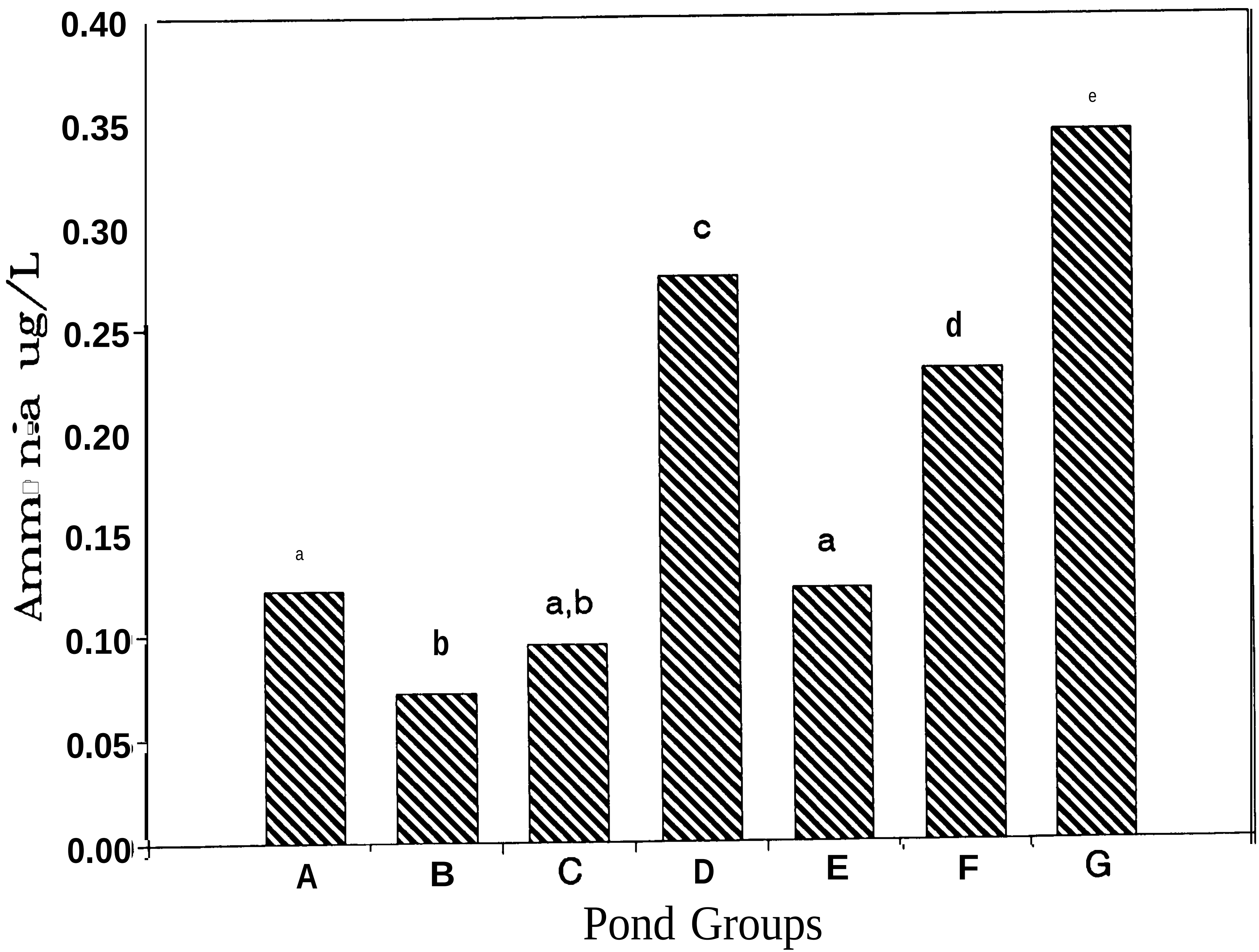
	Inflow	Inflow	A1	A2	B1	B2	C1	C2	D1	D2	Inflow	Inflow	E1	E2	F1	F2	G1	G2
02/09/93	0.02		0.11		0.06		0.07		0.20		0.03		0.12		0.24		0.31	
02/11/93		0.00		0.07		0.06		0.06		0.08		0.01		0.06		0.13		0.23
02/16/93	0.00		0.10		0.02		0.03		0.11		0.02		0.09		0.16		0.28	
02/18/93		0.02		0.05		0.04		0.05		0.07		0.01		0.06		0.11		0.15
02/23/93											0.01		0.04		0.07		0.16	
03/02/93	0.02		0.04		0.02		0.05		0.16									
03/04/93		0.03		0.13		0.09		0.08		0.17		0.03		0.09		0.13		0.22
03/09/93	0.02		0.07		0.07		0.08		0.16		0.04		0.05		0.12		0.21	

combined data indicated differences between groups (Figure 22). As the number of fish using a particular volume of water increased, the amount of ammonia in the water increased. The values obtained were well below the level of 0.0125 ppm considered detrimental to trout rearing (Smith and Piper 1975).

A preliminary study of cyclic changes in ammonia production was conducted on 02 March 1993. Samples were taken from the lower end of seven experimental ponds at hourly intervals for a period of 30 hours. Samples were placed on ice and transported to Corvallis for analysis of ammonium concentrations. Because pH was not monitored simultaneously, results were expressed as ammonium concentrations rather than ammonia concentrations.

Little evidence for a die1 pattern in ammonium excretion was observed after hourly sampling for a 30-hour period (Figs. 23, 24, and 25). Ammonium concentration increased in pond A2 from 0.1 mM to 0.25 mM from 1000 hours to 1800 hours, then remained relatively constant throughout the remaining 22 hours of sampling (Fig. 23). Ammonium levels in pond C2 remained constant at a slightly lower concentration (0.15 mM). Ammonium concentrations in pond B2 (Fig. 24) remained near that of pond A2, even though the density in pond A2 was twice that in B2. In pond D2, however, ammonium levels were nearly 2.5 times greater than those in pond A2 (Fig. 24). Michigan ponds showed increasing ammonium concentrations up to about 2200 hours, then constant levels throughout the rest of the sampling period (Fig. 25). Because the water is reused in series, ammonium concentrations increased with the passage of water through the series. Maximum levels of

Figure 22. Average ammonia concentrations (µg/L) at the outflow of experimental raceways at Willamette Hatchery, 1992-1993.



0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Ammonia ug/L
a
b
a,b
c
a
d
e
A
B
C
D
E
F
G
Pond Groups

Figure 23. Die1 changes in ammonium ions in the outflows of raceways containing groups A2 (-■-) and C2 (-+-). Samples were taken 02 March 1993.

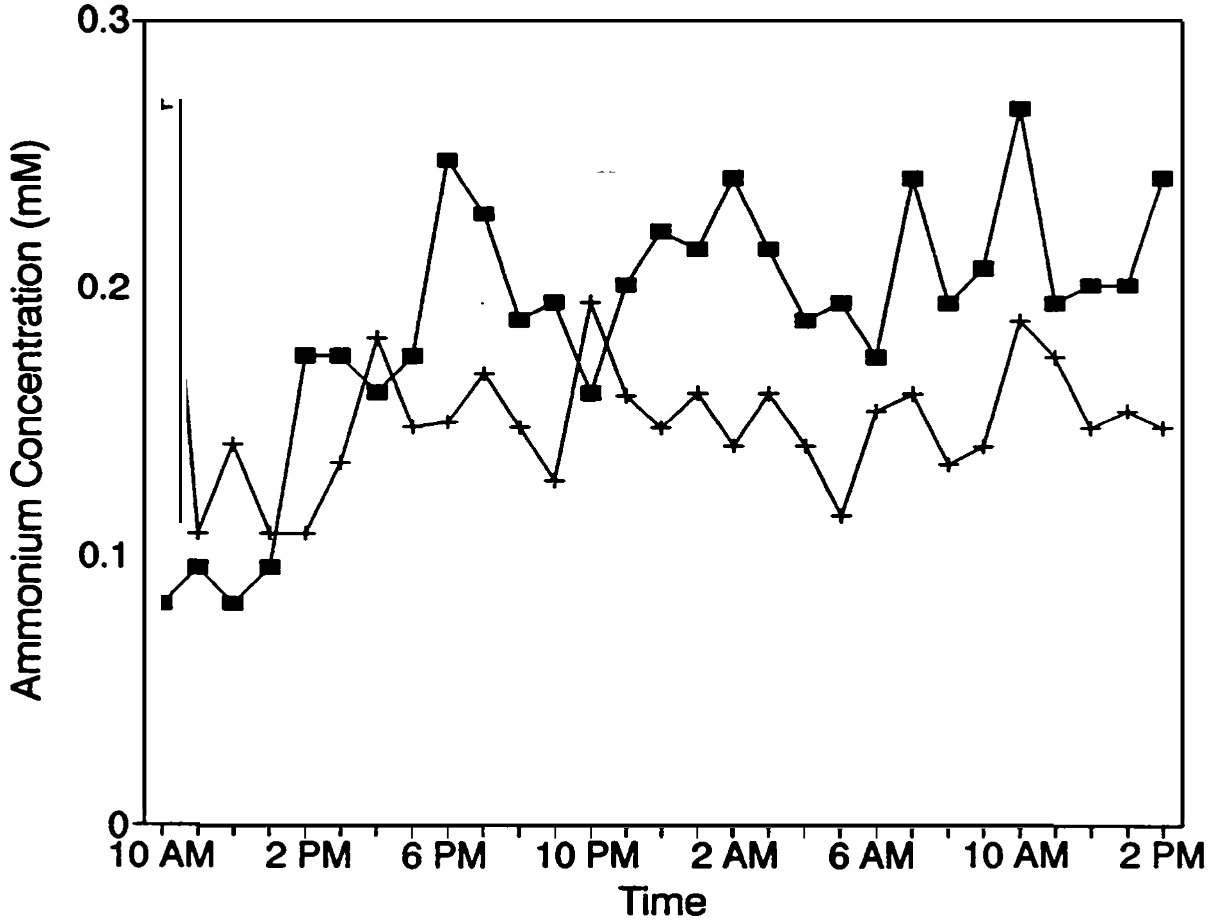
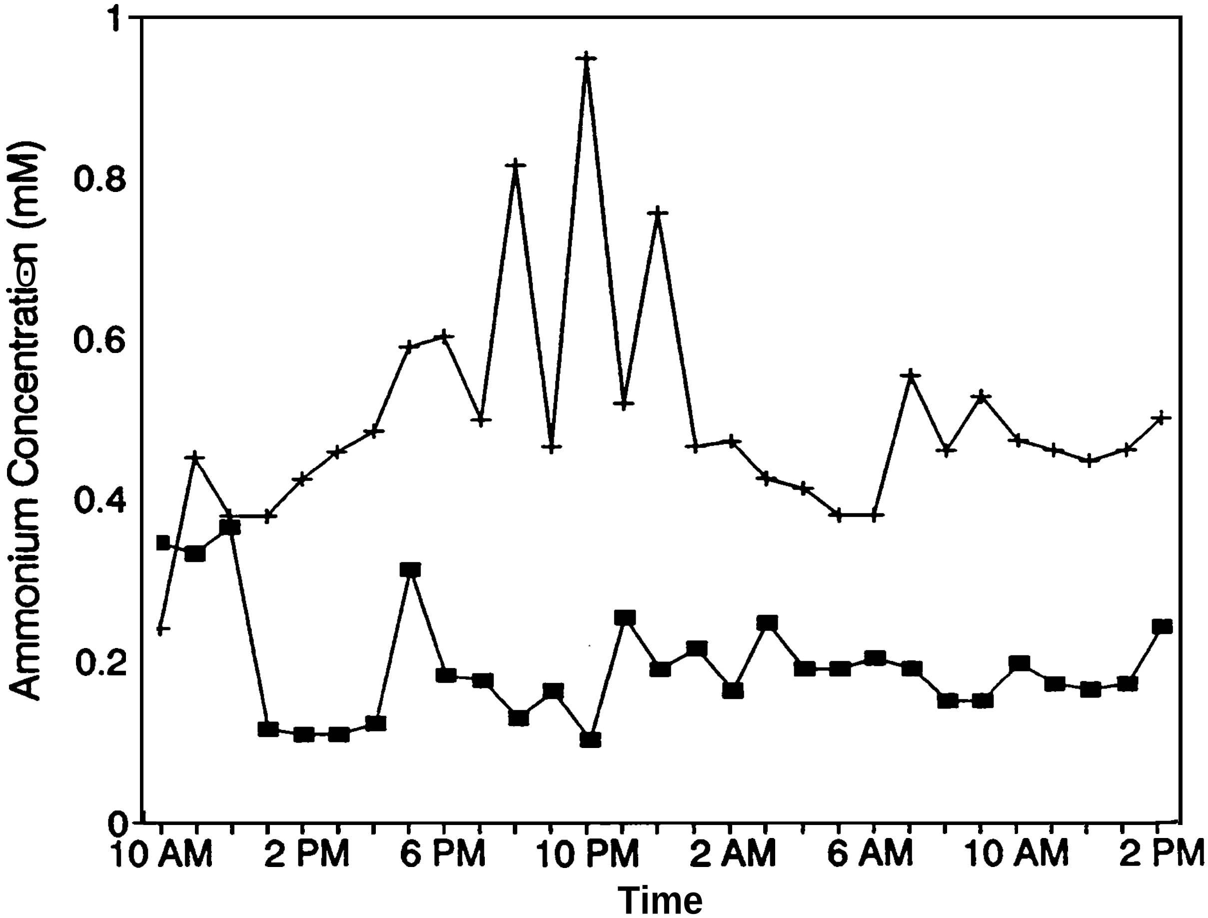
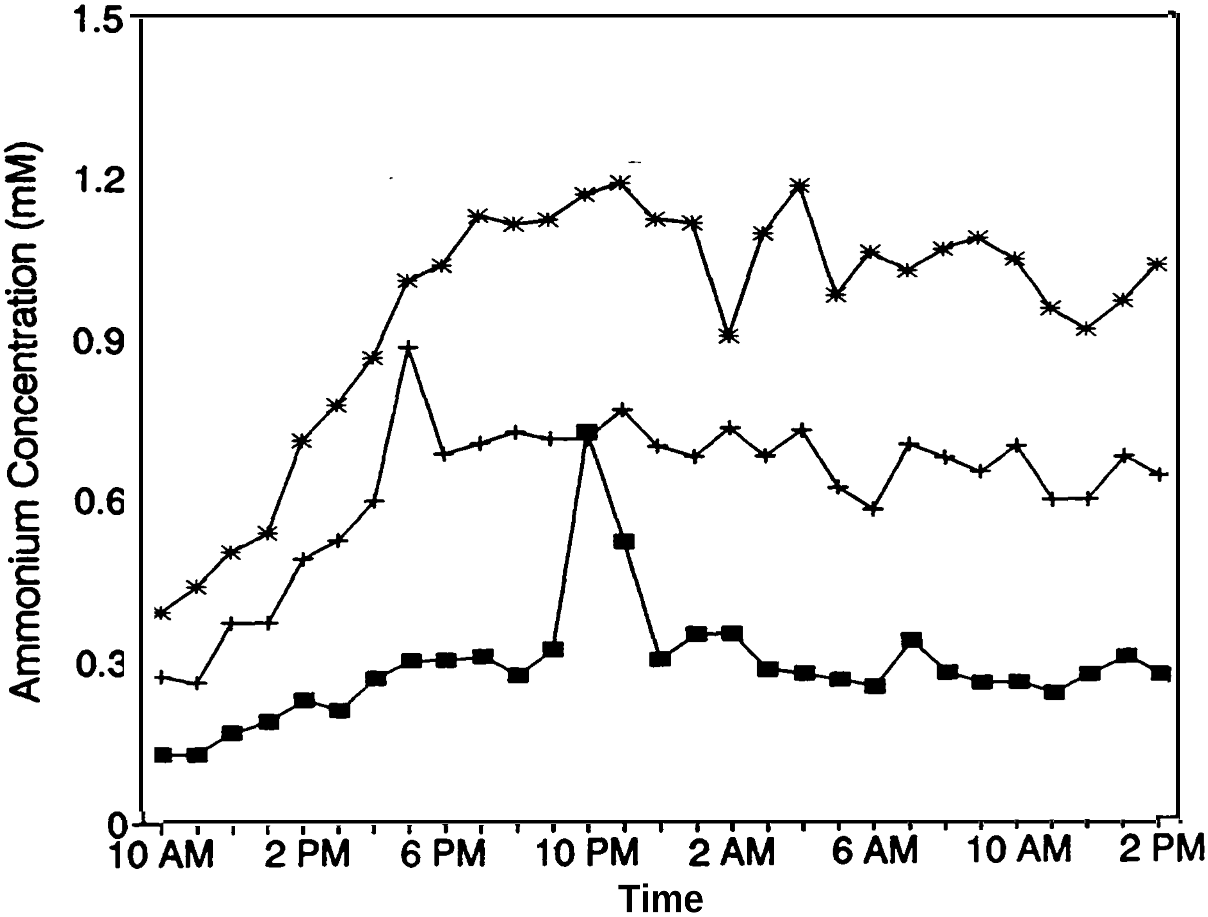

0.3
0.2
0.1
0
Ammonium Concentration (mM)
10 AM
2 PM
6 PM
10 PM
2 AM
6 AM
10 AM
2 PM
Time

Figure 24. Die1 changes in ammonium ions in the outflows of raceways containing groups B2 (-■-) and D2 (-+-). Samples were taken 02 March 1993..



Ammonium Concentration (mM)
1
0.8
0.6
0.4
0.2
0
10 AM
2 PM
6 PM
10 PM
2 AM
6 AM
10 AM
2 PM
Time

Figure 25. Die1 changes in ammonium ions in the outflows of raceways containing groups El (-■-), F1(-+-) and G1 (-✱-). Samples were taken 02 March 1993.


1.5
1.2
0.9
0.6
0.3
0
Ammonium Concentration (mM)
10 AM
2 PM
6 PM
10 PM
2 AM
6 AM
10 AM
2 PM
Time

ammonium ions reached about 0.3 mM in pond El, about 0.7 mM in pond Fl, and about 1.10 mM in pond Gl.

Solids

Data for suspended solids (Table 57) were combined from pairs of raceways for analysis. Analysis of variance showed a significant difference ($P \leq 0.05$) between groups. The significant difference obtained this year may reflect the increased sensitivity in the assay from the use of a Cahn microbalance. An increase in suspended solids occurs when rain or snow melt increases the erosion in the stream above the hatchery intake. Feeding is often curtailed because of the muddy water. During periods of heavy sediment, the ponds act as settling basins and decrease the amount of solids leaving the system. The solids are resuspended again during pond cleaning, subjecting the fish to heavy sediment loads once more. No attempt has been made to determine the suspended solid load during pond cleaning. The significance of solids in the incoming water to fish production is not clear at present.

Table 59. Lengths, weights, and hematocrits for 1991-brood spring chinook salmon released from Willamette Hatchery in March 1993.

Group	Tag code	Fish/kg	Average length (cm)	Average weight (g)	Average hematocrit
A1	07-59-21	20.4	15.68 ± 3.30	49.28 ± 2.41	40.0 ± 3.1
A2	07-59-22	20.9	15.63 ± 3.29	48.21 ± 3.09	41.0 ± 4.2
B1	07-59-35	19.9	15.58 ± 3.45	50.35 ± 2.89	40.7 ± 2.9
B2	07-59-36	21.1	15.53 ± 3.60	47.52 ± 3.36	39.7 ± 4.3
C1	07-59-23	18.5	15.40 ± 3.75	54.22 ± 3.71	38.9 ± 3.0
C2	07-59-24	20.6	15.44 ± 3.90	40.94 ± 4.05	41.1 ± 4.0
D1	07-59-25	20.7	15.39 ± 4.03	40.45 ± 3.38	38.2 ± 3.2
D2	07-59-26	21.2	15.34 ± 4.16	47.66 ± 5.15	40.3 ± 3.7
E1	07-59-27	26.7	15.29 ± 4.29	37.51 ± 1.96	40.6 ± 3.5
E2	07-59-28	28.7	15.24 ± 4.41	35.09 ± 3.14	38.9 ± 6.0
F1	07-59-29	26.3	15.19 ± 4.53	38.09 ± 2.04	30.7 ± 5.0
F2	07-59-30	27.3	15.14 ± 4.65	36.38 ± 2.32	29.4 ± 10.2
G1	07-59-31	25.4	15.09 ± 4.76	39.69 ± 3.02	39.9 ± 5.1
G2	07-59-32	28.7	15.04 ± 4.87	34.95 ± 2.00	36.7 ± 0.5
Dexter	07-59-33		14.99 ± 4.97		41.8 ± 3.4

Table 58. Data ● t liberation for 1991-brood spring chinook salmon released from Willamette Hatchery in March 1993.

