Culture of Chinook Salmon (*Oncorhynchus tshawytscha*) in Iron-Rich Groundwater: Stuart Pilot Hatchery Experiences

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September 1987

Canadian Manuscript Report of
Fisheries and Aquatic Sciences
No. 1944

eries Pêches
Oceans et Océans

Canada

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by

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Cat. No. Fs 97-41/1944 ISSN 0706-6473

Correct Citation for this publication:

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TABLE OF CONTENTS

ABSTRACT

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Chinook salmon (Oncorhynchus tshawytscha) were cultured at a pilot hatchery located in Fort Saint James, B.C., during 1981 and 1982-83, to test the suitability of the water from a deep, artesian well as a potential source for an enhancement facility to serve local stocks. The water is anoxic and has an iron content averaging 0.5 mg/L, which produces a heavy, red-brown flocculant when it is aerated. In 1981, studies showed that rearing fish from 1.0 to 3.5 g in iron-enriched water containing up to 5.0 mg/L of iron did not decrease survival and only slightly decreased growth rate compared to fish reared in filtered water (0.02 mg/L iron). Studies in 1982-83 showed that raw well water (0.3-1.0 mg/L iron) caused severe mortalities in incubating eggs and newly hatched alevins, due to suffocation by precipitated floc. Again, rearing success was not affected by iron content. It was concluded that simple aeration and mechanical filtration during the incubation phase of operation would make this water suitable for fish culture.

RÉSUMÉ

MacKinlay, D.D., D.D. MacDonald, M.K. Johnson and R.F. Fielden. 1987. Culture of chinook salmon (Oncorhynchus tshawytscha) in iron-rich groundwater: Stuart Pilot Hatchery experiences 1981-1983. Can. MS Rep. Fish. Aquat. Sci. 1944: 45 p.

Les auteurs ont élevé des saumons quinnats (Oncorhynchus tshawytscha) dans une installation piscicole pilote située à Fort Saint James (C.-B). Cet essai réalisé en 1981 et 1982-1983 avait pour but de vérifier si l'eau d'un puits foré profond pouvait servir à une installation de mise en valeur des stocks locaux. L'eau du puits est anoxique et présente une teneur de fer moyenne de 0,5 mg/L qui est la cause de la formation d'un important floc rouge-brun au moment de son aération. Des études effectuées en 1981 ont montré que la croissance des poissons, d'un poids de 1,0 g à 3,5g, dans une eau enrichie de fer jusqu'à une teneur de 5,0 mg/L n'avait pas pour effet de réduire la survie et ne réduisait que légérement le taux de croissance comparativement aux poissons témoins élevés en eau filtrée (0,02 mg/L de fer). Les études réalisées en 1982-1983 ont montré que l'eau du puits non filtrée provoquait une mortalité très élevée chez les oeufs en incubation et les alevins nouvellement èclos qui étaient suffoquées par le floc. Mais, ici aussi, la teneur en fer n'affectait pas la croissance. Les auteurs concluent qu'une simple aération suivie d'une filtration mécanique de l'eau au cours de l'étape d'incubation permettrait d'utiliser cette eau à des fins piscicoles.

INTRODUCTION

BACKGROUND

The Stuart Pilot Hatchery site is situated on a 6 ha tract of land in the village of Fort St. James, B.C. on the southeast end of Stuart Lake in the upper Fraser River drainage (Figure 1). The area has been proposed as a possible production hatchery location for enhancement of chinook salmon (Oncorhynchus tshawytscha) stocks from the Nechako, Stuart and Salmon Rivers. The Fort St. James site was considered to have potential because:

1) A large artesian aquifer of approximately 4 km^2, from which Fort St. James draws its domestic water supply, could provide an enhancement facility with relatively warm (9°C) water.
2) Three-phase B.C. Hydro line power, road access and other amenities are available very close to the site.
3) The site is relatively close to chinook spawning grounds on the Stuart River and centrally located to service stocks from the Salmon and Nechako River systems.