Group	Tag code	Number tagged	Total (Inventory)	Total (Liberation)	Fish/kg	Fish loss (percent)	Final density	Final load
A1	07-59-21	32281	39235	37014	20.4	5.66%	1.08	8.00
A2	07-59-22	31708	39224	36480	20.9	7.00%	1.04	7.69
Average					20.6	6.33%	1.06	7.85
B1	07-59-35	19992	19788	19792	19.9	-0.02%	0.59	4.37
B2	07-59-36	19972	19663	19968	21.1	-1.55%	0.56	4.16
Average					20.5	-0.79%	0.58	4.27
C1	07-59-23	32117	39285	38211	18.5	2.73%	1.23	9.08
C2	07-59-24	31547	39673	38023	20.6	4.16%	1.10	8.13
Average					19.5	3.45%	1.17	8.61
D1	07-59-25	31538	118121	101943	20.7	13.70%	2.92	21.62
D2	07-59-26	31506	119008	105792	21.2	11.11%	2.97	21.97
Average					21.0	12.40%	2.95	21.80
E1	07-59-27	31523	58836	42883	26.7	27.11%	1.91	4.71
E2	07-59-28	31829	57708	44016	28.7	23.73%	1.82	4.50
Average					27.7	25.42%	1.87	4.61
F1	07-59-29	31597	57992	50580	26.3	12.78%	2.28	5.63
F2	07-59-30	31503	55687	47500	27.3	14.70%	2.07	5.10
Average					26.8	13.74%	2.18	5.37
G1	07-59-31	31569	58764	52786	25.4	10.17%	2.04	6.10
G2	07-59-32	31420	56939	49191	28.7	13.61%	2.47	5.03
Average					27.0	11.89%	2.26	5.57
Dexter	07-59-33	31647						
	07-59-34	31505						

Fish Culture

Liberation Data

Liberation data for various experimental groups are shown in Tables 58 and 59. Total numbers of fish released were different by the two accounting methods of pond inventories and water displacement in liberation trucks. In general, numbers estimated from liberation truck displacements were lower than those estimated from pond inventories and mortality counts. Similar differences between the two inventory methods were observed last year (Ewing and Sheahan, 1991). In the previous annual report (Ewing and Sheahan, 1990), we described unaccounted losses in all ponds that varied from 0.1% to 20.3% of the initial populations in the ponds. At the time we suggested that errors in population estimates from fish displacement in the liberation trucks probably would not account for these unexplained losses. We suggested a high level of avian predation.

We concluded from data presented last year (Ewing and Sheahan, 1991) (Appendix G) that the major source of unaccounted "loss" in the raceways probably arose from the inaccuracy of determining the weight of fish in a pond. Predation, at least during the 1991-1992 rearing cycle, seemed insignificant. While the greatest source of error is probably the determination of the fish size, the errors involved in estimation of total weight of

Table 57. (Cont.) Suspended solids (mg/L) at the inflow and outflow of experimental ponds at Willamette Hatchery, 1992-1993.

	Inflow	Inflow	A1	A2	B1	B2	C1	C2	D1	D2	Inflow	Inflow	E1	E2	F1	F2	G1	G2
02/04/93		1.5		1.5		2.2		1.3		2.3		1.3		1.8		2.2		2.5
02/09/93			1.5		0.2		1.5		2.3		1.7		1.8		1.8		2.3	
02/11/93		1.3		1.5		2.0		1.5		1.8		1.7		1.7		2.7		2.7
02/16/93	1.2		1.0		0.8		1.2		2.2		0.8		1.0		1.0		1.3	
02/18/93		0.8		0.7		0.5		1.0		1.0		1.2		1.0		0.7		0.7
03/02/93	1.0		0.8		1.0		0.8		1.3		1.8		1.2		1.5		1.7	
03/04/93		4.0		3.8		3.2		3.2		3.5		4.5		4.3		3.8		3.3
03/09/93	2.7		2.5		2.8		2.7		3.8		4.0		3.7		3.3		3.2	

Table 57. (Cont.) Suspended solids (mg/L) at the inflow and outflow of experimental ponds at Willamette Hatchery, 1992-1993.

	Inflow	Inflow	A1	A2	B1	B2	C1	C2	D1	D2	Inflow	Inflow	E1	E2	F1	F2	G1	G2
10/29/92		0.7		0.8		0.5		0.7		1.2		1.0		1.3		1.0		0.8
11/03/92	1.2		1.8		2.0		2.5		2.0		2.0		2.0		2.3		2.7	
11/05/92		2.5		1.2		0.8		1.5		1.3		2.0		2.3		2.0		1.7
11/10/92	0.8		0.3		0.0		0.7		1.5		1.2		2.0		1.0		1.8	
11/12/92		0.5		0.2		0.7		0.5		0.8		0.7		0.7		1.8		1.7
11/17/92	0.5		0.3		0.3		1.0		2.7		0.5		1.2		1.2		1.0	
11/19/92		0.8		0.8		1.2		1.2		1.5		1.0		1.0		1.2		1.5
11/24/92	1.7		1.7		1.0		2.3		2.0		1.7		1.7		3.2		7.5	
12/01/92	1.0		1.2		0.7		0.8		1.3		1.3		1.2		2.0		3.0	
12/03/92		1.5		4.0		1.8		2.5		2.5		2.3		3.3		3.0		3.8
12/08/92	0.5		0.5		0.2		0.8		1.2		1.2		1.0		1.2		1.8	
12/10/92		12.2		11.5		10.7		11.7		12.0		13.5		15.0		10.5		7.8
12/17/92		1.5		4.0		1.8		0.7		1.5		1.5		1.3		1.2		1.2
12/22/92	1.5		1.5		0.7		1.8		3.8		1.5		1.8		3.2		5.3	
12/24/92		1.2		1.2		0.7		1.5		1.3		0.7		3.2		1.2		2.0
12/29/92	2.0		1.5		1.7		1.8		2.3		1.7		2.0		2.8		3.0	
12/30/92		1.7		1.3		1.3		1.3		3.5		1.3		1.5		4.0		3.7
01/07/93		1.0		0.8		1.2		1.3		2.2		1.0		1.3		1.3		2.2
01/12/93	0.5		0.7		1.2		0.8		0.8		0.7		0.5		0.7		1.0	
01/14/93		1.0		0.8		1.2		1.2		1.2		1.5		1.0		1.0		1.2
01/19/93	1.2		1.0		0.5		0.8		0.3		0.7		1.2		0.3		0.8	
01/21/93		4.7		4.7		4.5		4.7		5.2		4.7		5.8		5.3		7.3
01/26/93	2.0		1.8		2.0		1.7		2.8		2.5		2.2		2.0		2.2	
01/28/93		1.8		1.8		1.7		2.3		2.5		2.3		3.0		6.7		4.5
02/02/93	1.8		0.8		1.5		1.3		2.7		1.3		1.3		2.5		3.2	

Table 57. Suspended solids (mg/L) at the inflow and outflow of experimental ponds at Willamette Hatchery, 1992-1993.

	Inflow	Inflow	A1	A2	B1	B2	C1	C2	D1	D2	Inflow	Inflow	E1	E2	F1	F2	G1	G2
08/04/92	1.3		0.0		0.0		0.5		1.7		1.2		0.5		1.2		1.0	
08/08/92		0.0		0.2		0.1		0.1		0.5		0.0		0.1		0.3		0.4
08/25/92	1.0		1.0		0.8		1.5		2.3		1.0		1.7		1.2		8.0	
08/27/92		1.0		1.0		1.0		1.3		2.0		0.7		1.0		0.8		1.5
09/01/92	0.8		1.8		1.2		1.2		3.7		1.0		0.5		1.7		2.0	
09/03/92		0.7		1.2		0.8		0.5		0.8		1.0		0.7		1.2		1.2
09/08/92	1.7		1.5		0.5		2.3		2.7		0.8		0.8		1.0		1.3	
09/10/92		0.7		0.7		0.5		0.8		1.3		0.5		0.7		1.8		1.8
09/15/92	0.3		0.5		0.5		0.5		0.7		0.7		0.1		0.8		0.8	
09/17/92		0.8		1.2		0.7		0.8		1.3		0.7		1.2		1.7		1.5
09/22/92	1.0		1.5		0.8		0.8		1.2		0.7		1.2		1.7		0.7	
09/24/92		4.8		3.2		3.0		3.2		3.3		4.8		3.8		3.3		3.2
10/01/92	0.7		0.9		1.5		0.9		1.0		1.0		1.3		1.0		1.2	
10/06/92	0.8		1.0		0.5		1.0		1.2		1.0		0.8		0.8		1.7	
10/08/92		0.3		0.8		0.7		0.7		0.5		0.7		1.2		1.7		1.2
10/13/92	0.5		1.5		1.0		0.8		1.0		0.6		0.1		1.0		1.0	
10/15/92		0.3		0.8		0.8		0.5		0.8		0.5		0.3		0.8		1.2
10/20/92	0.5		0.5		0.5		0.5		1.5		0.5		0.7		1.0		2.0	
10/22/92		0.8		0.7		1.3		1.0		1.5		0.8		1.3		1.5		1.5
10/27/92	0.3		0.7		0.7		0.3		3.5		0.5		0.8		0.8		1.2	

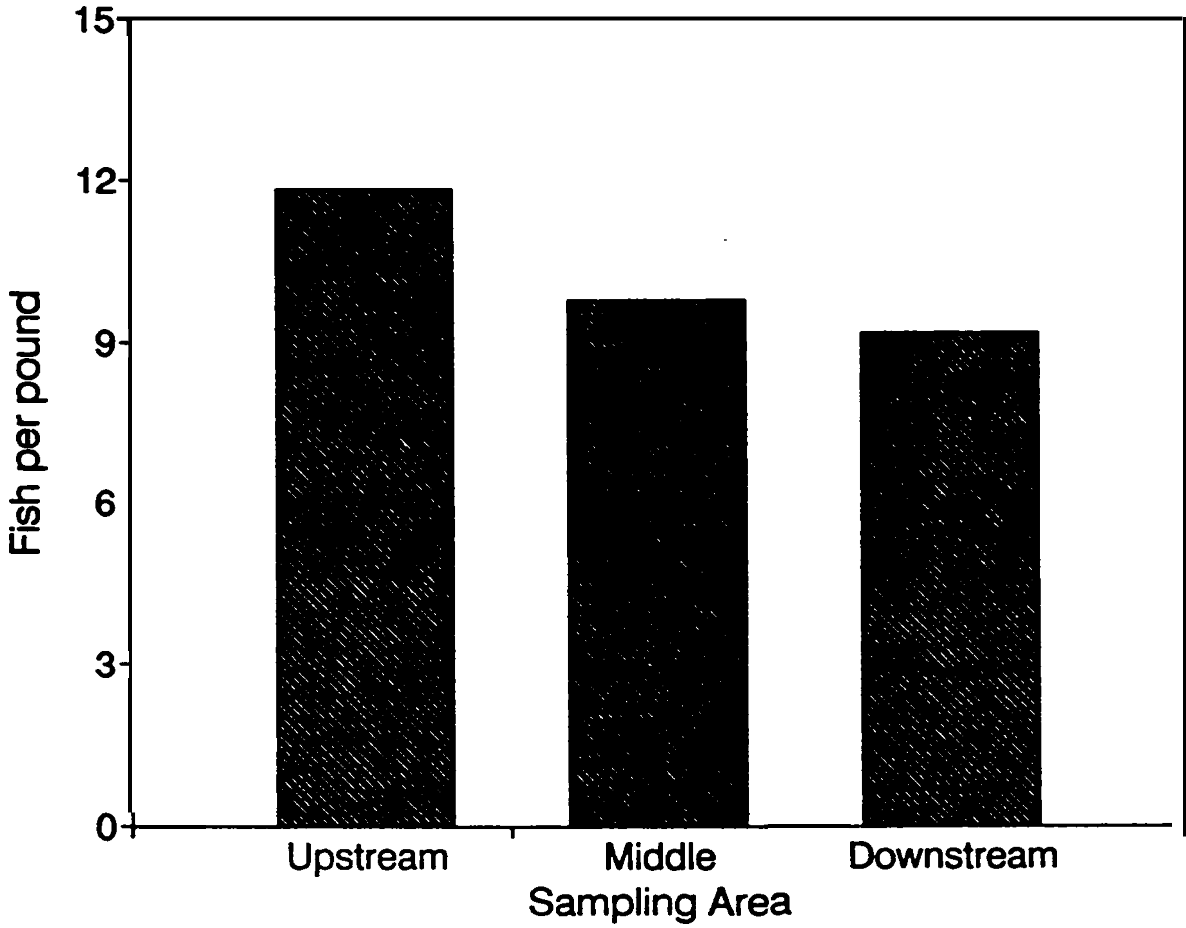
fish through displacement of water in the liberation truck still need further investigation.

Additional information on pond sampling was obtained during monthly determinations of fish weights. The location of the samples for fish weights was noted for each measurement. No differences in the size of the fish (in fish per pound) was found in different locations in the low density raceways (groups A2, B2, and C2). In the high density raceway (group D2), smaller fish were found at the upstream end of the raceway (Fig. 26).

In the Michigan pond series, compartments were numbered from 1 (at the upstream end) to 6 (at the downstream end) and the sizes of the fish sampled from each compartment were noted. All groups (groups E1, F1, and G1) tended to have smaller fish in compartment 1 and larger fish in compartments 3 and 4 (Fig. 27). For the best measurements of fish size in these raceways, samples are needed from all compartments. Further study of the distribution of fish in the Michigan ponds is certainly warranted.

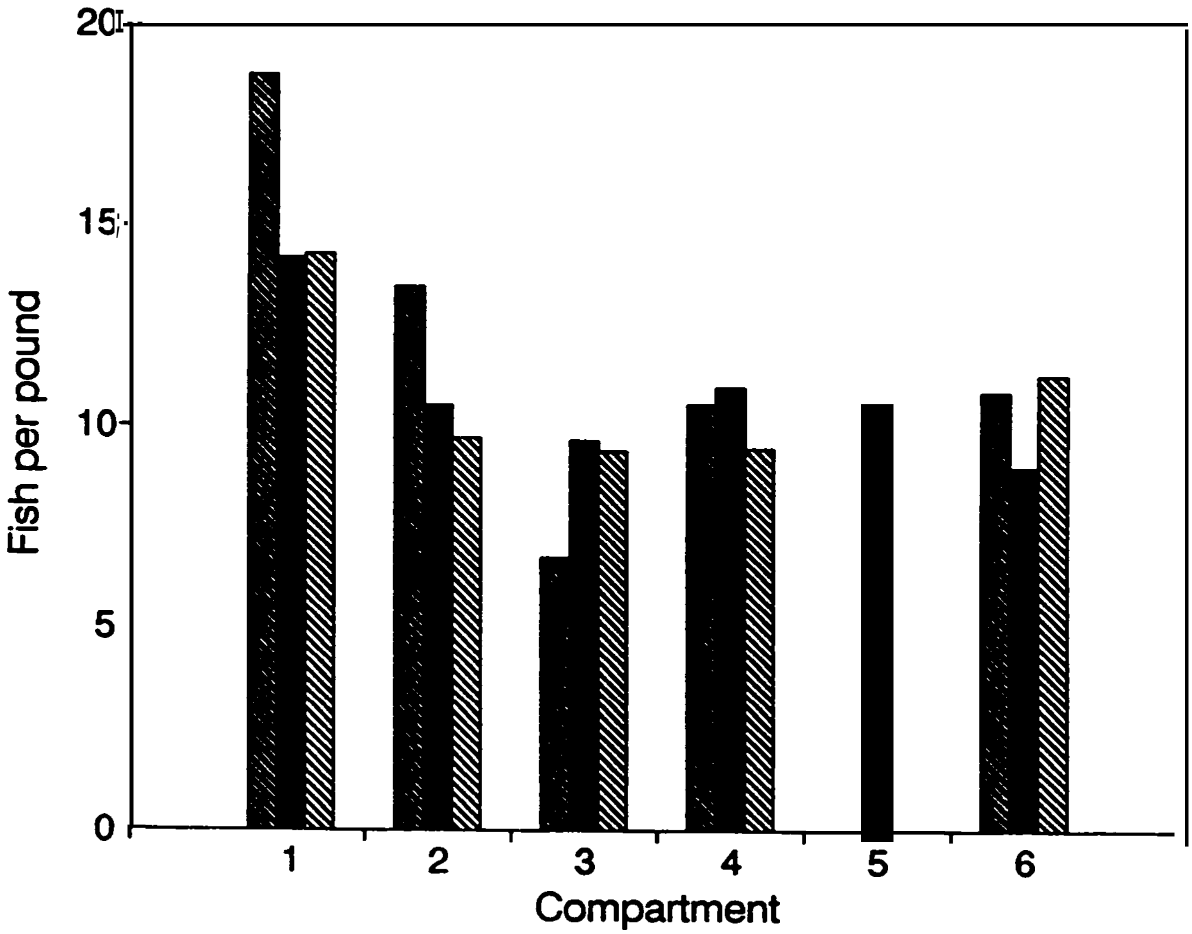
Condition factors of fish at release were not significantly different ($P \leq 0.05$). Hematocrits from fish from various groups at release, however, were significantly different ($P \leq 0.05$) (Table 60). Fish in Group F had hematocrits significantly lower than those in all other groups. This was primarily due to the low hematocrit levels in group F2, probably due to the incidence of bacterial kidney disease in that pond. No apparent pattern is

Figure 26. Size of juvenile chinook salmon in different areas of raceway D2 crowded for pond sampling on February 23, 1993. Values are means of 3 samples.



15
12
9
6
3
0
Fish per pound
Upstream
Middle
Downstream
Sampling Area

Figure 27. Size of juvenile chinook salmon captured in different compartments of Michigan ponds E2 (heavy bars, F1 (solid bars), and G1 (light bars) on 23 February 1993. Upstream end is designated compartment number 1. Values are means of l-3 samples.



20
15
10
5
0
Fish per pound
1
2
3
4
5
6
Compartment

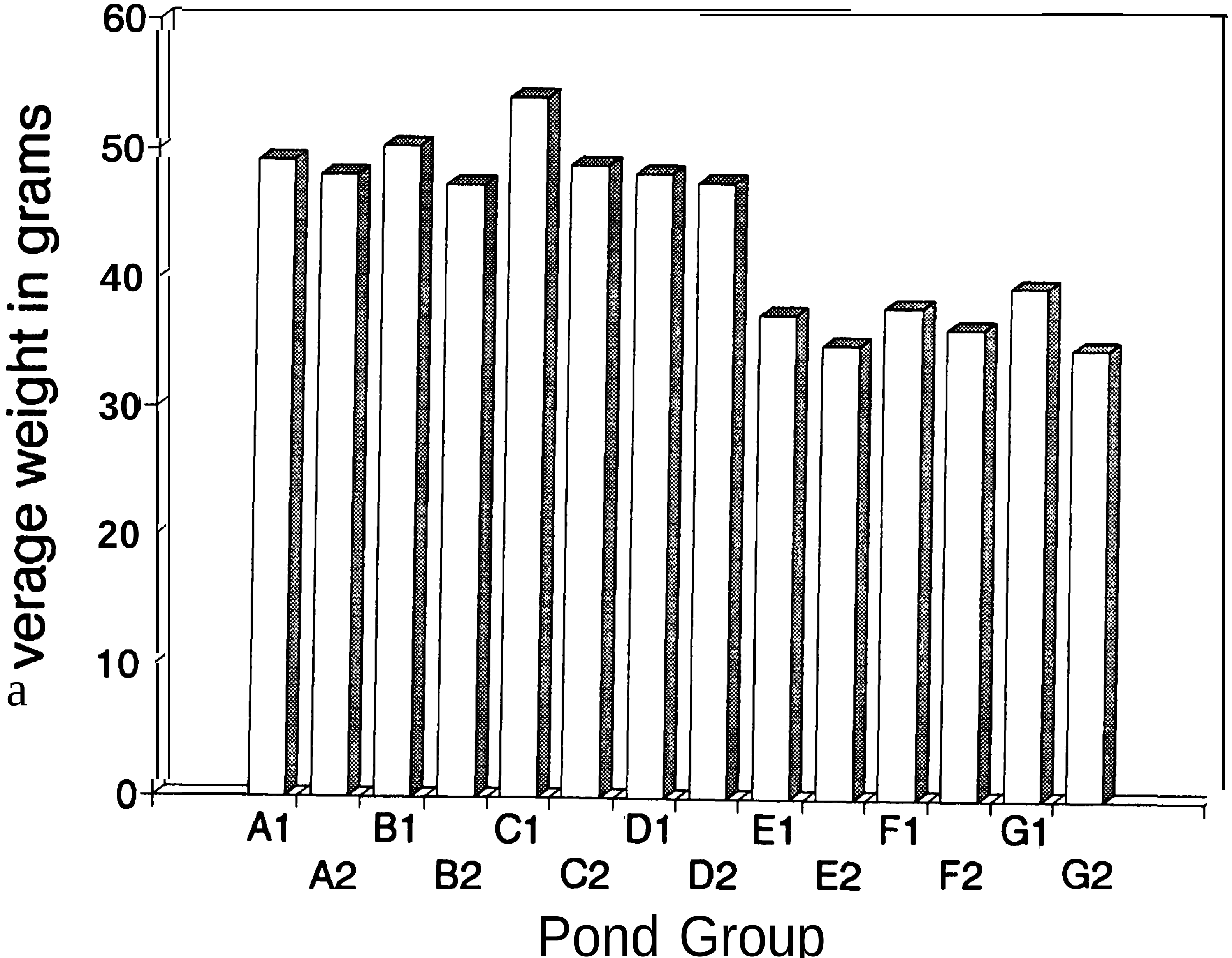
yet detectable between density or oxygen levels and blood hematocrits levels.

A significant difference ($P \leq 0.05$) in fish weight at release was observed between the groups (Fig. 28). This result was not desirable because changes in fish size at release can affect the subsequent survival of the juveniles to adulthood (Johnson 1970; Hagar and Noble 1976; Reisenbichler et al. 1982). However, the differences were small and should have little influence on survival.

These differences in fish size affected the final densities and loads in a number of ponds. Groups E, F, and G were all less than originally projected due to the smaller fish size in these groups (Table 60). Final densities and loads for Groups A, B and D were similar to those projected in the experimental design (Table 49).

Mortalities for all ponds were low and similar before January 1993 (Table 61). An increase in mortality was noted just prior to release due to infection by bacterial kidney disease (BKD). An increased loss of fish due to BKD was also observed at the Dexter holding pond. A sample of 60 fish was taken from each pond just prior to release for analysis of BKD levels by enzyme linked immunosorbent assays (ELISAs). Optical densities of less than 0.100 were classified as non-detectable because of background interference. Low, medium and high levels of BKD were defined by ranges of optical densities of 0.100-0.199, 0.200-0.499 and greater than 0.499, respectively. The percent of fish sampled in each of the low, medium and high groups are shown in

Figure 28. Average weight at release of juvenile chinook salmon from experimental ponds at Willamette Hatchery, 1993.



60
50
40
30
20
10
0
average weight in grams
A1
A2
B1
B2
C1
C2
D1
D2
E1
E2
F1
F2
G1
G2
Pond Group

Table 60. Comparison between ideal experimental conditions (listed in Table 49) and actual loads and densities at the time of release of experimental groups of spring chinook salmon from Willamette Hatchery in March 1993.

Group	Density (pounds/cubic foot)		Load (pounds/gallon/minute)	
	Ideal	Actual	Ideal	Actual
A_1	0.97	1.08	7.20	8.00
A2		1.04		7.69
B_1	0.49	0.59	3.60	4.37
B_2		0.56		4.16
C_1	0.97	1.23	7.20	9.08
C2		1.10		8.13
D_1	2.92	2.92	21.60	21.62
D2		2.97		21.97
E_1	2.92	1.91	7.20	4.71
E_2		1.82		4.50
F_1	2.92	2.28	7.20	5.63
F_2		2.07		5.10
G_1	2.92	2.04	7.20	6.10
G2		2.47		5.03

Table 61. Observed mortality recorded by month and group of juvenile spring chinook salmon reared in experimental ponds at Willamette Hatchery, 1992-1993[a].

Group	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Total
Al	171	20	16	11	66	20	18	27	68	433
A2	68	23	20	28	25	32	29	33	128	386
B1	85	70	10	2	4	22	7	10	66	276
B2	128	33	29	32	25	28	20	23	96	414
Cl	184	8	12	18	12	19	12	12	58	335
c2	57	27	26	46	34	30	26	29	102	377
D1	275	48	62	45	30	33	41	71	98	703
D2	177	169	83	75	63	81	108	52	120	928
El	175	57	25	37	13	62	64	44	133	610
E2	225	46	25	18	31	66	251	569	423	1654
F1	288	24	43	37	48	39	96	55	122	752
F2	1062[b]	58	59	24	38	62	328	1331	755	3717
G1	211	36	55	36	37	49	53	32	167	676
G2	213	56	57	26	26	26	239	1009	677	2329

[a]Fifteen fish were sacrificed each month for smolt quality assays from ponds A2, B2, C2, D2, El, F1, and G1.
[b]A group of 750 fish were lost to suffocation due to pump failure.

Fig 62. Groups E2, F2, and G2 all had a significant percentage of the fish in the medium and high level categories. All the fish in these groups came from the same batch of eggs. If the levels of BKD affect survival, the yields from these ponds can be compared with those from groups El, F1, and G1 to determine the effect of the BKD infection.

Growth

Fish were ponded in experimental raceways after tagging from 1 July 1991 to 31 July 1991. Sizes varied somewhat between raceways at ponding (Table 63).

Monthly growth of the fish was measured in three different ways (Ricker 1975). Absolute growth is shown in Table 64, relative growth is shown in Table 65, and instantaneous growth rate is given in Table 66. The large variations in growth between months resulted from a lack of precision in the pond counts. From work performed at this site and other hatcheries (Appendix A), it may not be possible to achieve a level of precision in pond counts sufficient to provide accurate monthly growth rates. The difference between the initial weight at ponding and the final weight at liberation may therefore provide a better comparison between raceways than a month-by-month comparison.

Monthly food conversions for each experimental pond are shown in Table 67. The large variations and negative values

Table 62. Mean optical density of groups of fish tested for BKD by ELISA and the percentage of fish that contained non-detectable, low, medium and high levels of BKD. Non-detectable levels are defined as optical densities less than 0.100. Low, medium and high levels are defined as optical densities of 0.100-0.199, 0.200-0.499, and greater than 0.499, respectively.

Group	Mean Optical Density	Percent in category: Non-detect	Low	Medium	High
Al	0.086	78.3	21.7	0.0	0.0
A2	0.098	62.7	35.6	1.7	0.0
B1	0.093	78.0	22.0	0.0	0.0
B2	0.085	88.3	11.7	0.0	0.0
Cl	0.097	70.0	28.0	2.0	0.0
C2	0.083	91.7	8.3	0.0	0.0
D1	0.088	86.7	13.3	0.0	0.0
D2	0.089	88.3	11.7	0.0	0.0
E1	0.118	56.7	36.7	5.0	1.7
E2	0.486	10.0	36.7	33.3	20.0
F1	0.093	80.0	20.0	0.0	0.0
F2	0.897	22.0	20.3	15.3	42.4
G1	0.109	80.0	15.0	3.3	
G2	0.597	26.7	33.3	8.3	3:::

Table 63. Starting weights and numbers for juvenile spring chinook introduced into the experimental ponds in July 1992 at Willamette Hatchery.

Group	Number/kg	Total Weight (kg)	Number
Al	98.8	399.2	39,437
A2	109.8	360.2	39,542
B1	92.6	215.1	19,919
B2	97.2	204.7	19,201
Cl	103.6	380.6	39,436
c2	97.7	409.4	39,993
D1	94.8	1250.3	118,549
D2	93.9	1274.8	119,759
El	89.8	660.3	59,271
E2	100.3	589.5	59,137
F1	97.2	601.2	58,456
F2	113.3	514.9	58,342
G1	107.1	552.8	59,229
G2	107.8	548.4	59,115

Table 64. Absolute change in weight in grams per month for spring chinook salmon reared in experimental raceways at Willamette Hatchery 1992-93.

Group	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Overall growth
Al	9.9	13.0	5.2	3.9	2.5	-0.4	4.4	0.6	39.0
A2	12.0	11.6	5.1	1.3	-2.5	5.8	6.0	-0.6	38.8
	11.0	12.3	5.2	2.6	0.0	2.7	5.2	0.0	38.9
B1	12.0	7.9	9.5	3.9	-2.0	1.6	6.0	0.5	39.4
B2	12.3	7.3	3.7	3.3	4.0	5.4	0.0	1.0	37.0
	12.2	7.6	6.6	3.6	1.0	3.5	3.0	0.7	38.2
Cl	9.6	12.9	3.9	6.8	-1.2	5.2	2.9	4.3	44.3
c2	12.2	8.6	7.2	3.1	0.0	2.4	7.1	-2.2	38.4
	10.9	10.8	5.6	5.0	-0.6	3.8	5.0	1.0	41.4
D1	9.3	10.7	5.8	5.7	-1.9	6.2	-4.2	6.0	37.7
D2	8.7	9.3	7.4	2.4	2.1	-0.4	2.1	4.9	36.6
	9.0	10.0	6.6	4.1	0.1	2.9	-1.1	5.5	37.1
El	9.9	3.8	15.0	-2.9	-1.7	2.6	-2.1	1.6	26.3
E2	7.9	5.8	9.6	1.3	-1.0	-2.3	3.0	0.7	24.9
	8.9	4.8	12.3	-0.8	-1.4	0.2	0.5	1.1	25.6
F1	8.9	7.2	5.4	6.4	0.3	0.3	-0.7	-0.2	27.7
F2	9.7	9.0	4.7	8.3	-5.1	3.3	2.1	-4.3	27.8
	9.3	8.1	5.0	7.4	-2.4	1.8	0.7	-2.3	27.77
G1	8.4	8.6	8.9	5.3	-6.4	4.0	0.7	0.6	30.1
G2	9.9	6.0	7.0	6.3	0.3	-0.7	3.1	-6.5	25.6
	9.2	7.3	7.9	5.8	-3.0	1.7	1.9	-3.0	27.8

Table 65. Relative change in weight in grams per month for spring chinook salmon reared in experimental raceways at Willamette Hatchery, 1992-93.

Group	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Overall growth
Al	0.98	0.65	0.16	0.10	0.06	-0.01	0.10	0.01	3.85
A2	1.32	0.55	0.16	0.03	-0.06	0.16	0.14	-0.01	4.26
	1.15	0.60	0.16	0.07	0.00	0.07	0.12	0.00	4.06
B1	1.12	0.34	0.31	0.10	-0.05	0.04	0.14	0.01	3.65
B2	1.20	0.32	0.12	0.10	0.11	0.13	0.00	0.02	3.60
	1.16	0.33	0.22	0.10	0.03	0.09	0.07	0.02	3.62
Cl	1.00	0.67	0.12	0.19	-0.03	0.12	0.06	0.09	4.59
c2	1.19	0.38	0.23	0.08	0.00	0.06	0.16	-0.04	3.75
	1.09	0.53	0.18	0.14	-0.01	0.09	0.11	0.02	4.17
D1	0.88	0.54	0.19	0.16	-0.04	0.15	-0.09	0.14	3.57
D2	0.82	0.48	0.26	0.07	0.05	-0.01	0.05	0.12	3.43
	0.85	0.51	0.22	0.11	0.00	0.07	-0.02	0.13	3.50
El	0.89	0.18	0.60	-0.07	-0.05	0.07	-0.06	0.05	2.36
E2	0.79	0.32	0.41	0.04	-0.03	-0.07	0.10	0.02	2.49
	0.84	0.25	0.50	-0.02	-0.04	0.00	0.02	0.03	2.43
F1	0.86	0.38	0.20	0.20	0.01	0.01	-0.02	-0.01	2.69
F2	1.10	0.49	0.17	0.26	-0.13	0.09	0.05	-0.11	3.15
	0.98	0.43	0.19	0.23	-0.06	0.05	0.02	-0.06	2.92
G1	0.90	0.48	0.34	0.15	-0.16	0.12	0.02	0.01	3.22
G2	1.07	0.32	0.28	0.19	0.01	-0.02	0.08	-0.16	2.75
	0.98	0.40	0.31	0.17	-0.07	0.05	0.05	-0.07	2.99

Table 66. Instantaneous rate of change in weight in grams per month for spring chinook salmon reared in experimental raceways at Willamette Hatchery, 1992-1993.

Group	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Overall growth
Al	0.30	0.22	0.06	0.04	0.02	0.00	0.04	0.01	0.71
A2	0.37	0.19	0.06	0.01	-0.03	0.06	0.06	-0.01	0.72
	0.33	0.20	0.06	0.03	0.00	0.03	0.05	0.00	0.70
B1	0.33	0.13	0.12	0.04	-0.02	0.02	0.06	0.00	0.67
B2	0.34	0.12	0.05	0.04	0.04	0.05	0.00	0.01	0.66
	0.33	0.13	0.08	0.04	0.01	0.04	0.03	0.01	0.66
Cl	0.30	0.22	0.05	0.08	-0.01	0.05	0.03	0.04	0.75
c2	0.34	0.14	0.09	0.03	0.00	0.02	0.07	-0.02	0.68
	0.32	0.18	0.07	0.05	-0.01	0.04	0.05	0.01	0.71
D1	0.27	0.19	0.08	0.06	-0.02	0.06	-0.04	0.06	0.66
D2	0.26	0.17	0.10	0.03	0.02	0.00	0.02	0.05	0.65
	0.27	0.18	0.09	0.05	0.00	0.00	-0.01	0.05	0.65
El	0.28	0.07	0.20	-0.03	-0.02	0.03	-0.02	0.02	0.53
E2	0.25	0.12	0.15	0.02	-0.01	-0.03	0.04	0.01	0.54
	0.26	0.10	0.18	-0.01	-0.01	0.00	0.02	0.02	0.54
F1	0.27	0.14	0.08	0.08	0.00	0.00	-0.01	0.00	0.57
F2	0.32	0.17	0.07	0.10	-0.06	0.04	0.02	-0.05	0.62
	0.30	0.16	0.08	0.09	-0.03	0.02	0.01	-0.03	0.60
G1	0.28	0.17	0.13	0.06	-0.07	0.05	0.01	0.01	0.63
G2	0.32	0.12	0.11	0.08	0.00	-0.01	0.03	-0.07	0.57
	0.30	0.15	0.12	0.07	-0.04	0.02	0.02	-0.03	0.60

Table 67. Food conversion of spring chinook salmon reared in experimental raceways at Willamette Hatchery, 1992-1993. Conversions are based on pond reports at the end of each month.

Group	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
A1	1.39	1.03	1.43	1.62	2.28	-7.93	1.10	1.56
A2	1.17	1.01	1.65	4.65	-2.31	0.84	0.88	1.71
B1	1.21	1.34	1.06	1.75	-2.68	2.92	1.04	0.43
B2	1.24	1.37	2.57	2.10	1.70	0.87	-58.61	3.16
C1	1.44	0.99	2.23	0.88	-4.12	0.90	1.71	0.44
C2	1.19	1.19	1.21	1.91	-175.63	1.97	0.73	0.62
D1	1.33	1.10	1.45	1.00	-2.65	0.62	-0.96	-0.45
D2	1.39	1.29	1.20	2.35	3.04	-9.81	1.92	1.24
E1	1.05	2.53	0.67	-1.72	-2.43	0.98	-1.56	-0.15
E2	1.33	1.78	1.02	4.03	-4.17	-1.05	1.20	-0.31
F1	1.23	1.38	1.82	0.95	16.01	12.21	-4.84	-0.30
F2	1.05	1.10	1.89	0.68	-0.84	0.88	2.88	-0.18
G1	1.20	1.21	1.12	1.07	-0.67	0.72	5.49	-0.61
G2	1.02	1.73	1.47	0.94	15.19	-3.30	1.37	-0.17

resulted from lack of precision in the pond counts. Monthly food conversions are therefore probably of little value unless the error in determining pond counts can be reduced. This problem is greater in the winter months when cold temperatures can result in negative weight gains for the fish. Overall food conversions are probably of greater importance to this study. Overall weight gain and feed conversion for the 1990-1991 and 1991-1992 rearing years are compared in Table 68. When the overall feed conversions were combined for all years, analysis of variance ($P < .05$) showed that group E was significantly higher than all other groups while groups F and G were significantly higher than groups C and D. Edsall and Smith (1990) found that oxygen levels of 187% saturation had no effects on weight gain or feed conversion of rainbow trout. The higher flows in the Michigan ponds may increase the food conversion rate of fish reared in this system. More energy would be required to maintain position in the higher flows.

Feed conversions for individual months have another problem in their calculation. The change in biomass of the fish per month is never completely known because the number of fish in the pond is never certain. The observed mortality can be obtained through routine records but the loss of fish to predators or other unknown causes is not obtainable unless the entire pond is inventoried. There is presently no estimate of the number of predators feeding at the Willamette hatchery.

Table 68. Overall feed conversion by group for rearing years 1990-1991, 1991-1992, and 1992-1993.

Group	1990-1991	1991-1992	1992-1993	Group Average
Al	1.70	1.69	1.61	1.76
A2	2.13	1.77	1.69	
B1	1.57	1.72	1.56	1.76
B2	2.22	1.80	1.70	
Cl	1.72	1.78	1.36	1.68
c2	1.60	2.04	1.56	
D1	1.60	1.70	1.72	1.68
D2	1.70	1.59	1.76	
El	2.11	2.15	2.93	2.38
E2	1.77	2.34	2.96	
F1	1.93	2.09	2.20	2.00
F2	1.71	1.89	2.21	
G1	1.90	1.89	1.88	2.00
G2	1.93	1.90	2.47	

Length frequencies

Length frequencies were obtained in July during tagging, September, December and February. Skewness as a measure of symmetry around the mean showed a signficant difference between groups A and C and group E. This was primarily due to the low values of ponds A2, Cl and C2 and the high values of pond E2 (Table 69). No apparent pattern was found with density or treatment groups.

Table 69. Skewness values from length frequency data for spring chinook salmon in various experimental raceways at Willamette Hatchery, 1992-1993. Positive values indicate the population is skewed to the smaller sizes and negative values indicate the population is skewed to the larger sizes.

Group	Jul	Sep	DeC	Feb
Al	-0.310	0.063	-0.130	0.007
A2	0.144	0.616	0.451	0.258
Bl	-0.647	0.204	0.096	0.127
B2	-0.026	0.651	0.346	0.701
Cl	-0.172	0.747	0.323	0.461
c2	-0.810	0.860	0.986	0.822
Dl	0.351	0.372	0.323	0.309
D2	-0.449	1.138	1.077	1.058
El	-1.209	0.752	0.917	1.053
E2	0.245	0.328	0.869	0.821
Fl	-0.332	0.364	0.760	0.668
F2	-0.283	0.096	0.496	0.226
Gl	-0.037	0.301	0.524	0.272
G2	-0.398	0.533	0.414	0.553

SMOLT QUALITY ASSESSMENT

Introduction

In the Columbia River Fish and Wildlife Program (1987), the Northwest Power Planning Council emphasized the importance of improving the effectiveness of hatcheries through the release of better-quality smolts. Section 703(e)5 calls for development of "a sensitive, reliable index for predicting smolt quality and readiness to migrate. The index shall be validated by conducting a test using a selected species and selected hatcheries." The Hatchery Effectiveness Technical Work Group suggested an activity 4.1.1: "Select and monitor through the rearing cycle, fish quality indices at four or more spring chinook hatcheries, and correlate these with performance indicators including survival through the adult state."

A study was funded from 1989 to 1992 by the Bonneville Power Administration to address these concerns. The study, Smolt Quality Assessment of Spring Chinook Salmon, Project No. 89-046, sampled fish from five hatcheries in the Columbia River basin to determine smolt characteristics. One of these hatcheries was Willamette Hatchery. The sampling design at Willamette Hatchery, however, did not address some of the more interesting issues concerning the effect of oxygen supplementation on smolting. During the first year of the study, no fish from the oxygen supplementation study were available. During the next two years, budget constraints permitted sampling of only two of the seven experimental groups in the Oxygen Supplementation Project.

In 1992-1993, we began sampling of all seven experimental groups of chinook salmon in the study for hematocrits, condition factor, liver glycogen and triglycerides, gill (Na+K)-ATPase activity, and plasma thyroxine, cortisol and glucose. This sampling extended the data base from the previous Smolt Quality Assessment project to provide a continuous three-year record of smolting in some of the experimental groups at Willamette Hatchery. It also provided a comparison of smolting in fish reared under the seven experimental conditions described in Table 48. Data will also be used to correlate migration rate and survival to adulthood with the degree of smolting exhibited at Willamette Hatchery as this data becomes available.

This report describes the results from the first year of sampling for smolt quality parameters at Willamette Hatchery.