Initial water quality analyses revealed that the water was not ideally suited for fish culture, because of supersaturated nitrogen, virtually nil oxygen and high iron concentrations. The gas pressures were not of concern because they could be rectified with aeration. However, the iron concentrations, which marginally exceeded the recommended fish culture limit of 0.3 mg/L (Sigma, 1983 Taylor and Pierce, 1987) may have been unacceptable. The criterion for iron concentration was not clearly defined, so it was not known whether the levels would have to be reduced.

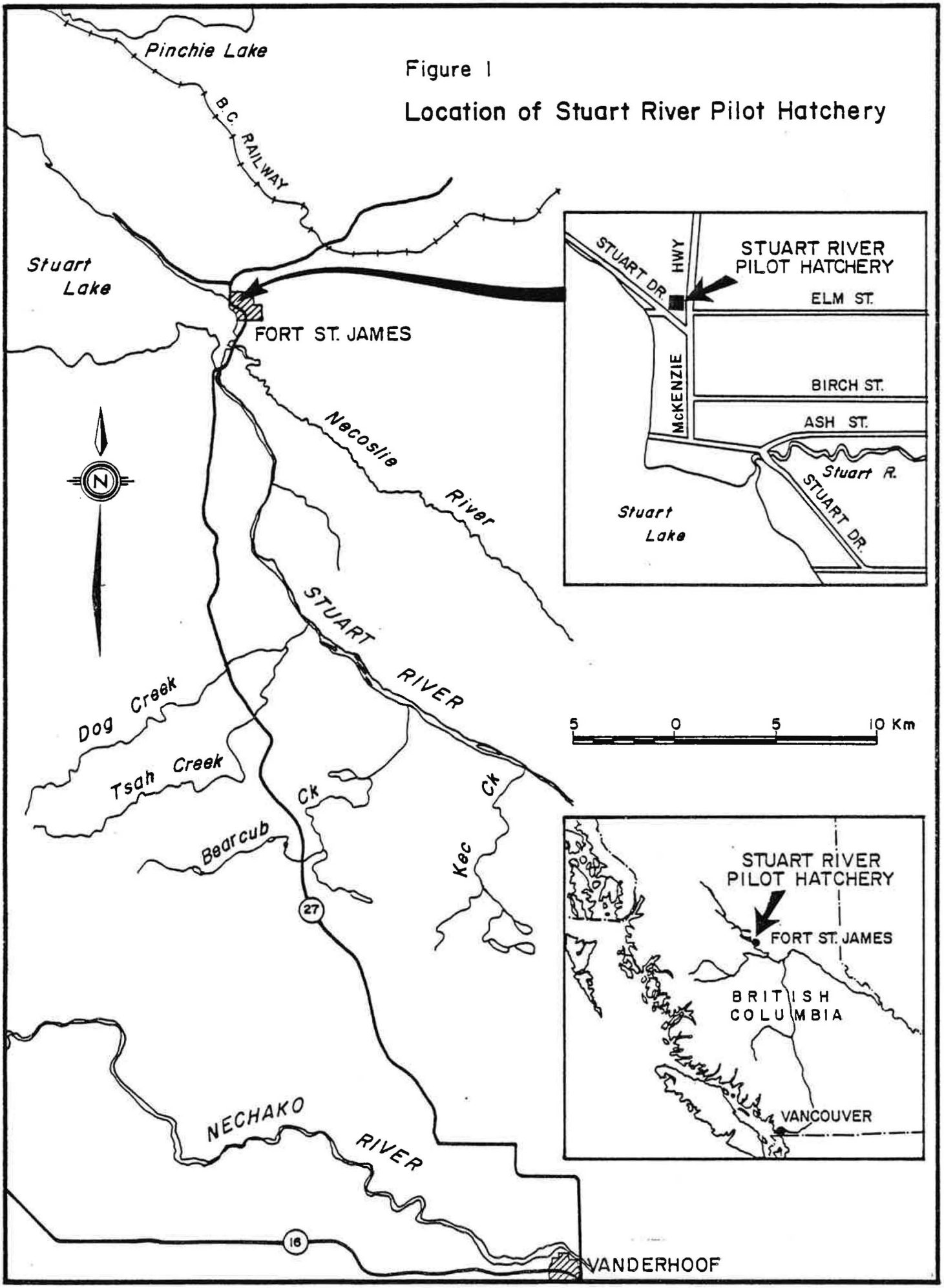
When iron is present in anoxic water, such as that of the Fort St. James groundwater aquifer, it usually exists in the soluble ferrous (Fe^{+2}) form. When the water is aerated, the increased oxygen causes the iron to be oxidized to the insoluble ferric (Fe^{+3}) form which precipitates out of solution, primarily as ferric hydroxide according to the equation:

$$2H_2O + Fe^{++} + O_2 \rightleftharpoons Fe(OH)_3(ppt) + OH^-$$

This iron precipitate, or 'floc', has been found to cause fish culture problems by coating chorionic membranes of embryos or clogging gill surfaces of rearing

Figure 1

Location of Stuart River Pilot Hatchery



fry, thereby impeding dissolved gas and metabolic waste transport (Smith et al., 1973). Smith and Sykora (1976) suggested criteria of 1 mg/L Fe for coho salmon and 7.5 mg/L Fe for brook trout, after several studies showed no ill effects of rearing fish in various concentrations. A detailed look at the experimental procedures used in their tests, which used small numbers of eggs of fish suspended in large aquaria with pulse input of iron-laden water and bubble aeration, indicated that since their conditions were not at all like the conditions in production-scale hatcheries, their resultant criteria may not be applicable.

Furthermore, the mortality and growth rate measurements used in standard bioassays do not take into account more subtle effects which may affect the survival of the animals after their release into the wild. The purpose of the Salmonid Enhancement Program's facilities is to produce adult salmon to rehabilitate fisheries and escapements, not simply to produce fingerlings for release. Fish that survive a bioassay may have been affected in some subtle way that would decrease (or increase) their survival to adult.

Therefore it was felt that a bioassay was necessary before a full-scale hatchery could be committed to this water supply.

OBJECTIVES

The overall objective of the Stuart Pilot Hatchery was to test the suitability of water from the Fort St. James artesian aquifer for salmon culture. The pilot program primarily investigated the effects of iron on the incubation and rearing of chinook salmon. The program objectives were:

1. To conduct bioassays on incubating and rearing chinook salmon to determine the degree of iron-removal treatment necessary to provide suitable water for fish culture.

2. To examine the sublethal effects of various iron concentrations on incubating and rearing chinook.

3. To develop and assess a simple filtration system to effectively decrease the iron floc in the hatchery water.

4. To release tagged fish of two sizes to determine overall and comparative survival to adult.

METHODS

FACILITIES

A 200 mm diameter, 72 m deep well was drilled into the Fort St. James aquifer at the hatchery site in 1979. The well produced a steady-state free flow of 2400 LPM through a 75 mm diameter supply pipe at 40 psi pressure, which is equivalent to a hydrostatic head of 28 m.

The original facility to conduct rearing experiments was built in June 1981 (Figure 2). A 75 mm diameter steel pipe from the wellhead fed into the top of a six-segment, 200 mm diameter packed column that projected through the roof of a 45 m^2 metal sheathed building (Figure 3). The packed column was placed over a 1.2 m long x 1.2 m wide x 1.0 m deep plywood head tank that acted as a catchment basin for the aerator and provided gravity-feed water to the rest of the facility. A plywood retention tank, the same size as the head tank, was placed adjacent to the head tank to allow the iron floc formed in the aeration process to agglomerate into larger particles and settle out. The retention tank had a theoretical retention time of 2.4 hr at the highest flow used.