Materials and Methods

Groups of 15 fish were sampled from the lower half of each of seven experimental raceways using a long-handled dipnet. Experimental groups are described in Table 48. Dipnet sampling was examined by the Smolt Quality Assessment study (1989) and found to provide representative samples from raceways. To minimize stress, groups of 10 or less fish were netted and sampled at any one time. The fish were transferred immediately to a bucket containing 200 mg/L MS-222 and 1 ml 5M imidazole/L and killed with an overdose of anesthetic to prevent changes in physiological parameters due to stress.

Fish were measured, weighed, and visually judged to be parrs, smolts or partly smolted. Parrs were defined as fish in which the parr marks were strongly developed, while smolts were defined as those in which the parr marks were barely visible. Partly smolted fish had silvery color which partly obscured the parr marks. Condition factor was calculated by the formula: KFL = weight (g)/length $(cm)^3$.

The caudal peduncle was severed and approximately 0.2 ml of blood was removed to a microcentrifuge tube and placed on ice. A heparinized microhematocrit tube was also filled with blood for hematocrit analysis. The liver was then removed and placed in a glass tube on dry ice. Gill filaments were excised and homogenized in a medium composed of 0.2 M sucrose, 0.01 M sodium EDTA, 0.01 M 2-mercaptoethanol, and 0.1 M imidazole, pH 7.2. The homogenate was transferred to a glass tube on dry ice for transport. If skin samples were taken, the fish was placed on dry ice for several minutes until frozen. A strip of skin was removed from the midline just below the dorsal fin and placed in a glass tube on dry ice.

Small blood samples were centrifuged for 5 minutes in hematocrit centrifuge and read to the nearest 0.5 percent with a hematocrit reader. Large blood samples were centrifuged for 2 minutes at 1000 x g at room temperature, the plasma was removed with pasteur pipettes, and the plasma was stored on dry ice in 0.5 ml microcentrifuge tubes.

After transport to the laboratory, livers were homogenized in 2.0 ml water. Two aliguots of 0.05 ml were removed for protein analyses, and aliguots of 0.2 ml were removed for triglyceride analyses. Glycogen was precipitated from the remainder with 5 volumes of ethanol according to the method of Montgomery (1957). Glycogen was measured by the colorimetric method of Dubois et al (1956). Triglyceride samples were diluted to 1.0 ml with water and heated at 75°C for 15 minutes. The samples were then cooled and centrifuged at 6000 rpm for 10 minutes in a Mistral 2000 refrigerated centrifuge. Supernatants were decanted for triglyceride analyses by the method of Bucolo and David (1973).

Gill ATPase activity was measured by the method of Johnson et al. (1977). Protein was determined by a modification of the method of Lowry et al. (1941). Skin samples were extracted for 48 hours in 1 N HCl and assayed for guanine by the method of Staley and Ewing (1992).

Plasma thyroxine was measured by a modification of the radioimmunoassay method of Dickhoff et al. (1978). Plasma glucose was measured by a glucose oxidase method developed by Biotech Research and Consulting, Inc., for microliter quantities of plasma. Plasma cortisol was measured by an enzyme immunoassay developed by Biotech Research and Consulting, Inc. based on the method of Ogihara et al. (1977).

Comparisons between parameters of experimental groups and times were examined by 2-way analysis of variance (ANOVA). When significant differences were observed, individuals were compared by Tukey's test. Growth rates derived from dipnet samples were compared with those derived from monthly pond counts by chi square analysis. All analyses were performed at the 95% confidence level.

Results and Discussion

Sampling Procedures

Two potential problems inherent in dipnet sampling were examined: 1) Whether the sample of 15 fish was representative of the population: 2) whether the fish were stressed from handling.

To examine the first question, weights of the 15 fish from each time point in the smolt sampling program were compared with those obtained by crowding the population and determining weights by pond counts (see Appendix G). Chi squared analysis indicated that the weight of the fish in the smolt samples was significantly different from that of the pond counts (X^2 = 85.69; $X^2_{(0.95)}$ = 79.08). If the standard error associated with each weight from smolt sampling was used to calculate a 95% confidence limit about the mean, 26.89 of the weights for the pond counts were beyond this limit. However, if the error associated with the pond counts was also used to form a 95% confidence limit, only 17.9 % of the weights from pond counts and smolt samples did not overlap.

The deviation of the weight of the smolt samples from the pond counts was not a random occurrence. Most of the weights from the smolt samples were smaller than those estimated from the pond counts. In particular, weights of smolt samples from group C were significantly smaller than that of the pond samples in 5 of the 8 samples.

Growth rates of the fish in the smolt samples were calculated by changes in fork length and weight and compared to those obtained from smolt samples (Table 70). Most growth rates based on changes in fork length were similar except in groups E and F. Group F in particular was much lower than the other growth rates and the regression was not particularly good. The low values of regression coefficients (R^2) for the Michigan ponds both in pond counts and in smolt samples suggested the difficulty in sampling these ponds. This difficulty will be discussed later.

These results suggest that the dipnet sampling tends to capture fish smaller than the population mean size. This is not too surprising because the bigger fish are usually stronger and faster and able to avoid the net more readily. Our results do not agree with that of the Smolt Quality Assessment group, who found that the dipnet sampling provided an adequate sampling of the population. However, the methods employed were sufficiently different that the two are difficult to compare directly. We are examining our procedures to determine if we can perhaps obtain a more random selection of fish.

Table 70. Growth rates from smolt samples calculated as change in fork length (cm) per day and the change in weight (g) per day. Both growth rates were obtained by linear regression analysis.

Group	Growth Rate (cm/day)	R^2	Growth Rate (g/day)	R^2	Growth Rate[1] (g/day)	R^2
A	0.0228	0.912	0.175	0.887	0.087	0.858
B	0.0188	0.724	0.149	0.635	0.102	0.953
C	0.0204	0.905	0.133	0.875	0.100	0.892
D	0.0214	0.763	0.127	0.833	0.079	0.873
E	0.0106	0.333	0.064	0.272	0.038	0.418
F	0.0055	0.207	0.026	0.096	0.054	0.525
G	0.0193	0.655	0.114	0.448	0.060	0.499

[1]Growth rate calculated from pond inventories shown in Appendix.

The most interesting part of the analysis was the indication that the fish in group C were the most difficult to sample with a dipnet. This suggests that the extra oxygen may have provided some additional energy to the escape behavior. This will be discussed further in the section on liver glycogen and triglyceride analyses.

The second question, that of stress to the fish during netting, is addressed in the smolt index portion of this report.

Smolt Indices

Visual assessment of smolting indicated a size relationship to the coloration of the fish. Smaller fish tended to have less silvering, while larger fish had deciduous scales associated with smolting in chinook and obscured parr marks by silvering. Partially smolted individuals were intermediate in size (Fig. 29). The average length for fish in each of the smolt categories increased slightly with time (Fig. 30).

The percent of the sample consisting of parrs decreased continuously during the sampling year (Table 71), as would be expected if the smolt status was a function of size. However, these data were from pooled samples from all the raceways. There was a tendency for fish in the Michigan ponds to be somewhat more silvery than those in raceways. Skin samples were taken on February 24-25 to look at guanine levels and attempt to guantitate these visual observations. Results showed that the

Fig. 29. Length frequencies of fish in the three smolting categories. Values are for fish from 105 samples taken in December 1992. Parrs, heavy stripes; partial smolts, solid bars; smolts, light stripes.

Smolting Vs Length
December 1992

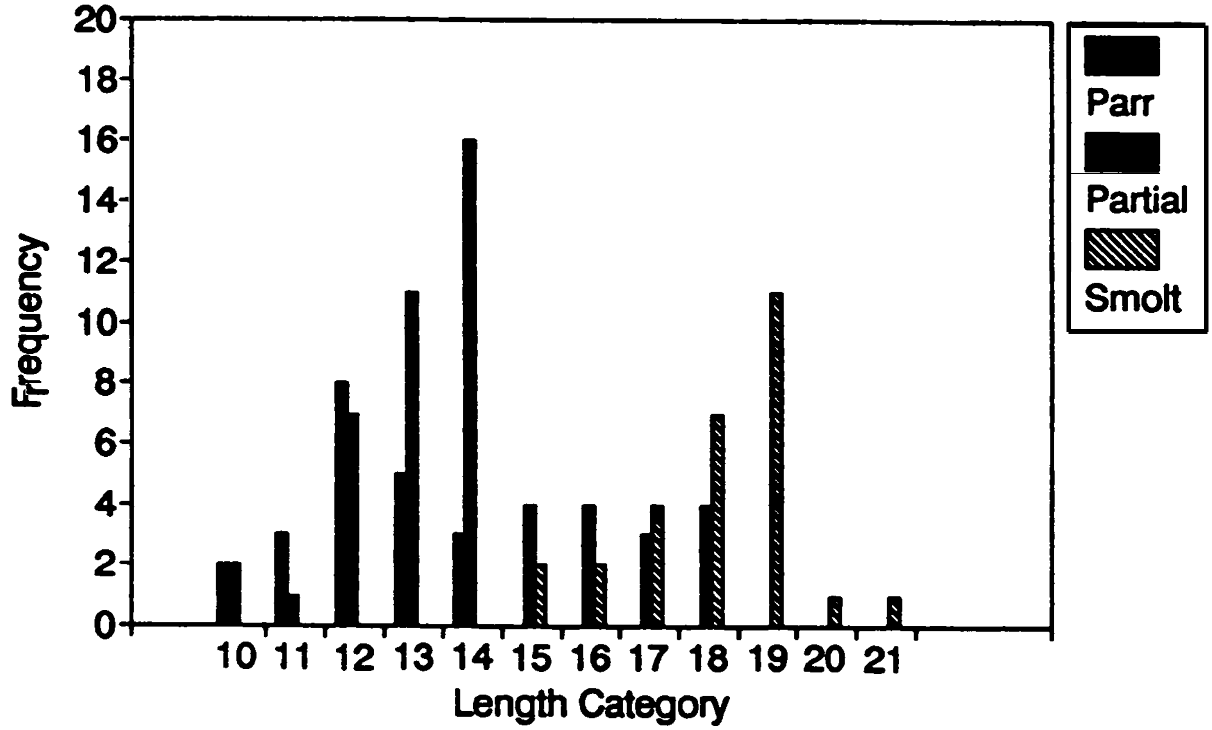
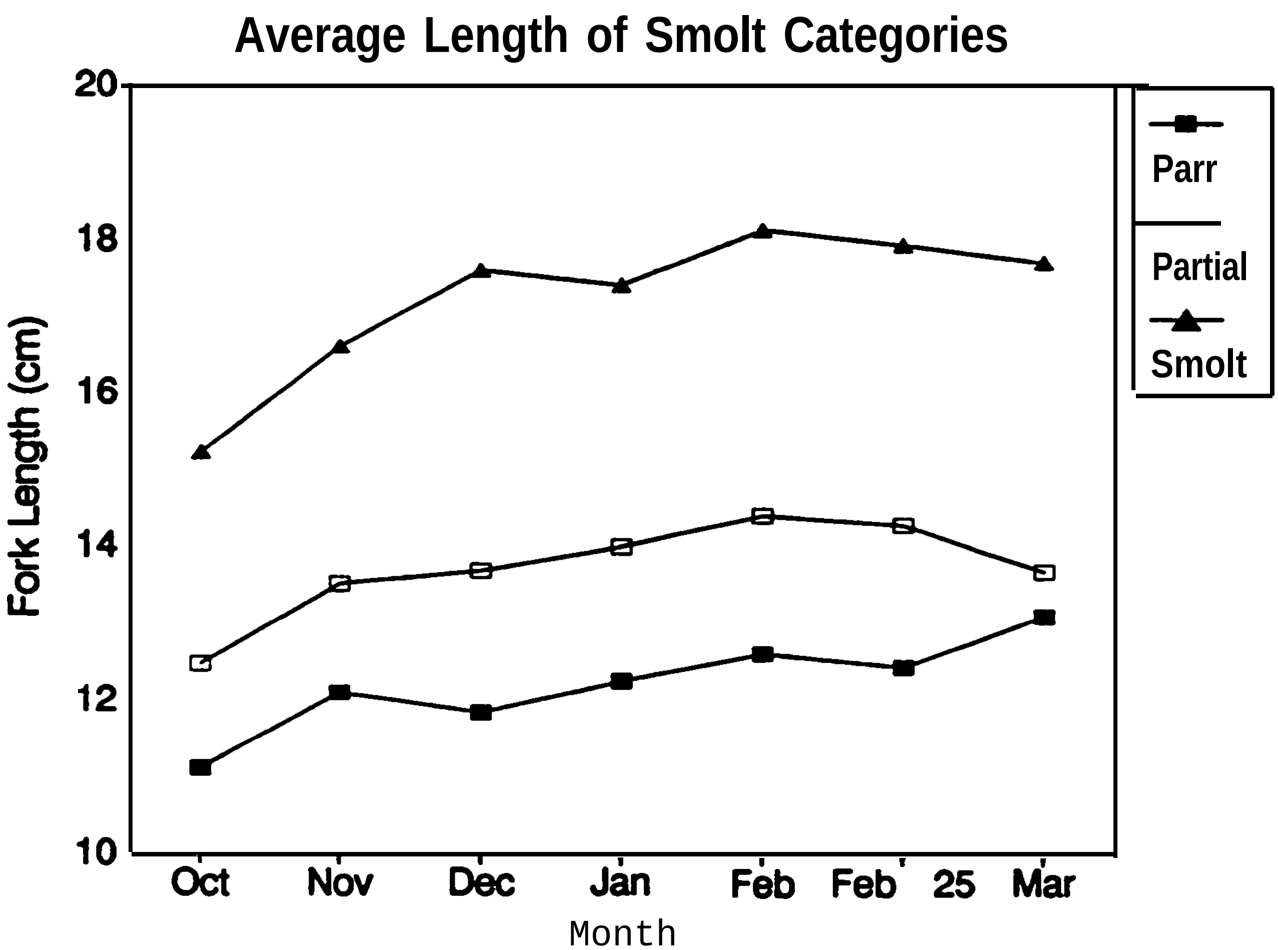


Fig. 30. Average fork length (cm) for fish in parr, partially smolted, or smolted condition with time of sampling. Parr, -■-; partial smolts, -□-; smolts, -A -.



Average Length of Smolt Categories
Fork Length (cm)
20
18
16
14
12
10
Oct
Nov
Dec
Jan
Feb
Feb 25
Mar
Month
Parr
Partial
Smolt

Table 71. Percent of sample from all raceways visually assessed to be parrs, partially smolted, or smolts.

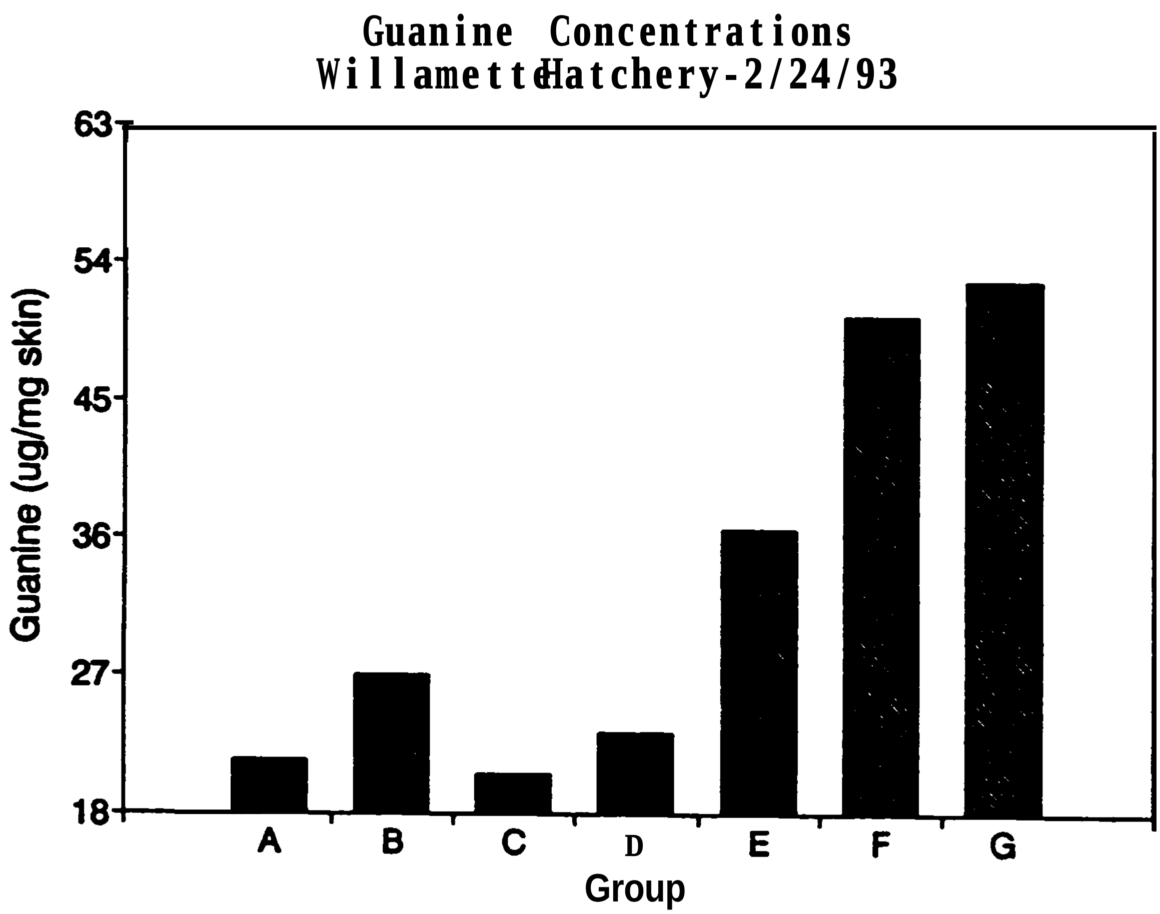
Date	Parr	Partial	Smolt	Precocious Males
October	55.9	5.9	35.3	2.9
November	31.2	35.5	32.3	1.1
December	20.6	51.0	28.4	0.0
January	32.0	32.0	35.0	1.0
February	16.2	40.0	41.9	1.9
February 25	8.6	50.5	43.0	0.0
March 11	9.3	48.6	40.0	2.1

skin of fish in the Michigan ponds had significantly more guanine than those in normal raceways (Fig 31).

The relationship between size and coloration had been suggested earlier for chinook salmon (Ewing and Birks, 1982). They suggested that chinook salmon reared in tanks lost their parr marks at 7 cm and remained silvery throughout the rest of their life until they entered freshwater as adults. The present results suggest that the size required for silvery coloration and loss of parr marks in raceways was at least 15 cm. Most of the fish tended to be in the partially smolted category, where the parr marks were still visible through an overlying layer of guanine.

The increase in silvering observed in the Michigan ponds was intriguing and unexplained. Bouck (1972) reported that rock bass subjected to periods of hypoxia lost their olive green color and appeared more silvery. When normal levels of oxygen returned, the fish regained their normal color. The differences in coloration in the Michigan raceways should not be a result of hypoxia, because the oxygen levels at the inflow are no different than those seen in other raceways (Table 50). Michigan ponds are characterized by high levels of ammonia, however, and the guanine content seems to increase with increased ammonia content (Fig 31). Increases in ammonia may lead to increased glutamine content in the fish and may result in increased purine synthesis. The breakdown of purines to urea may also be inhibited by the presence of high levels of ammonia. Further experimentation on

Fig. 31. Guanine concentrations from skins of fish in the seven experimental raceways. Sampling was done on 24 February 1993.



Guanine Concentrations
Willamette Hatchery-2/24/93
63
54
45
36
27
18
Guanine (ug/mg skin)
A
B
C
D
E
F
G
Group

the nitrogen metabolism of the chinook salmon is needed before these questions can be answered.

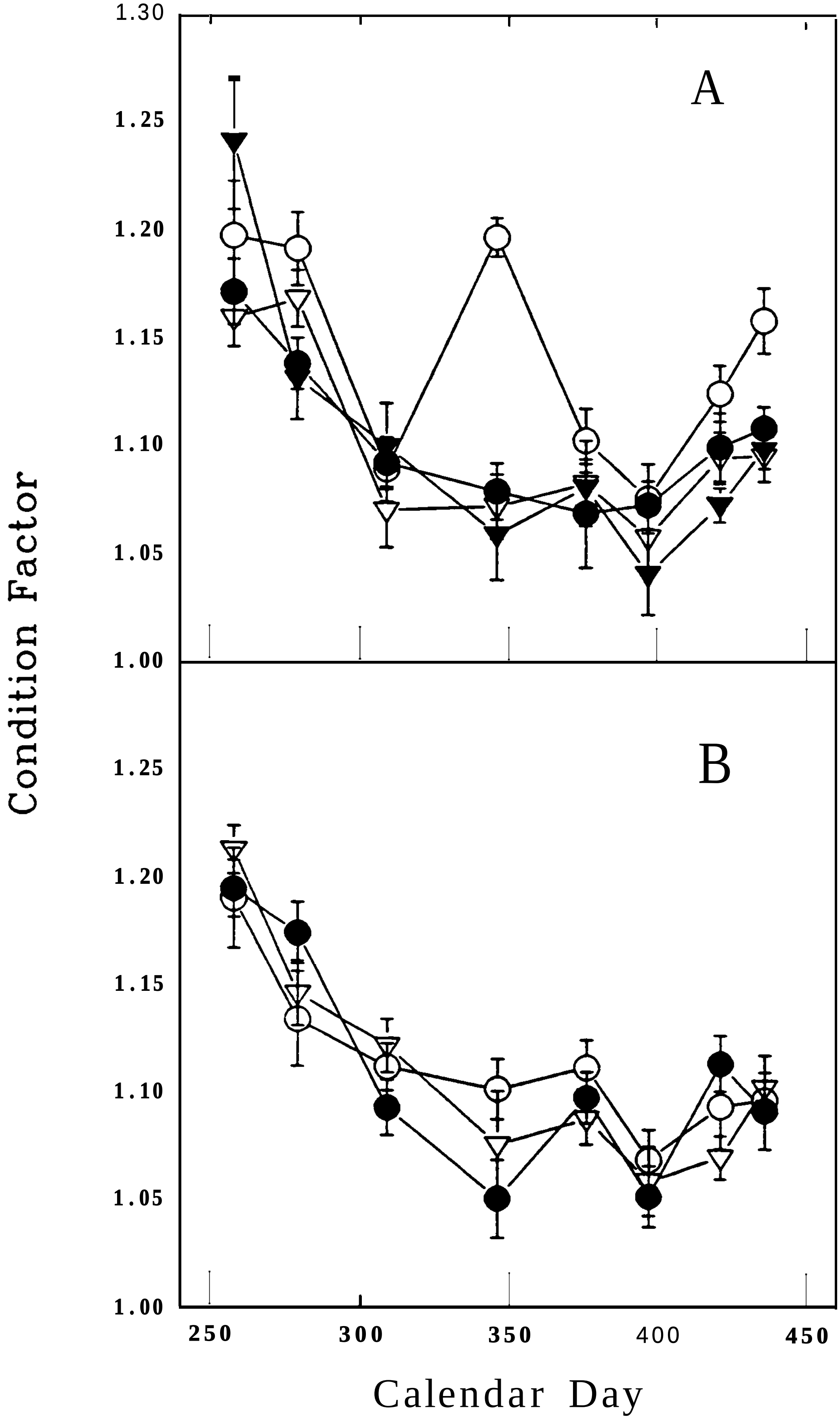
Condition factor was calculated monthly from length and weights of smolt samples (Fig. 32). Maximum levels attained in all ponds occurred in September. Values then dropped to reach a minimum in January and February. During the last two samples on February 25 and March 11, condition factor was again increasing. There seemed to be little difference in the patterns of change in condition factor between groups.

Gill (Na+K)-ATPase activity showed fall peaks in activity in groups A, B, C, and D (Fig. 33A and 33B). Groups A, C, and D had peaks in activity in November, while group B had maximum activity in October. During the spring, activity rose sharply in all four groups. Analysis of variance indicated significant differences in activity throughout the year.

In contrast, the Michigan ponds showed little indication of any patterns of changes in activity (Fig. 33C and 33D). Analysis of variance did not indicate significant differences in activity in group E and F during the year. Group G showed an F value (F = 2.44) that was only slightly greater than that for significance at the 95% confidence level (F = 2.09, 7, 112 df).

Liver glycogen showed a minor peak in October and a larger peak in February. Similar patterns were observed in all ponds (Fig. 34). In October, glycogen levels seemed inversely related to the density at which the fish were reared. Highest levels were observed in group B, while lowest levels were seen in group D. The correlation coefficient (R) for the relationship between

Figure 32. Changes in condition factors with time for spring chinook salmon reared in seven experimental raceways at Willamette Hatchery, 1992-1993. A. Oregon raceways: group A, -o- ; group B, -●-; group C, -▽-; group D, -▼-. B. Michigan raceways: group E, -o-; group F, -●-; group G, -▽-.



A
B
1.30
1.25
1.20
1.15
1.10
1.05
1.00
250
300
350
400
450
Condition Factor
Calendar Day

Fig. 33. Changes in gill (Na+K)-ATPase specific activity with time in spring chinook salmon reared in experimental raceways at Willamette Hatchery, 1992-1993. A. Group A, -O-; group B, -●-. B. Group C, -0-; group D, -●-. C. Group E, -O-; group F, -●-. D. Group G, -0-.

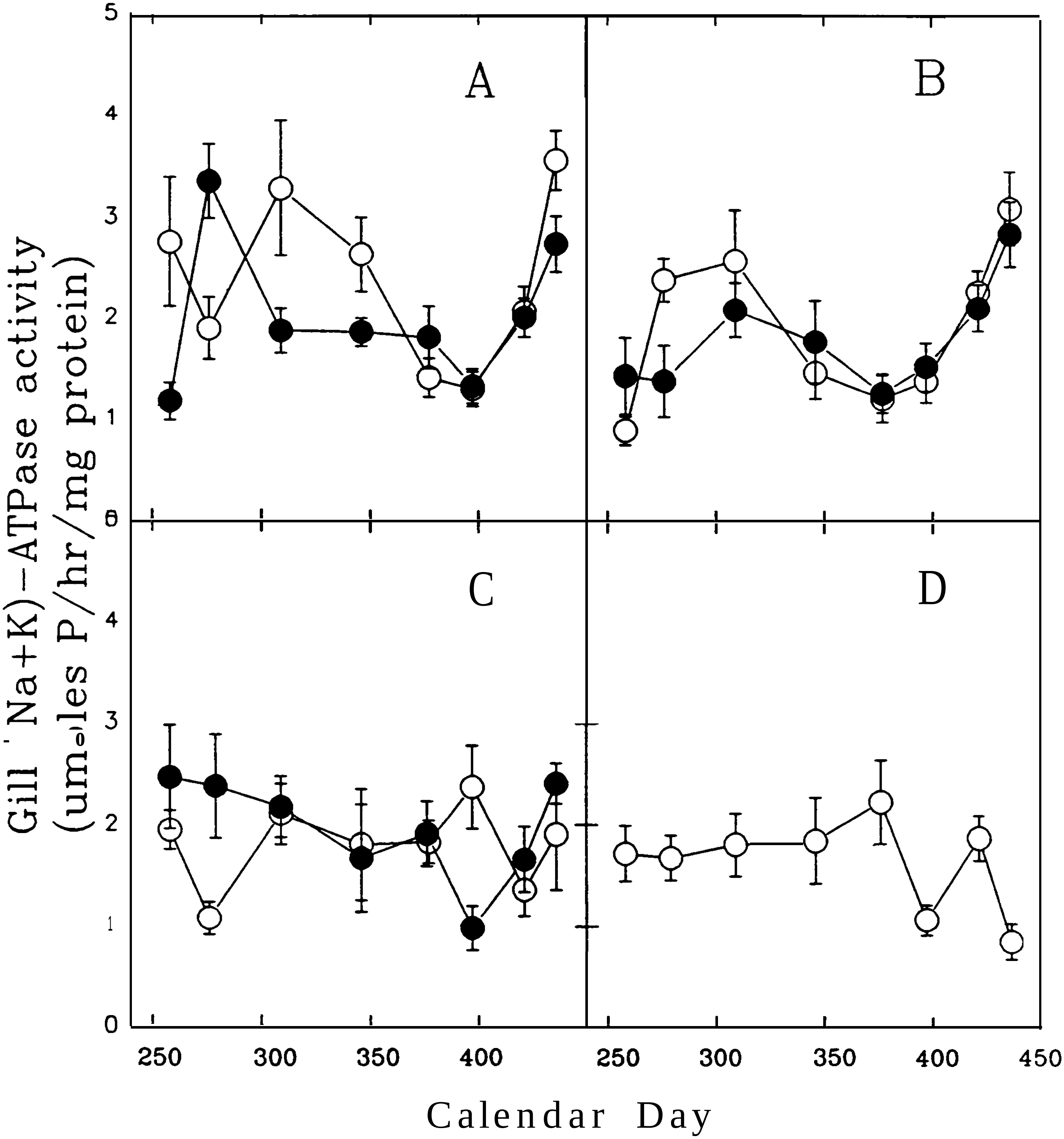
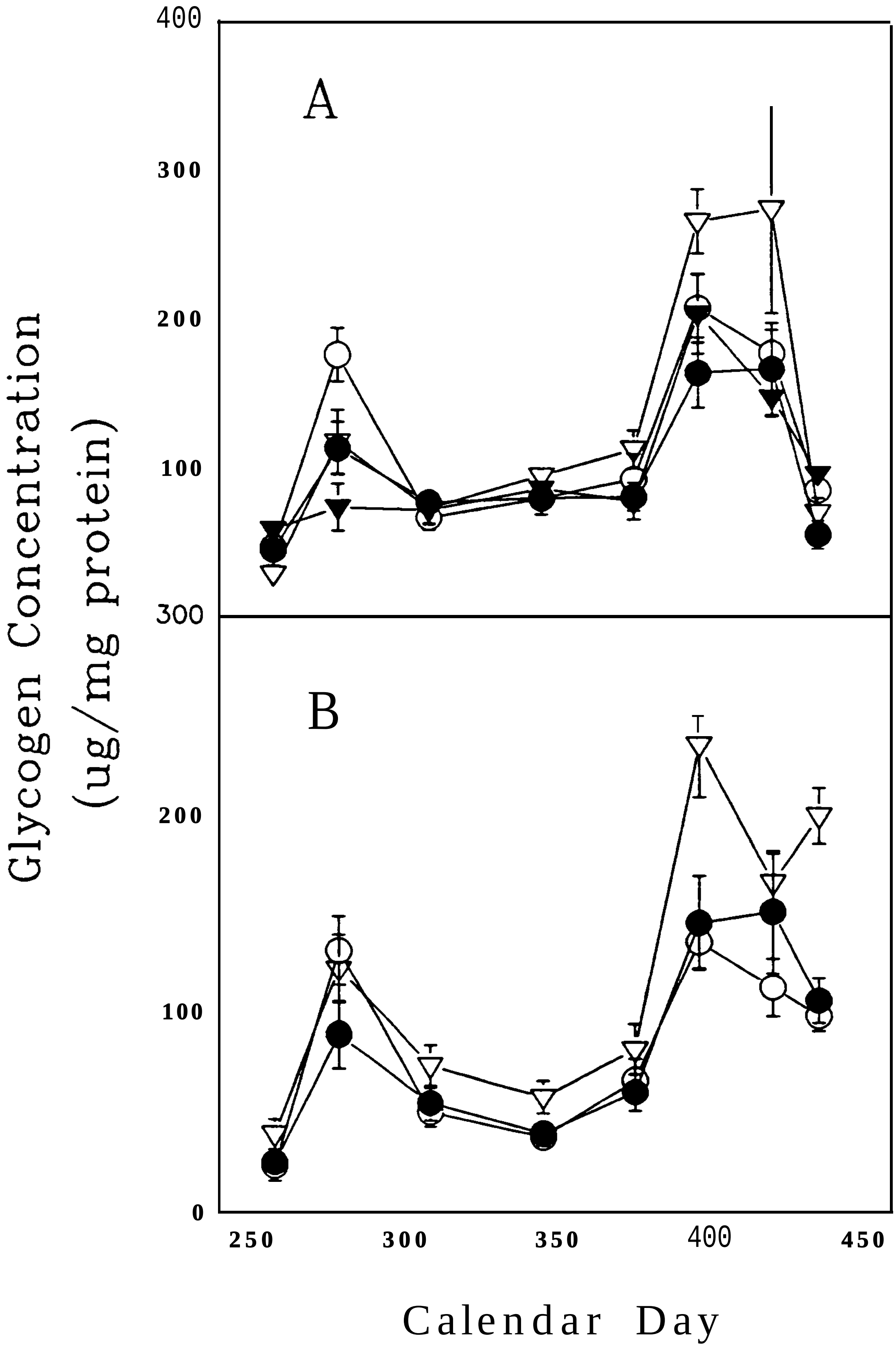

A
B
C
D
Gill 'Na+K)−ATPase activity
(um₀les P/hr/mg protein)
0
1
2
3
4
5
250
300
350
400
450
Calendar Day

Fig. 34. Changes in liver glycogen (ug/mg protein) with time in spring chinook salmon reared in experimental raceways at Willamette Hatchery, 1992-1993. A. Oregon raceways: group A, -o-; group B, -●-; group C, -▽-; group D, -▼-. B. Michigan ponds: group E, -0-i group F, -●-; group G, -V-.



A
B
Glycogen Concentration
(ug/mg protein)
400
300
200
100
300
200
100
0
250
300
350
400
450
Calendar Day

density and glycogen concentration was 0.664, which was not significant at the 95% confidence level. During the peak in glycogen in February, the correlation between density and glycogen concentration was not significant (R = 0.458).

Liver triglycerides were assayed in samples from December until release. All groups showed similar patterns (Fig. 35). A peak in triglycerides was reached in February and then decreased just before release. In the Michigan ponds in February, fish from group E had a lower concentration of triglycerides than fish in groups F and G. Triglyceride levels seemed to vary with ammonia concentrations in these raceways. The signficance of this is unknown.

The suggested increase in energy metabolism indicated by the capture of smaller fish in group C is not supported by the measurements of compounds used to provide energy for the fish, glycogen and triglycerides. No differences in levels of glycogen or triglycerides were observed between group A without oxygen and group C with added oxygen. These are relatively crude measurements of energy reserves, however. Greater refinements of energy utilization in the fish of the two different groups, such as energy charge, creatine phosphate concentrations, or mitochondrial function, may be required before these differences can be distinguished.

Blood hematocrits showed rather complex changes during the year (Fig. 36). All groups except group A showed maximum hematocrits in October. Group A had maxima in September and November. All groups tended to increase in March just before

Fig. 35. Changes in liver triglycerides (ug/mg protein) with time in spring chinook salmon reared in experimental raceways, 1992-1993. A. Oregon raceways: group A, –○–; group B, –●–; group C, –▽–; group D, –▼–. B. Michigan ponds: group E, –○–; group F, –●–; group G, –▽–.

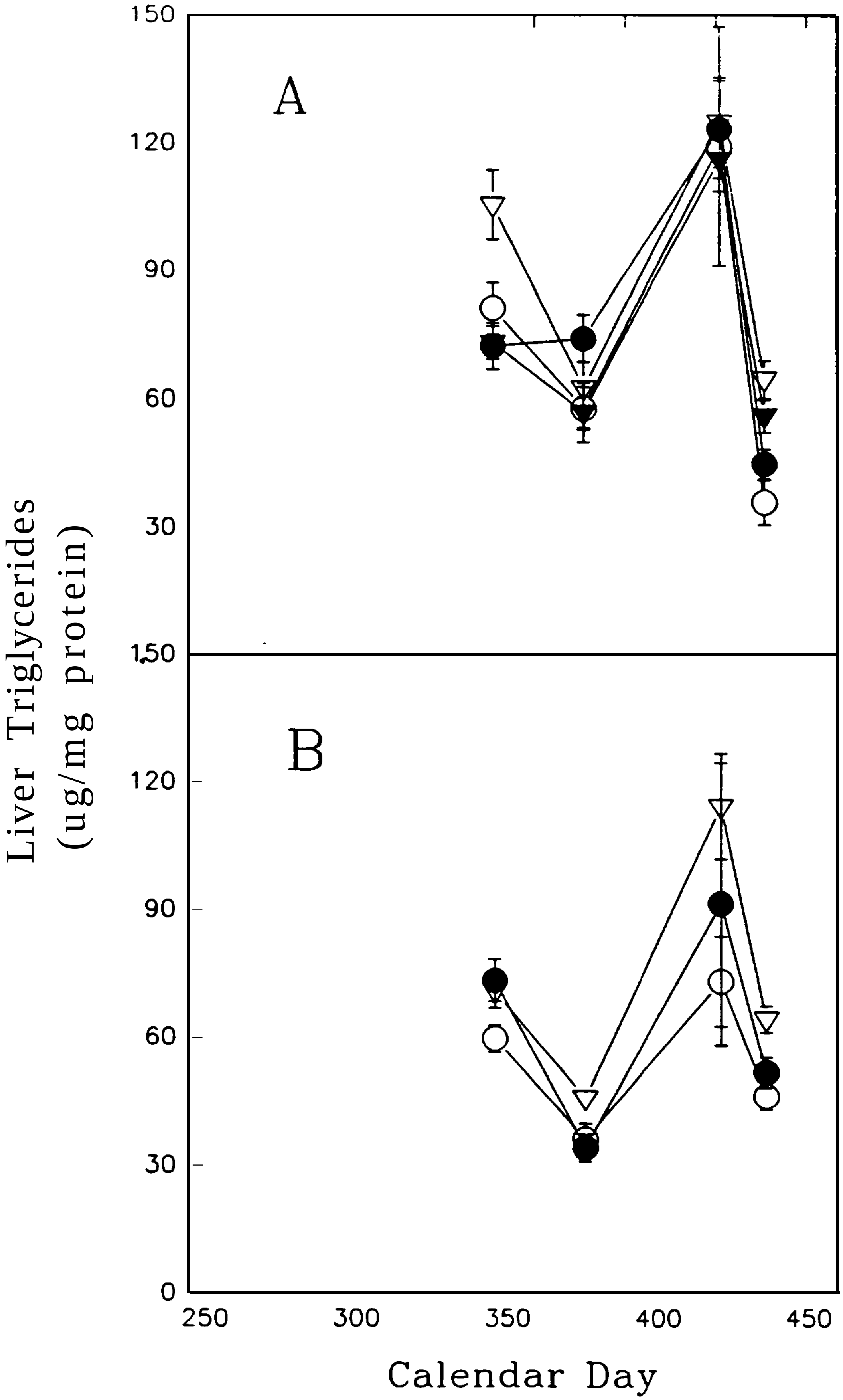
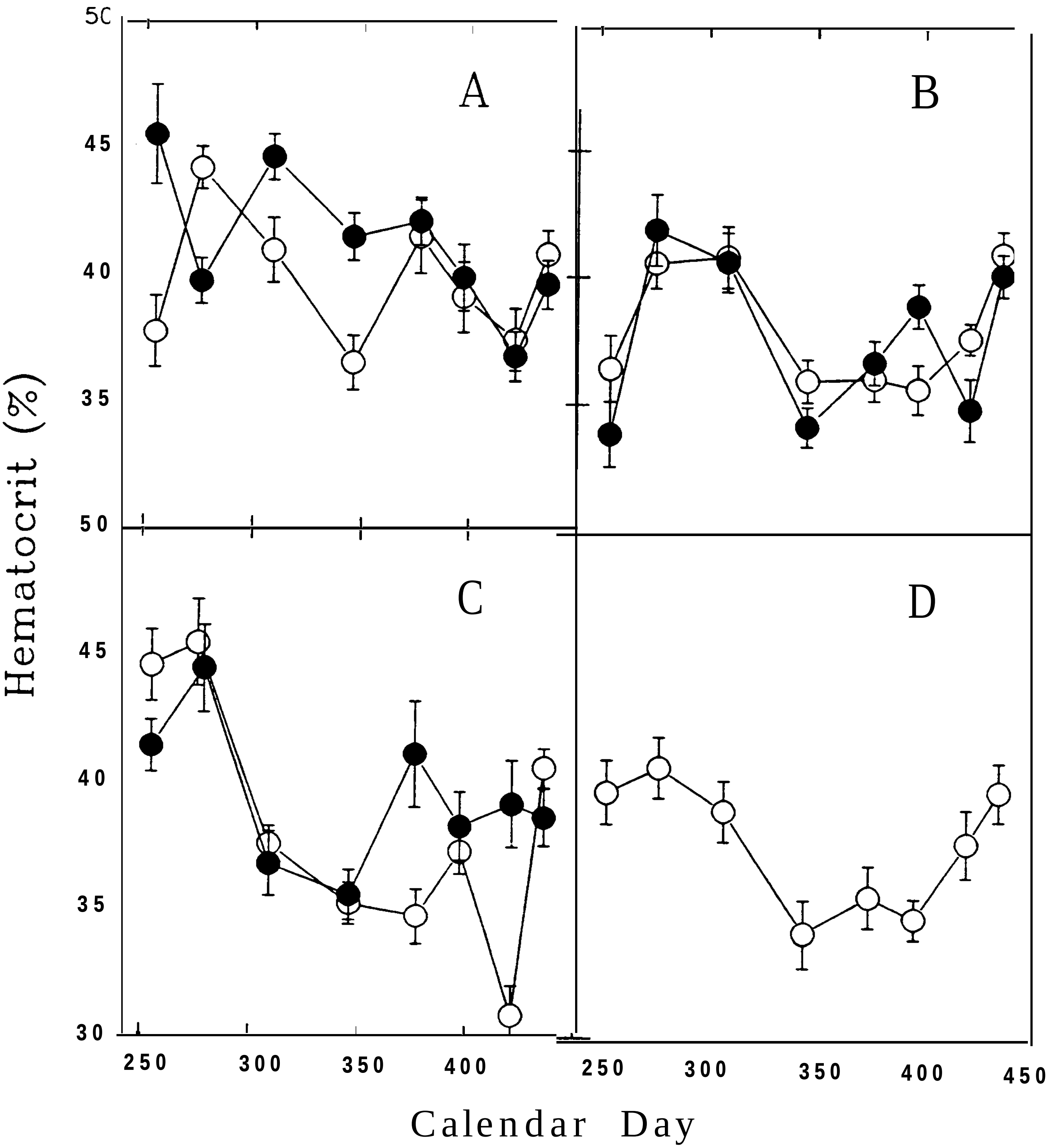

A
B
150
120
90
60
30
0
250
300
350
400
450
Liver Triglycerides
(ug/mg protein)
Calendar Day

Fig. 36. Changes in blood hematocrit with time in spring chinook salmon reared in experimental raceways at Willamette Hatchery, 1992-1993. A. Group A, -0-i group B, –●–. B. Group C, –O–; group D, –●–. C. Group E, –O–; group F, –●–. D. Group G, -0-.