A total of 4,500 fry could be reared in three groups of three 35 L plastic tubs (Figure 4). One group was plumbed into a 0.6 m wide x 0.6 m long x 1.2 m high plywood box filled with silica sand which was designed to filter out the iron floc. Water from the retention tank entered the top of the filter box, which then percolated through the sand and out through a bottom drain. A high pressure line was connected to the bottom of the filter box directly from the wellhead to occasionally backflush the system and clean the sand. The second group of tubs were supplied with aerated, unfiltered water from the retention tank. The third group of rearing tubs was connected to a mixing tank, to which a ferrous sulphate solution from a Mariotte bottle (Engstrom-Heg, 1971) could be added to aerated, unfiltered water. This arrangement allowed fry to be reared in filtered water, unfiltered water and iron-added water, giving three widely different levels of iron concentration.

This facility was operated during the summer of 1981, then was closed down due to lack of funds until August of 1982. For the 1982/83 Pilot, the building size was doubled and the facilities were expanded to include incubation and increased rearing space (Figures 5, 6 & 7). Four eight-tray vertical incubator stacks (Figure 8) and four 2.3 m^3 capacity aluminum Capilano-style rearing troughs (Figure 9) were installed, and the plastic rearing tubs were removed.

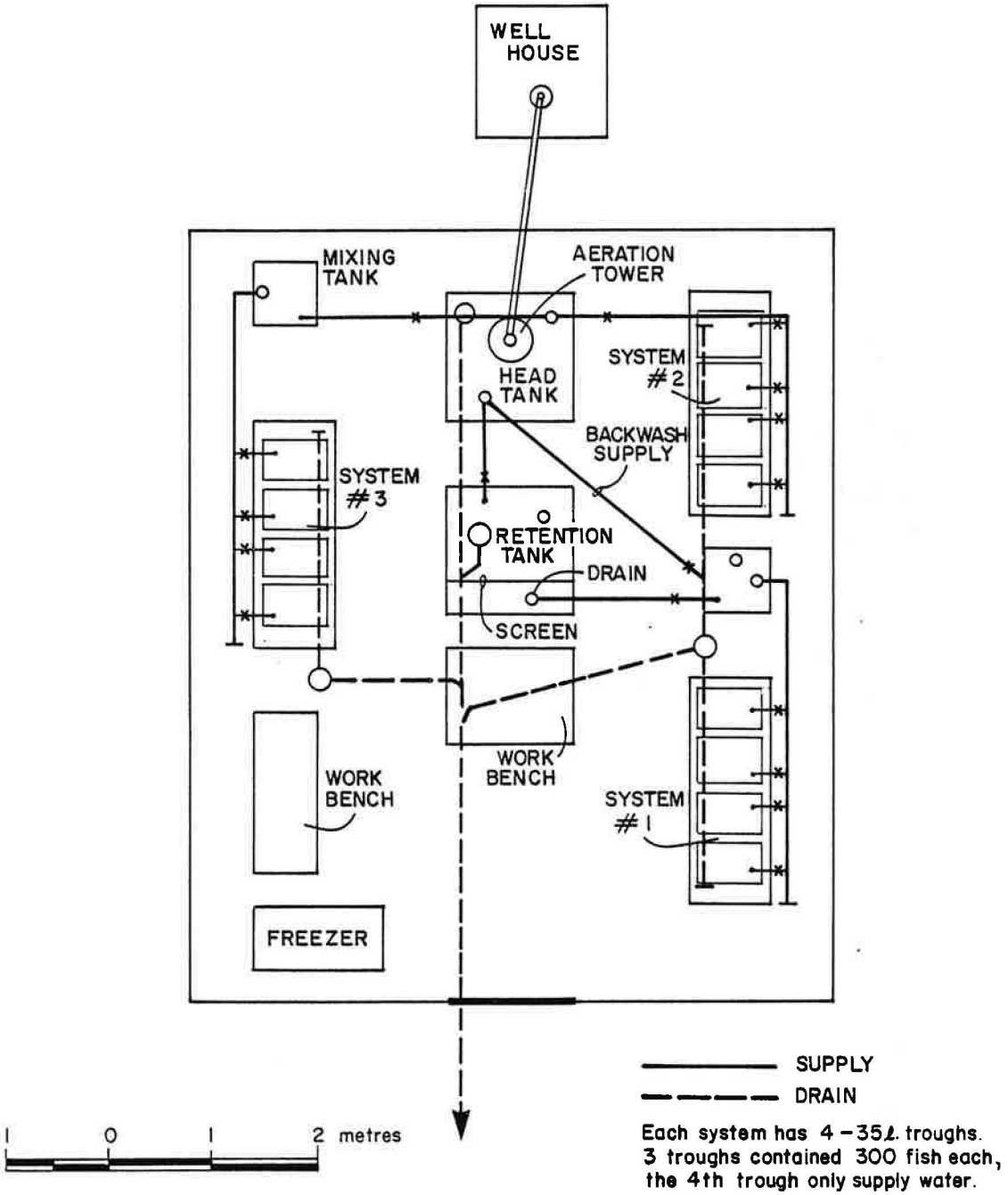
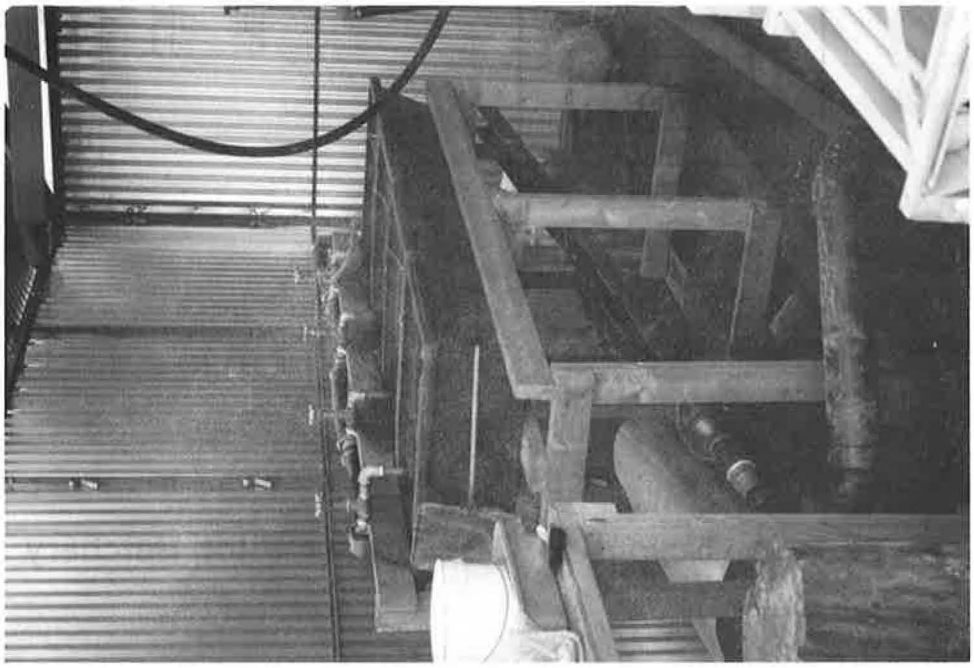