A
B
C
D
Hematocrit (%)
50
45
40
35
30
250
300
350
400
450
Calendar Day

release. The patterns suggested that hematocrit levels of greater than 40% occurred during smolting and levels less than 40% occurred during non-smolting periods.

In the raceways, the changes in hematocrit appeared to mimic the changes in gill ATPase activity. Regressions of ATPase activity against hematocrit had a regression coefficient (R) of 0.563, which suggests a slight but significant relationship (Fig 37). This did not occur in the Michigan pond series because the changes in enzyme activity were suppressed and not significantly different throughout the sampling period. Whether this relationship has a physiological basis is not known at present.

Plasma thyroxine reached maximum levels in October in most groups (Fig. 38), then remained low for the rest of the year. Only group D, which had elevated densities, and group F, the second pond of the Michigan series, showed little change in thyroxine levels in October. The suppression of the thyroxine peak in group D supports the conclusions of others (Patino et al, 1989) that increased densities inhibit thyroxine surge development, but this effect was not seen in groups E or G, which were reared at similar densities.

Plasma glucose levels gradually increased to a peak in February, then decreased abruptly (Fig. 39). The pattern was approximately the same in all raceways. Maximum levels attained approached 200 mg/dL, which seems high for non-stressed fish. If the fish were stressed during capture and sampling, these effects should be evident from the cortisol values observed. However,

Fig. 37. Relationship between hematocrit and gill (Na+K)-ATPase activity for spring chinook salmon reared in Oregon raceways. The points include sampling dates from September 1992 to March 1993.

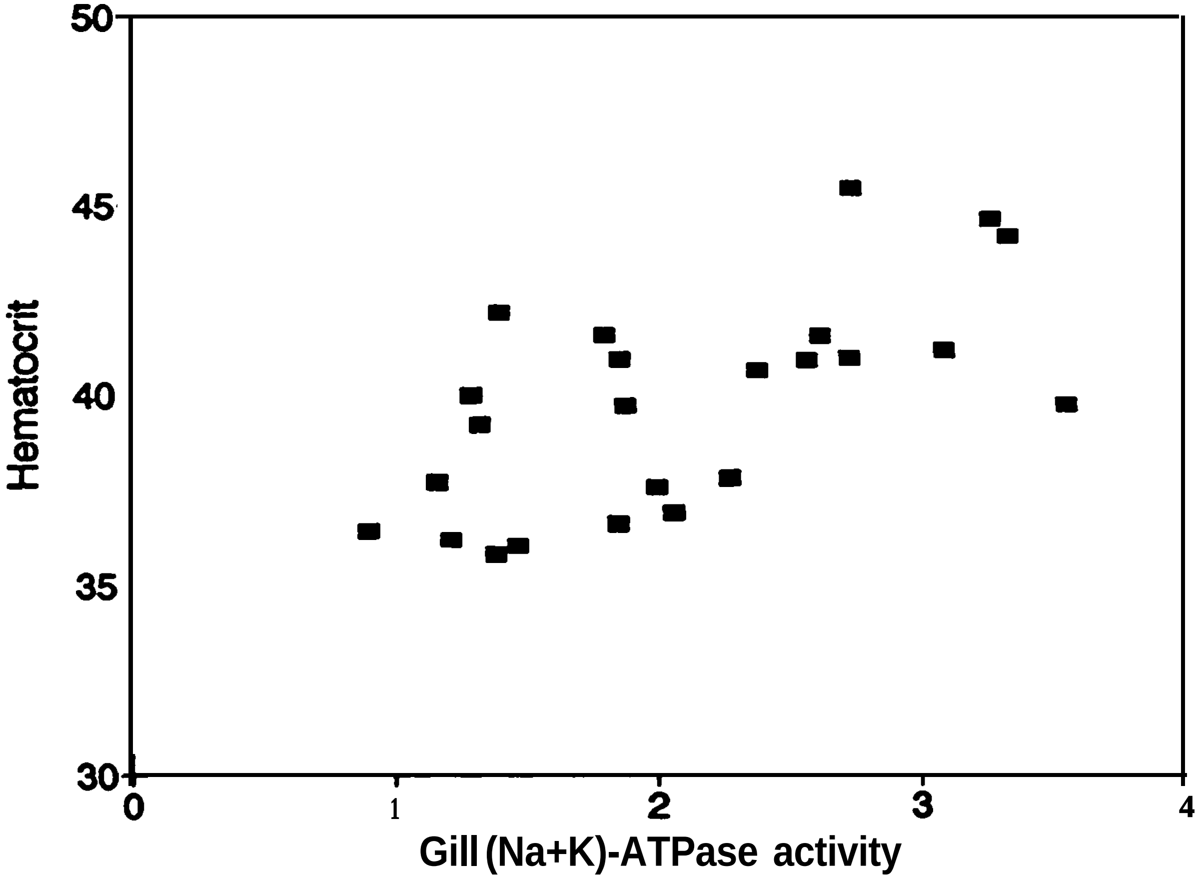
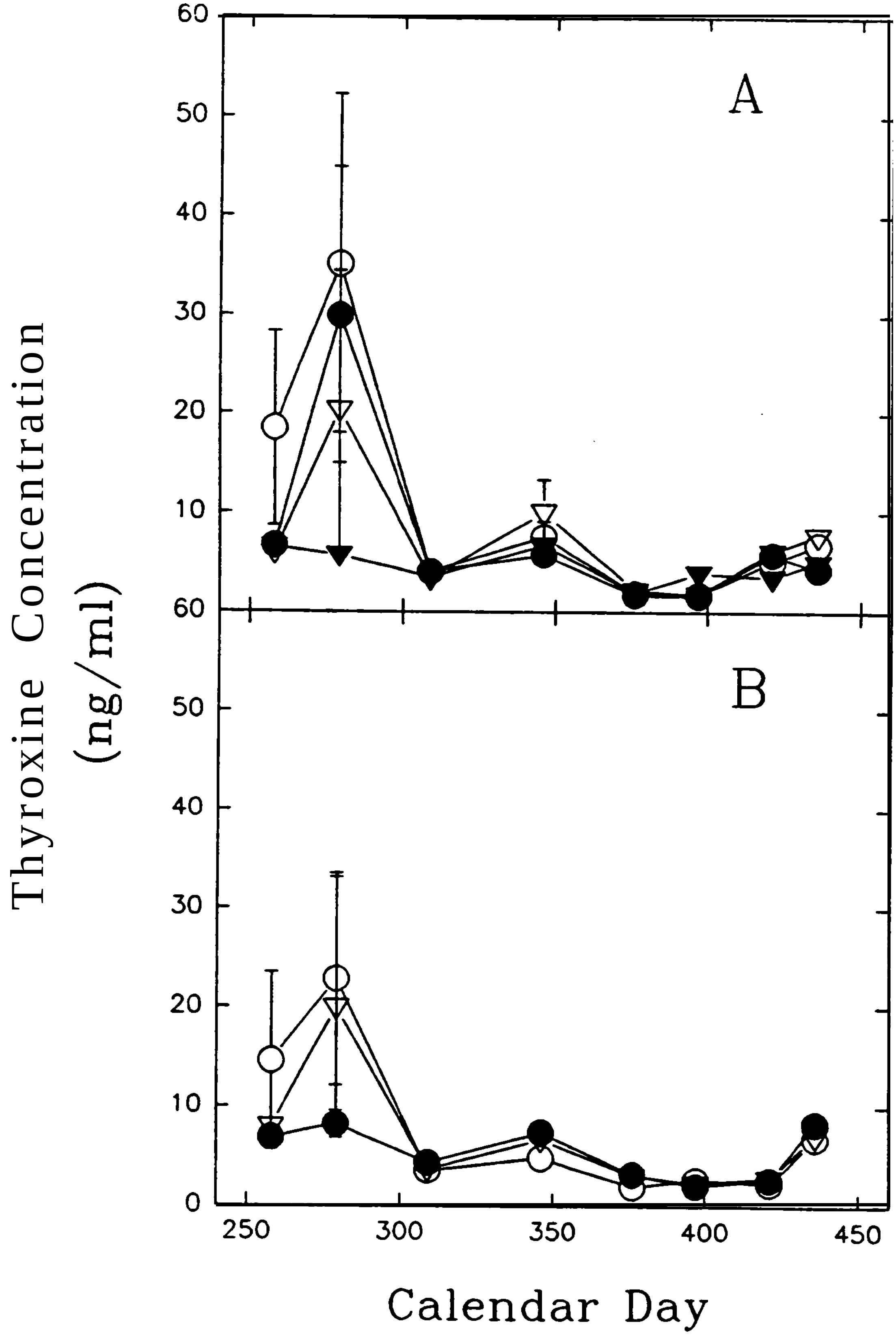
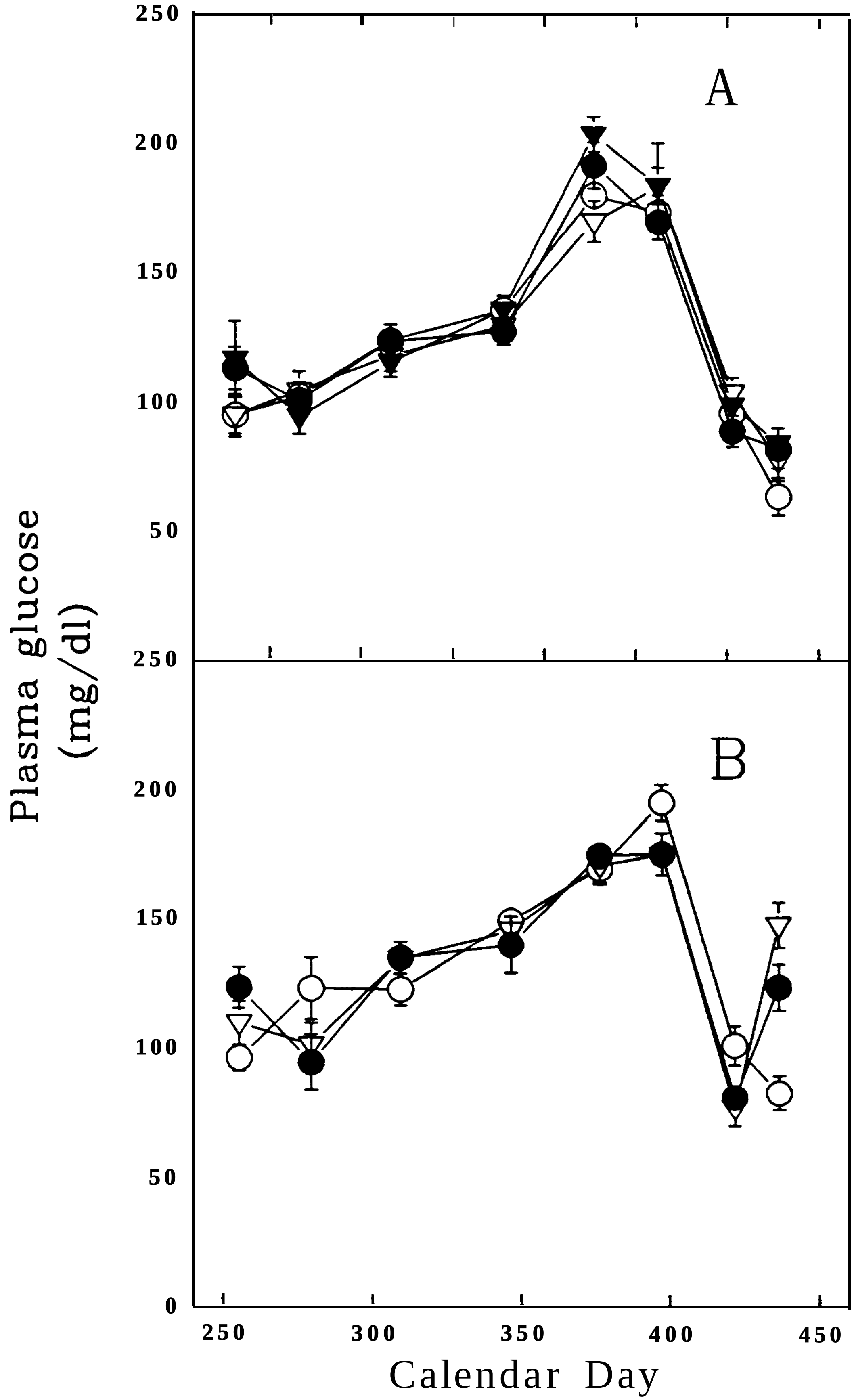

50
45
40
35
30
Hematocrit
0
1
2
3
4
Gill (Na+K)-ATPase activity

Fig. 38. Changes in plasma thyroxine concentration (ng/mL) with time in spring chinook salmon reared in experimental raceways, 1992-1993. A. Oregon raceways: group A, -○-; group B, -●-; group C, -▽-; group D, -▼-. B. Michigan ponds: group E, -○-; group F, -●-; group G, -▽-.



A
B
Thyroxine Concentration (ng/ml)
60
50
40
30
20
10
0
250
300
350
400
450
Calendar Day

Fig. 39. Changes in plasma glucose concentration (mg/dL) with time in spring chinook salmon reared in experimental raceways, 1992-1993. A. Oregon raceways: group A, -0-; group B, -●-; group C, -▽-; group D, -▼-. B. Michigan ponds: group E, -0-i group F, -●-; group G, -▽-.



Plasma glucose (mg/dl)
A
B
250
200
150
100
50
0
250
300
350
400
450
Calendar Day

cortisol analysis was not yet complete at the time of this report. The results of cortisol analyses will be described in the next annual report.

LIBERATION STUDIES

During smolt releases on 15 and 16 March 1993, 21 fish liberations were videotaped at Pengra boat ramp located 2 km below Dexter Dam. The ramp at Pengra is about 15 meters long and inclined at a 25° angle. Fish were liberated at the end of the ramp where the water was about 1 meter deep with a moderate current. The weather was overcast with constant drizzling rainfall. Water level in the river was high and the water was somewhat murky. All liberations were videotaped from a bank on the downstream side of the boat ramp so that the entire liberation process could be observed.

The 21 liberations taped were made from 8 liberation trucks (Table 72). Liberations were of three types. With the large tankers (X3 and #8 in Table 72), each truck was backed to the edge of the water, a port was opened at the back, and the fish were poured out of the back of the truck into the water.

In the second style of liberation, an extension to the outlet of the tanker protruded from 2 to 4 feet beyond the body of the truck. The truck was backed to the edge of the water so that the extension pipe almost touched the surface. The port was then opened and the fish released.

The third and most common type of liberation was that with a combination of flexible and rigid pipe. One end of an 8-foot flexible pipe was attached to the outlet of the tanker, and an 8-foot section of rigid pipe was attached to the other end. The truck was parked a distance from the water's edge and the pipes

Table 72. Techniques of liberation for various trucks used for liberating chinook salmon in March 1993.

Truck	Time to Unload (sec)	Technique
1	107.7	2.5-3 foot pipe out back. Truck backs to water's edge.
2	68.0	Double hose just above the water.
3	38.3	Liberated directly out of back of the truck. No hoses or pipes.
4	53.7	2.5-3 foot pipe out back. Truck backs to water's edge.
5	50.3	Double hose used. Liberated at water level.
6	72.5	Liberated from a cone-shaped nozzle at the back of the truck. Fish drop about 4 feet.
7	42.5	Single hose used, held at waist level.
8	159.0	Liberated directly out of the back of the truck. No hoses or pipes.

were adjusted so that the fish flowed nearly horizontally out of the pipe and into the deep portion on the river. Angles and heights at release varied with the drivers.

Each release was examined closely in the video tape for the height at which the fish were liberated and the angle at which they struck the water. The time required for complete liberation of the fish was measured.

In addition to physical characteristics of the releases, an attempt was made to guantitate behavior patterns of the released fish from the videotapes. Several behavior patterns were observed in the liberated fish. Fish presumed to be the most stressed turned over and floated in the current in the area of release. Other stressed fish leaped into the air away from the area of liberation. Leaps were defined when the caudal fin left the water surface so that the entire body of the fish was in the air. Another behavior pattern associated with stress was skittering. In this behavior, fish swam rapidly for variable distances on or near the surface of the water away from the area of liberation. More than four rapid tail beats were required to be counted as skittering. Bobbing also occurred at the area of liberation and appeared to be associated with stress. Fish bobbed in the area of release with their heads and gill covers protruding into the air but with the rest of their body submerged.

Grounding was a behavior associated with liberation stress that was observed in previous years but not in 1993. In this behavior, fish rushed from the area of liberation, often by skittering, and swam partially up on the bank, usually with their backs out of water. These fish could be touched without evoking a fright response and were obviously highly stressed.

Behavior of the fish was quantified by counting the number of fish that were skittering and leaping. In each liberation sequence, the fish were counted three times and the numbers averaged. In addition, an arbitrary rating was assigned to each liberation according to a general impression of the release. A rating of 1.0 was the most gentle on the fish, a rating of 5.0 was the harshest. We attempted to count bobbing in each liberation, but the numbers exceeded 1000 in the few liberations we counted and the final number was probably grossly inaccurate. Consequently, this measurement was abandoned.

Results are shown in Table 73. Unfortunately, there was only a single significant correlation between the parameters (Table 74). The correlation between rank and leaps probably indicates that the viewer was unconsciously using the fish leaping as a criterion for the ranking. The lack of correlation between leaping and skittering suggests that these are responses to different types of stress imposed by liberation.

At this time, we have not yet analyzed the flow from the tankers and the numbers of fish held by each tanker. We suspect that the number of fish released per second and the speed at which they strike the water will reflect the extent of the stress upon the fish. The data is available in liberation tickets so we hope to be able to match up the liberations on videotape to the appropriate liberation tickets.

Table 73. Liberation techniques and fish behavior for all videotaped releases.

Number	Tanker	Unload Time (sec)	Drop (feet)	Angle (degree)	Leaps	Skitters	Rank
1	1	66	2.5	50	4.7	8.3	2.5
2	2	85	0.25	10	22.3	13.0	2.0
3	3	38	3.0	60	59	27.7	4.0
4	4	53	2.5	45	25.7	39.3	3.5
5	1	110	2.0	40	3.0	7.3	1.5
6	5	49	0	0	6.7	15.7	2.0
7	2	67	1.0	30	7.0	12.7	2.0
8	6	75	3.5	60	26.0	14.0	4.5
9	7	41	2.5	30	5.0	5.0	1.0
10	3	38	2.0	50	62.0	24.7	5.0
11	4	55	3.0	45	13.7	13.0	2.5
12	8	159	3.0	40	75.7	23.0	5.0
13	2	71	0	10	4.7	6.3	1.0
14	1	109	2.0	50	14.3	11.0	2.5
15	5	51	0	0	10.3	21.3	3.0
16	3	39	2.5	60	64.7	15.0	5.0
17	4	53	2.5	40	21.7	11.3	2.5
18	1	104	1.5	45	51.0	19.0	2.5
19	7	44	3.0	50	36.3	5.7	4.0
20	6	70	3.0	50	78.7	7.7	4.5
21	5	51	1.0	20	36.0	19.3	3.0

Table 74. Correlations between the parameters measured and reported in Table 72.