Figure 2 Layout of 1981 Stuart Pilot Hatchery

Figure 3
1981 Hatchery and Aeration Column

Figure 4
1981 Pilot Rearing Facilities



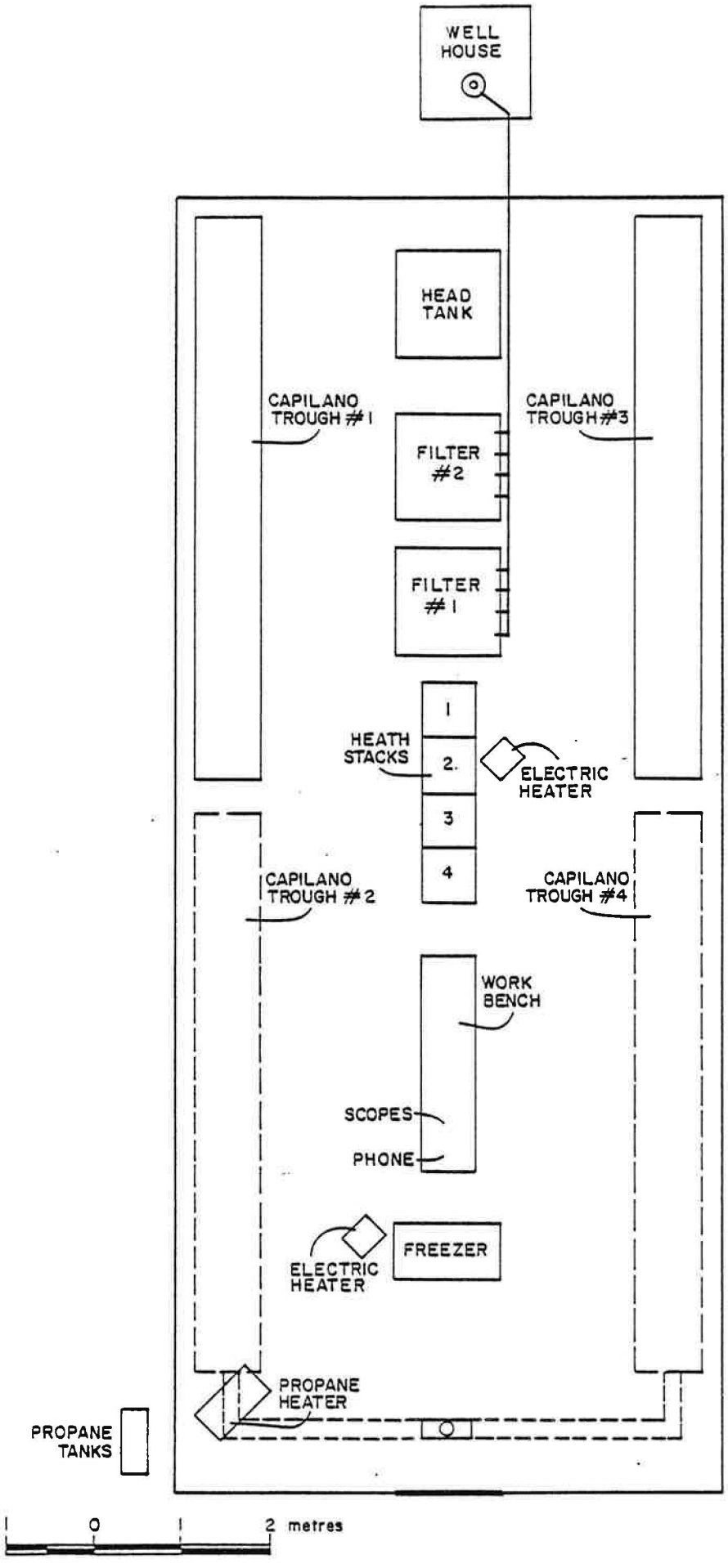