Parameters		R^2
Unload time	vs rank	0.0002
	vs leaps	0.007
	vs skitters	0.009
	vs angle	0.009
	vs height	0.0105
Rank	vs leaps	0.691*
	vs skitters	0.196
	vs angle	0.335
	vs height	0.300
Leaps	vs skitters	0.128
	vs angle	0.241
	vs height	0.189
Skitters	vs angle	0.008
	vs height	0.0009

*Significant at the 95% level of confidence.

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Appendix A. Manuscript Submitted to Progressive Fish Culturist.

Evaluation of Fish Transport Procedures:

I. Estimates of Weights of Fish

in Raceways and Liberation Trucks

R. D. Ewing

Biotech Research and Consulting, Inc.

2340 SE. Ryan Street

Corvallis, OR 97333

and

T. R. Walters

M. A. Lewis

J. E. Sheahan

Oregon Department of Fish and Wildlife

850 S.W. 15th Street

Corvallis, Oregon 97333

Correspondence should be addressed to:

R. D. Ewing
Biotech Research and Consulting, Inc.
2340 SE Ryan St
Corvallis, Oregon 97333

ABSTRACT

Techniques and sources of error in estimating size and numbers of fish in hatchery raceways and on liberation trucks were examined in three hatcheries using three species of salmonids. The greatest source of error in determining fish size depended upon the number of individual samples taken from a raceway. Error also varied with percent of the population sampled but the correlation between error and percent of population sampled was not as great as that between error and the number of samples taken. Samples of 15 pounds did not show better precision than samples of 5 lbs. Variability in fish size seemed to affect the minimum error associated with estimates of fish size. From these studies, we suggest that errors in fish size of 2-5% are common. We recommend 7-9 random samples to attain an acceptable level of error in size estimates.

The status and management of anadromous salmonids in the Pacific Northwest has directed attention to the effect of hatcheries on local economies, the cost effectiveness of hatcheries, and the effect of hatcheries on wild fish. With the current concern about endangered stocks of fish, the effects of stocking hatchery fish in river systems is especially critical. To evaluate these aspects of hatchery operations, accurate release information, including date, location, size, and number of fish stocked, is essential. Hatchery-released salmonids can be stocked either by direct release from the hatchery rearing pond or by transport to a release site remote from the hatchery. When fish are released directly from the hatchery, the number of fish stocked is based on hatchery records of the number of fish initially placed in raceways minus the subsequent mortalities. When fish are transported for release, a second method of estimating the number of fish stocked is commonly used. Gauges of the liberation trucks determine the amount of water displaced by the fish. This water displacement is then converted to pounds of fish loaded by multiplying the pounds or kilograms of water displaced by the specific gravity of the fish (Leitritz and Lewis, 1976). If the average fish weight is known, the number of fish stocked can be determined by dividing the pound of fish stocked by the average fish weight.

In Oregon, we have often found discrepancies between inventories from hatchery records and those based on displacement and average fish size at the time of stocking. Occasionally, a discrepancy as great as 20% would occur. Typically, these discrepancies were attributed to bird predation. In 1991, we were asked to examine the procedures for estimating the number of fish loaded onto liberation trucks. This study describes some of the sources of error that we identified in these procedures.

METHODS

Studies estimating average fish size were made with three species of salmonids at three Oregon hatcheries: rainbow trout (Oncorhvnchus mvkiss) at Wizard Falls Hatchery and Irrigon Hatchery, steelhead (0. mvkiss) at Irrigon Hatchery, and chinook salmon (0. tshawvtscha) at Willamette Hatchery.

On 26 June 1991, rainbow trout reared at Wizard Falls Fish Hatchery were loaded into a 5,000 gallon liberation truck. To accomplish this, about 60% of the trout in the raceway were crowded to the upper end of a raceway, measured to the nearest millimeter and loaded into liberation trucks. When most of the fish were loaded, the remainder of the raceway population was crowded and the fish collected with dipnets. These fish were then poured into baskets which were hung from Challenger Model 3260 electronic scales. The baskets were left hanging for approximately five seconds, or until the readings stabilized, and the weight of the sample recorded. After every 150 lb (68 kg) of fish, technicians weighed and counted the fish in a basket to determine the average individual fish weight. Average size of a counted basket was 5.95 kg of fish. When approximately 1000 pounds (454 kg) of fish were weighed, they were pumped into a single compartment of the liberation truck with a Nielsen fish PumP. The liberation truck driver then used displacement gauges on the truck (Leitiritz and Lewis, 1976) to estimate total fish weight. The total weights of fish determined by inventory methods and by displacement methods were then compared.

Techniques throughout the inventory, loading, and displacement estimation were observed to insure that no unintentional bias was introduced.

We checked the accuracy of the Challenger electronic scale by sequentially weighing 2 liter quantities of water to a total volume of 12 liters. The difference between the true weight of the water (derived from volume, specific gravity, and temperature) and the reading from the scale was recorded.

Fish loaded on the liberation trucks were hauled to Irrigon Hatchery, where they were inventoried two days later. The trout were crowded to the lower half of the raceway and subgroups were then crowded toward the middle of the pond where they were inventoried similar to that described for Wizard Falls Hatchery. Average size of counted baskets was 15.23 kg.

To determine the effect of various numbers of basket counts on the variability of the inventory estimates, the 27 basket counts at Wizard Falls Hatchery and the 8 basket counts at Irrigon Hatchery were divided into subgroups using a Monte Carlo selection technique. Varying numbers of randomly selected baskets were chosen from within these subgroups for weight determinations. For example, to determine the effect of taking only 3 basket counts at Wizard Falls Hatchery, we split the 27 total basket counts into three subgroups (l-9, 10-18, and 19-27). A random number generator was then used to select one basket count from each subgroup to create a sample of 3 basket counts.

The same type of selection was conducted for sample sizes of 5, 7, 9, and 13 basket counts at Wizard Falls Hatchery, and 3 and 5 basket counts at Irrigon Hatchery. The process was repeated 40 times for each sample size at Wizard Falls Hatchery and 20 times for each sample size at Irrigon Hatchery. Fish weight estimates from each sample size were averaged and the 95% confidence limit determined from the standard error. The 95% confidence limit was then reported as a percent of the mean. For simplicity, this value is referred to as "error" in the Results and Discussion section.

A similar study was performed with two raceways of summer steelhead at Irrigon Hatchery on 24 March 1992. Fish were crowded to the lower half of the raceway with aluminum crowders and sampled as described for rainbow trout. All the fish in each raceway were weighed. Twenty basket samples from each pond were weighed and counted. Average sample weights were 9.1 and 10.4 kg (20.0 and 22.9 pounds) for raceways 9 and 13, respectively. Data was treated in a manner similar to that for rainbow trout.

On February 20-22, 1991, 14 raceways of chinook salmon at Willamette Hatchery were crowded and 35 basket samples were taken from each raceway. The samples were weighed and counted, but no attempt was made to weigh the remainder of the fish in the raceways. Samples averaged about 4.5 kg (10 pounds) in weight. Errors in estimates of fish size were calculated as described above.

To determine the effect of basket sample weight on the error in fish size determinations, we sampled chinook salmon in raceway

18 at Willamette Hatchery on 17 December 1991. Fish were crowded and the entire population was weighed and liberated behind the crowders. Samples were weighed and counted after every 20 kg of fish. This sampling regimen was done twice, once with net loads of fish that averaged 2.54 ± 0.10 kg (5.6 ± 0.2 pounds) and once with net loads that averaged 6.43 ± 0.21 kg (14.4 ± 0.5 pounds). Data were treated similarly to that of rainbow trout, except that plots of error versus sample size or percent of the population sampled were transformed logarithmically for comparison by regression analysis.

On 20 February 1992, we weighed three raceways of chinook salmon at Willamette Hatchery to determine the total weight of fish. Counts were performed as described above. Estimates of population size were compared between hatchery records, total weight of fish, and displacement values from liberation trucks.

RESULTS

Accuracy of the Challenger electronic scales used at Wizard Falls varied with the amount of weight placed on the scale. According to the scale specifications, accuracy varies from 22.65% at 3 kg to ±0.52% at 13 kg. Our measurements showed that the two scales used at Wizard Falls Hatchery were accurate to ±0.0% and ±2.5%, respectively, at 3 kg and ±0.42% and ±0.83%, respectively, at 13 kg. These errors seemed reasonably close to the scale specifications and these estimates of accuracy were used for the scales used at other hatcheries in this study.

Estimates of fish size decreased throughout the sampling period at Wizard Falls Hatchery (Fig. 1). No consistent change in fish size was observed at Irrigon Hatchery for the same group of trout, or for any of the other groups reported here. The reason for this change in size estimates was not determined but it suggests that, for best results, samples for size estimates should be taken throughout the inventory process.

The total weight of fish estimated from water displacement at Wizard Falls Hatchery was only about 1% different from the weight estimate by raceway inventory (Table 1). Within truck compartments, the difference varied from 2.2% to 0.68%. In compartments l-3, weight estimates from water displacement were less than pond weight estimates, whereas in compartments 4-5, displacment estimates were greater than pond estimates. The truck was moved after filling compartments l-3. This may have altered the readings from the displacement gauge.

The level of error in estimates of fish size from pond inventories depended upon the number of basket counts (Fig. 2A). Error ranged from 19.2% of the mean with three basket counts to 3.0% of the mean with 27 basket counts. Increasing the number of basket counts from 3 to 9 provided the most improvement in precision, while more than nine basket counts increased precision very little. Similar results were observed at both Wizard Falls and Irrigon Hatchery.

The level of variability also changed with percent of the population sampled. Average percent of the population weighed in each basket at Wizard Falls Hatchery was 0.25%, while an average of 0.65% of the population was weighed in each basket at Irrigon Hatchery. The relationship between error in weight estimation and the percent of the population sampled is shown in Fig. 2B. About 2% of the population at Wizard Falls Hatchery and 3% of the population at Irrigon Hatchery were required for best precision with the least effort.

To determine the variability of these estimates of error in different populations and species of fish, a second study was undertaken at Irrigon Hatchery with summer steelhead. Computation of errors in estimates of fish size suggested that the errors approached minimum values after 7-9 samples or 5% of the population was measured (Fig. 3). Population weights from the pond inventories were 3.7% and 6.1% higher in the two raceways examined than estimates derived from truck displacement measurements (Table 2).

Because of the design of the experiments with steelhead and rainbow trout, there was no way to determine if numbers of sample counts or the percent of the population sampled was more important for the precision of the size estimates. To examine this question more closely, we sampled spring chinook salmon at Willamette Hatchery. Thirty-four samples of either heavy (6.4 kg) or light (2.5 kg) baskets of fish were taken throughout two inventories of a single raceway. Fish from the heavy samples were estimated to be significantly larger than those from the light samples (Table 3). Minimum error was reached after 7-10 samples (Fig. 4). Equations describing the logarithmic transformation of error versus number of baskets from heavy and light baskets were $\ln$ (error) = -0.7784 $\ln$ (sample number) + 3.8786 and $\ln$ (error) = -0.7775 $\ln$ (sample number) + 3.7129, respectively. Correlation coefficient (R) for the logarithmic transformation of the relationship between error and number of samples was 0.963, while the logarithmic transformation of the relationship between error and percent of the population had a correlation coefficient of 0.875. These results suggested that the number of replicate samples was the primary factor decreasing the error in the estimates of the weight rather than the percent of the population that was sampled.

The minimum levels of error obtained at high sample numbers were greater at Willamette Hatchery than those observed for summer steelhead at Irrigon Hatchery or those for rainbow trout at Wizard Falls Hatchery. We considered two explanations for these differences: 1) The number of fish per basket was important for reducing the error in the weight estimates, and 2) the variability in fish size in the population determined the minimum error in weight estimates attainable.

The first of these hypotheses was tested by estimating the average number of fish per basket, obtained from the average size of the fish and the average basket size for each group of fish. When average number of fish per basket was plotted against minimum error of fish weight attained (usually at 20 samples), no significant relationship was observed (Fig. 5), suggesting that the number of fish counted in each basket had little effect on the error in the estimate of fish weight.

To test the second hypothesis, we determined fork lengths and standard deviations from all the samples described in this study. A significant ($P \leq 0.05$) relationship was found between the coefficient of variation (standard deviation/mean) of samples of fork lengths and the minimum errors of estimates of weights attained (Fig. 6). The correlation coefficient for this relationship was 0.664. This suggests that variability in fish size influences the minimum error associated with estimates of fish size, that is, one can obtain lower errors in estimates of fish size in populations of more uniform size.

DISCUSSION

Reports of studies on sampling fish for size are few and rarely reported in the literature. We found only passing references to techniques of inventoring raceways of fish. Klontz (1979) recommended a minimum of five samples containing 150 to 250 fish for sample counts. No single count should differ more than 10% from the others. He provided no evidence to support these recommendations, however. Leitritz and Lewis (1976) describe the methods used for determining fish per pound but do not consider the error associated with these estimates. Buchanan (1991) examined variations in length associated with sampling procedures and found few significant differences in length with a variety of sampling methods.

The present study provides some guidelines for sampling fish and estimating fish size for hatchery personnel. We recommend from our data that 1) samples for determination of fish per kilogram be taken throughout the weighing or loading period, and 2) 7-9 samples be taken for estimates of fish per kilogram to achieve minimum error. The minimum error achieved increases with the variation in size in the population. Sampling a percentage of the population does not seem to affect the error in the size estimate as much as the number of samples. Finally, error in the size estimate appears to be only slightly affected by the weight of the net loads of fish. We suggest for convenience that hatchery personnel use 7-9 net loads weighing only 2.5 kg each for making pond counts. Precautions should be taken, however, that the light net loads do not introduce a bias in the samples. For example, if a heavy net load of fish is sampled, it should not be lightened by allowing some of the fish to swim out.

Minimum errors in estimates of fish weight varied according to population of fish, but errors of 5% were common. This is only one source of error in the rather complex procedure of determining population numbers of fish. Therefore, it is not surprising that large discrepancies are sometimes observed between different methods of estimating populations. We have reported on another source of error, that of variable specific gravity of fish (Lewis et al., 1992). Other sources of error arise from the error associated with the scale, from changes in weight after periods of starvation and stress, and from lack of care in making the measurements of weight, displacement, or numbers. In any case, there seems to be little reason to blame predators for differences in population sizes estimated by different methods unless there is indisputable evidence of heavy predation.

Further studies of sampling fish in raceways should be performed to answer a number of pressing questions. For example, we have described experiments that examine the precision of estimates but not their accuracy. To determine the accuracy of population estimates, the entire raceway of fish should be counted and estimates compared to that value (Buchanan, 1992). Also, we have not extensively examined the changes in weight that may occur from periods of starvation or stress diuresis.

Preliminary studies have indicated that some changes may occur over relatively short periods of time. These changes may affect estimates of fish size and consequently population size. Finally, alternative methods for population estimates, such as marked/unmarked ratios in coded-wire tagged fish (Schaefer, 1951), impedance counters (Liscom and Volz, 1975), or image analyses, should be explored.

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FIGURE LEGENDS

Fig. 1. Average weight of rainbow trout estimated from basket weights and counts throughout an inventory at Wizard Falls (-•-) and Irrigon (-A-) Fish Hatcheries.

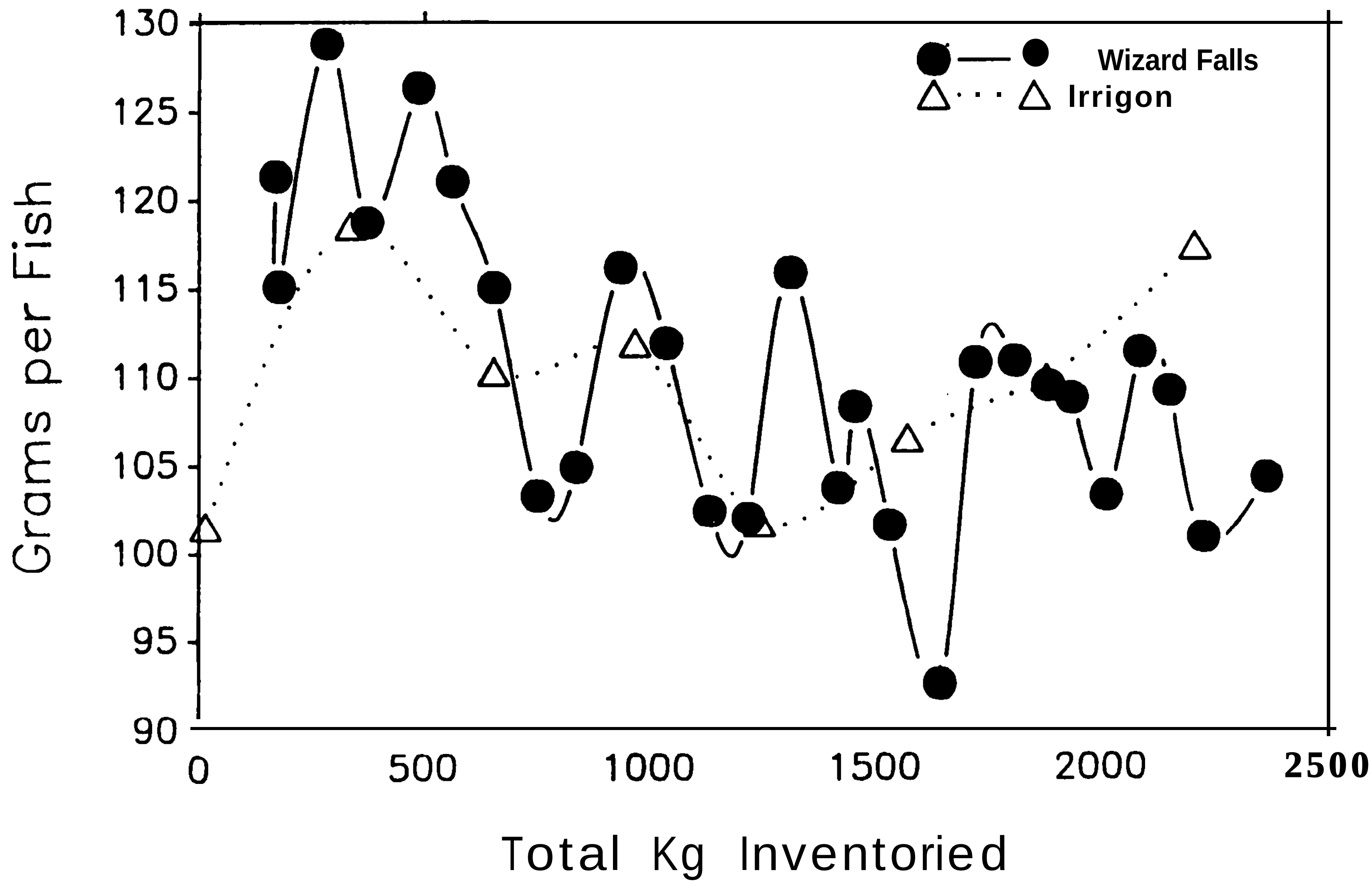
Fig. 2. Average error (95% confidence interval as a percent of the mean) in estimates of rainbow trout weight at Wizard Falls (-0-) and Irrigon (-•-) Fish Hatcheries in relation to (A) number of basket counts or (B) percent of the population sampled.

Fig. 3. Average error (95% confidence interval as a percent of the mean) in estimates of summer steelhead weight at Irrigon Hatchery in relation to (A) number of basket counts or (B) percent of the population sampled.

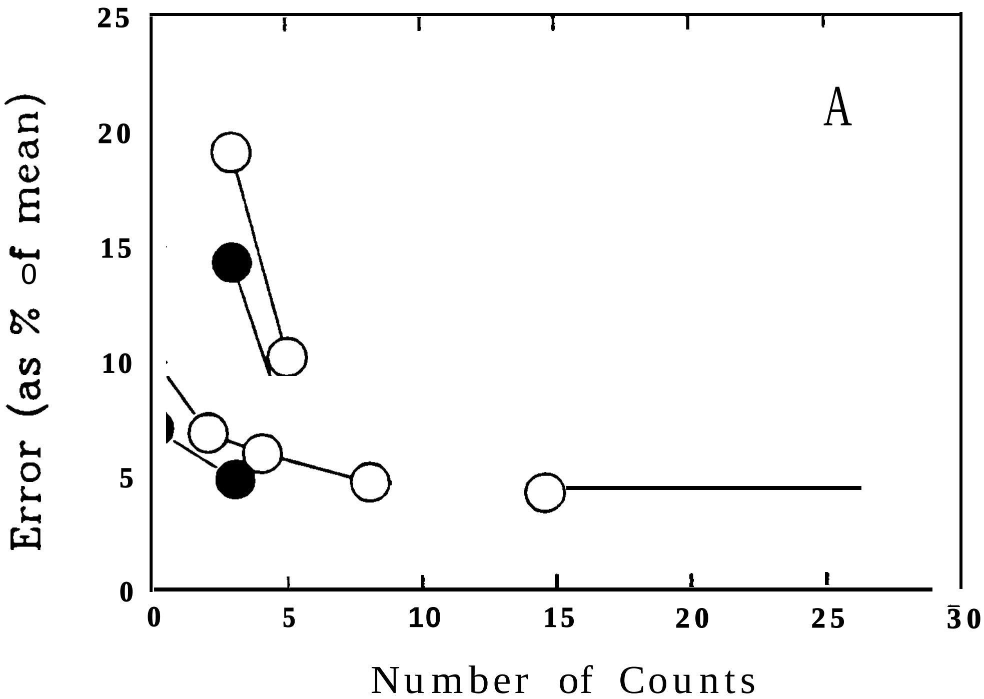
Fig. 4. Average error (95% confidence interval as a percent of the mean) in estimates of weight of chinook salmon at Willamette Hatchery in relation to (A) number of basket counts or (B) percent of the population sampled. Heavy baskets, -●-●-; light baskets, -O-O-.

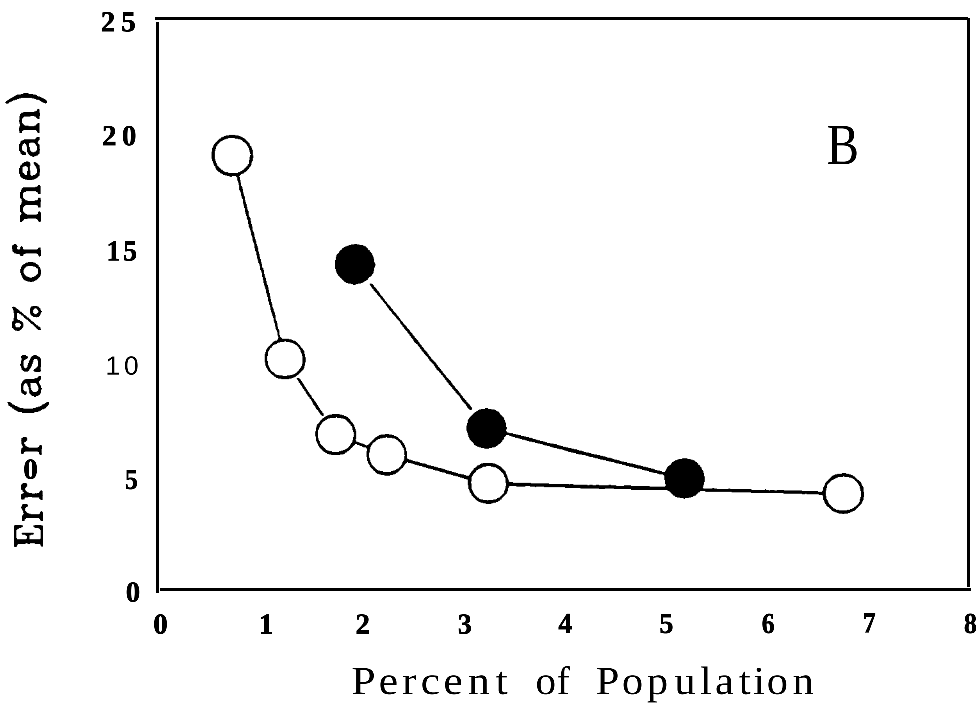
Fig. 5. Relationship between the average number of fish in a basket during weighing and the minimum error attained in estimates of fish weight.

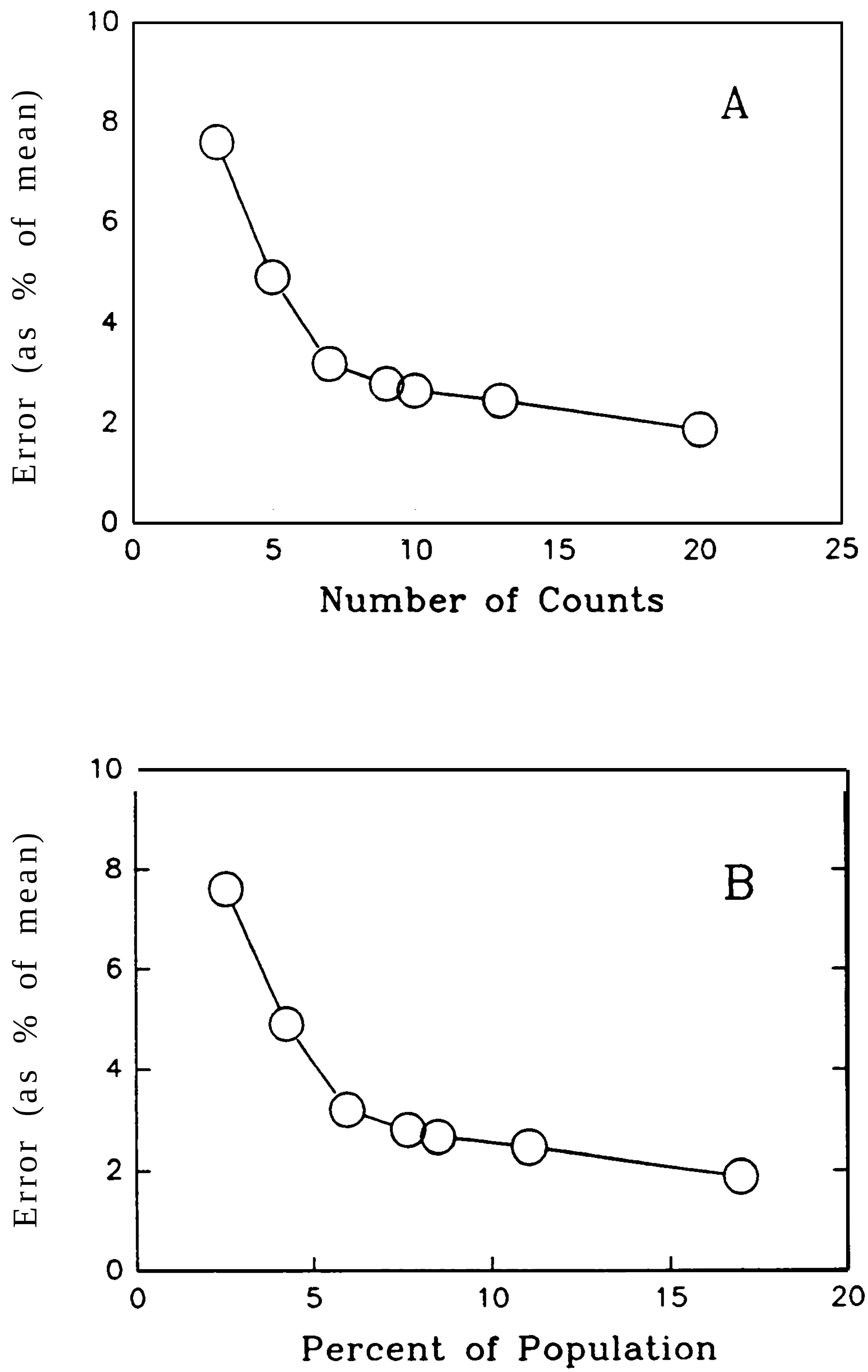
Fig. 6. Relationship between coefficient of variation (standard deviation/mean) of fork lengths of all populations of fish measured in this study and the minimum error attained in estimates of fish weight.

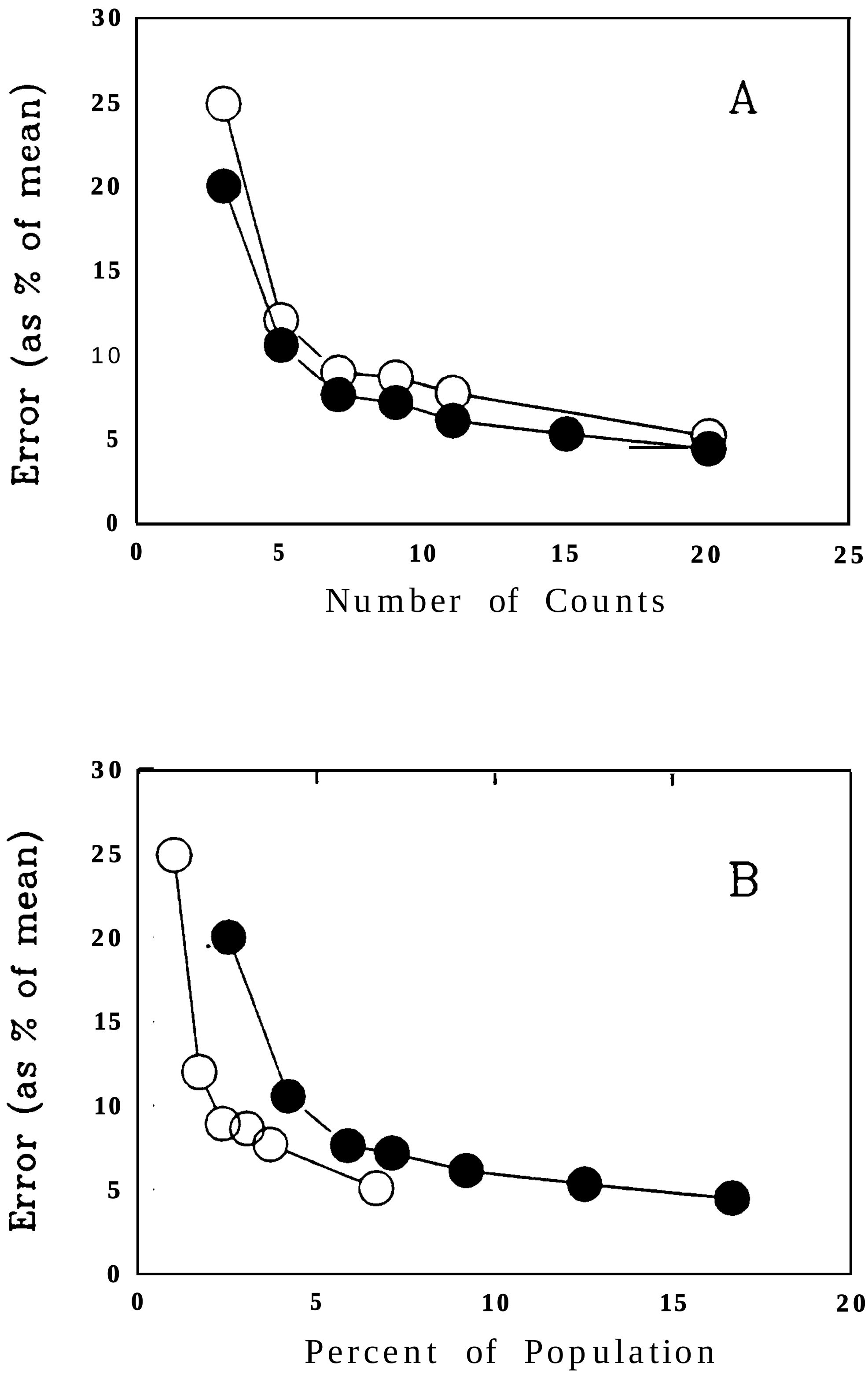


Wizard Falls
Irrigon
Grams per Fish
130
125
120
115
110
105
100
95
90
0
500
1000
1500
2000
2500
Total Kg Inventoried

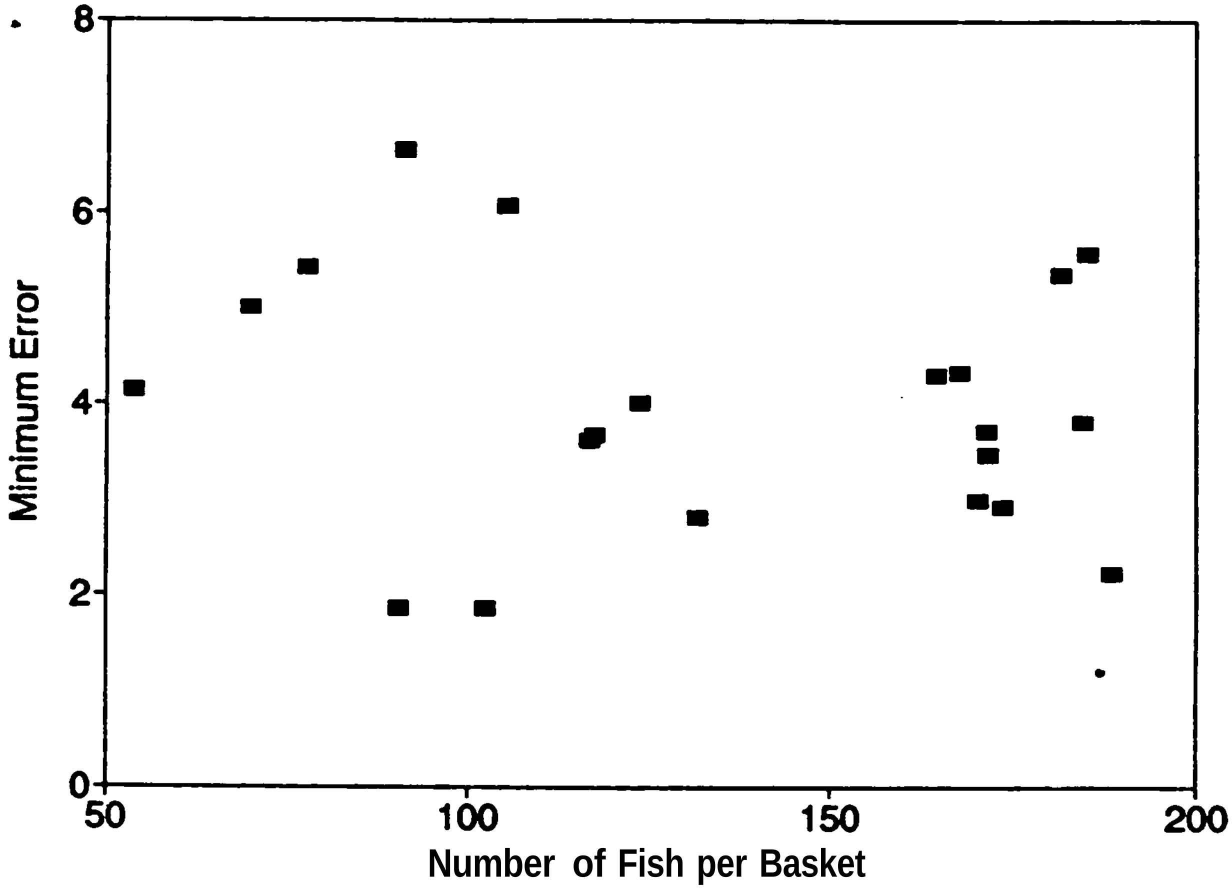

A
Error (as % of mean)
Number of Counts
0
5
10
15
20
25
30

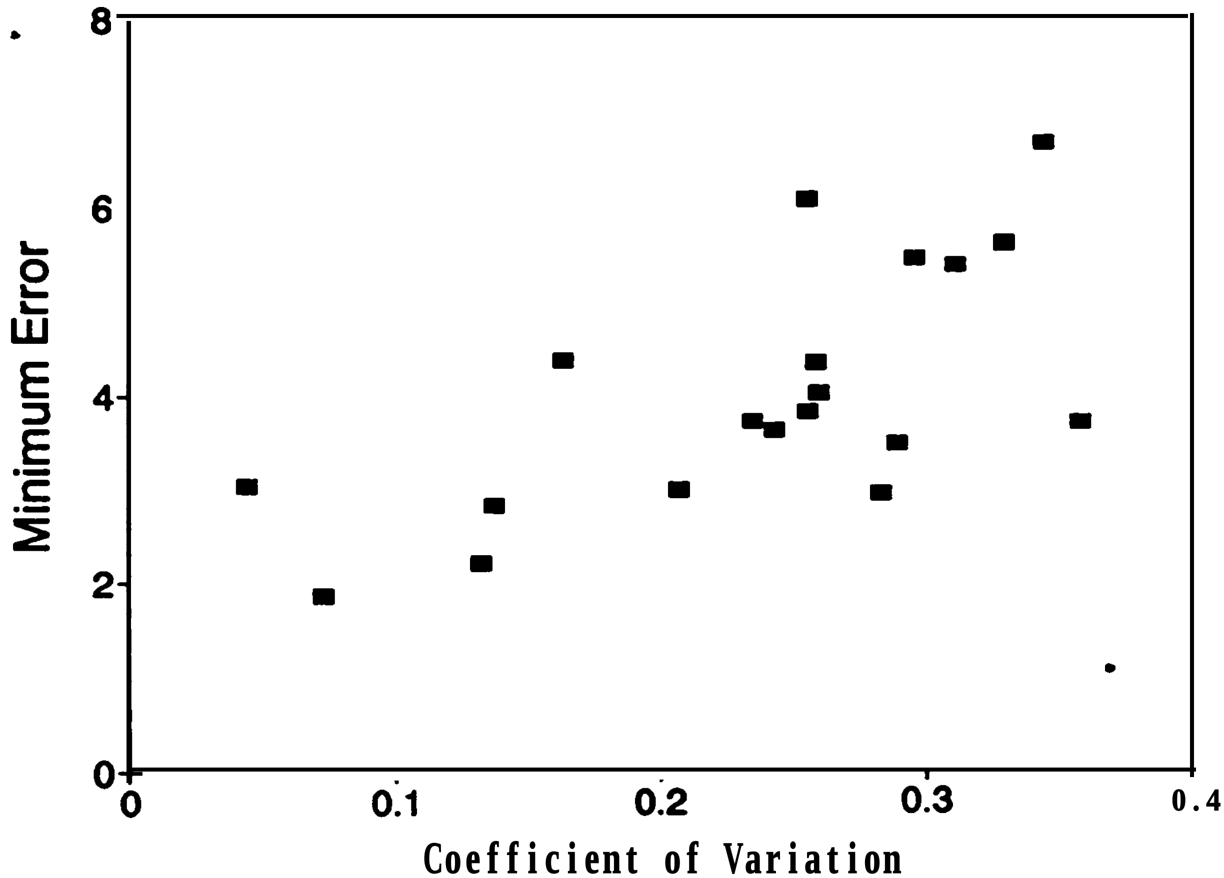

B
Error (as % of mean)
Percent of Population
0
1
2
3
4
5
6
7
8
10
15
20
25


A
Error (as % of mean)
Number of Counts
0
5
10
15
20
25
0
2
4
6
8
10
B
Error (as % of mean)
Percent of Population
0
5
10
15
20
0
2
4
6
8
10



A
Error (as % of mean)
Number of Counts
B
Error (as % of mean)
Percent of Population


8
6
4
2
0
Minimum Error
50
100
150
200
Number of Fish per Basket



Minimum Error
8
6
4
2
0
0
0.1
0.2
0.3
0.4
Coefficient of Variation

Table 1. Comparison of estimates of total weights of rainbow trout by hatchery inventory and by liberation truck displacements.

Truck Compartment	Weight Estimates (kg) Inventory	Displacement	Percent Difference
1	487.3	478.5	1.84
2,3	933.0	911.7	2.34
4,5	948.3	954.8	0.69
Total	2,368.5	2,345.0	1.00

Table 2. Comparison of estimates of weights and population numbers in two ponds of summer steelhead at Irrigon Hatchery. Estimates were derived from hatchery inventories or from displacement of water on liberation trucks.

	Pond 9	Pond 13
Average fish weight (g; mean ± standard error)	100.62 ± 0.90	101.62 ± 0.83
Total kg fish		
Inventory	1,064.3	2,392.1
Displacement	1,025-l	2,245.3
Difference	39.2	146.8
Population estimates		
Inventory	10,578	23,682
Displacement	10,188	22,230
Difference	390	1,452
Percent Difference*	3.7%	6.1%

*Percent difference was calculated from the difference in weight or fish number between methods divided by the estimate of weight or fish number derived from hatchery inventory methods.

Table 3. Comparison of weights and population numbers of spring chinook salmon in pond 8 at Willamette Hatchery when sampled by light and heavy basket loads. Values are means ± standard errors.

	Basket Size	
	Light	Heavy
Average basket weight (kg)	2.54 ± 0.10	6.43 ± 0.21
Average fish weight (g)	36.76 ± 0.71	39.29 ± 0.61
Total kg weighed	768.22	774.20
Estimate of population	20,898	19,707
Population size from hatchery inventory	20,037	
Percent of hatchery inventory	104%	98%