Figure 5 Layout of 1982/83 Stuart Pilot Hatchery

Figure 6
Picture of 1982/83 Pilot Building Exterior

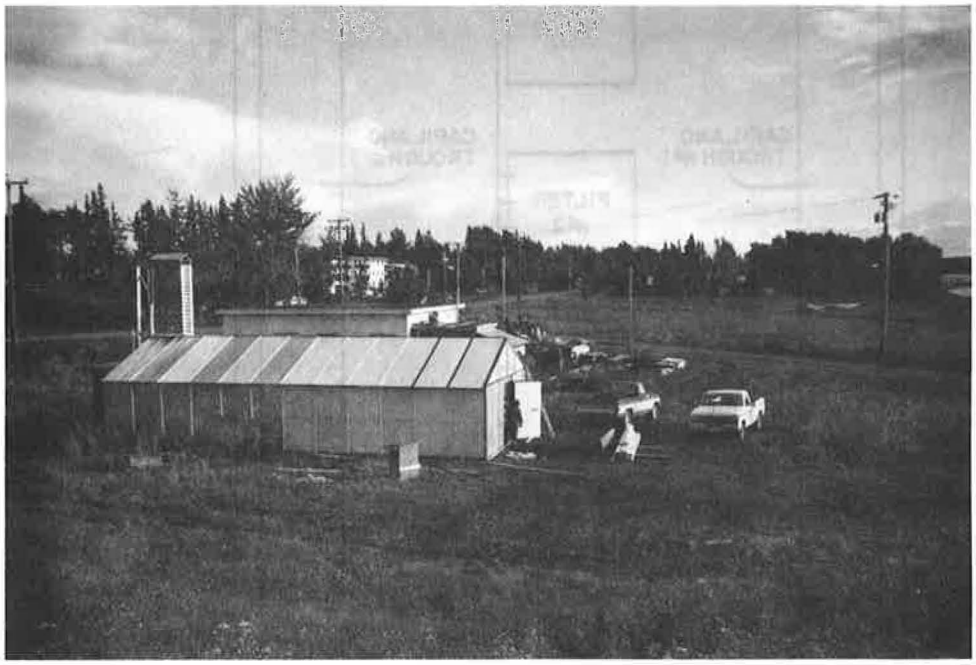
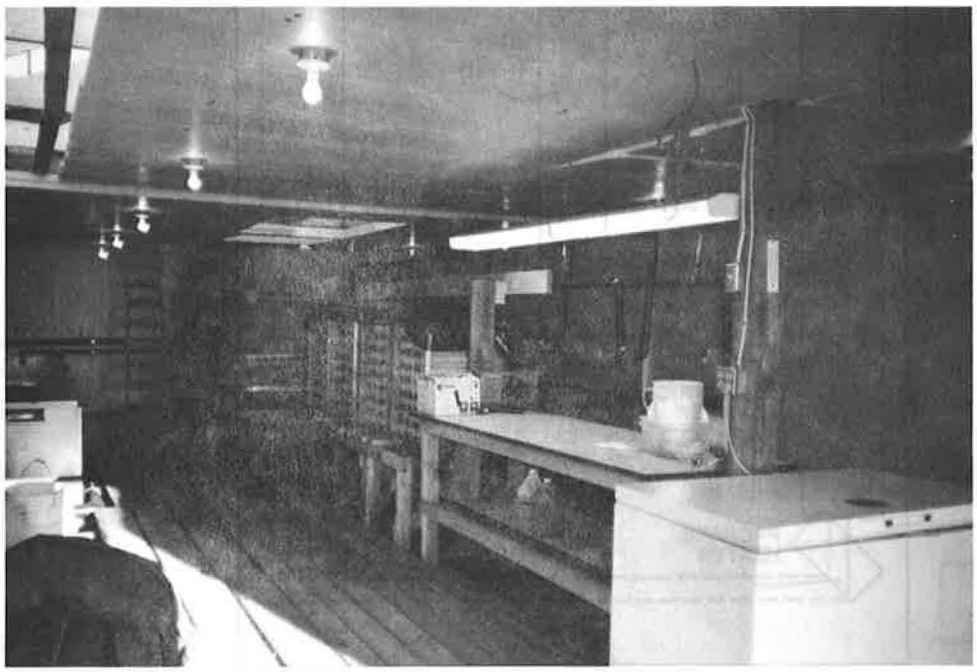
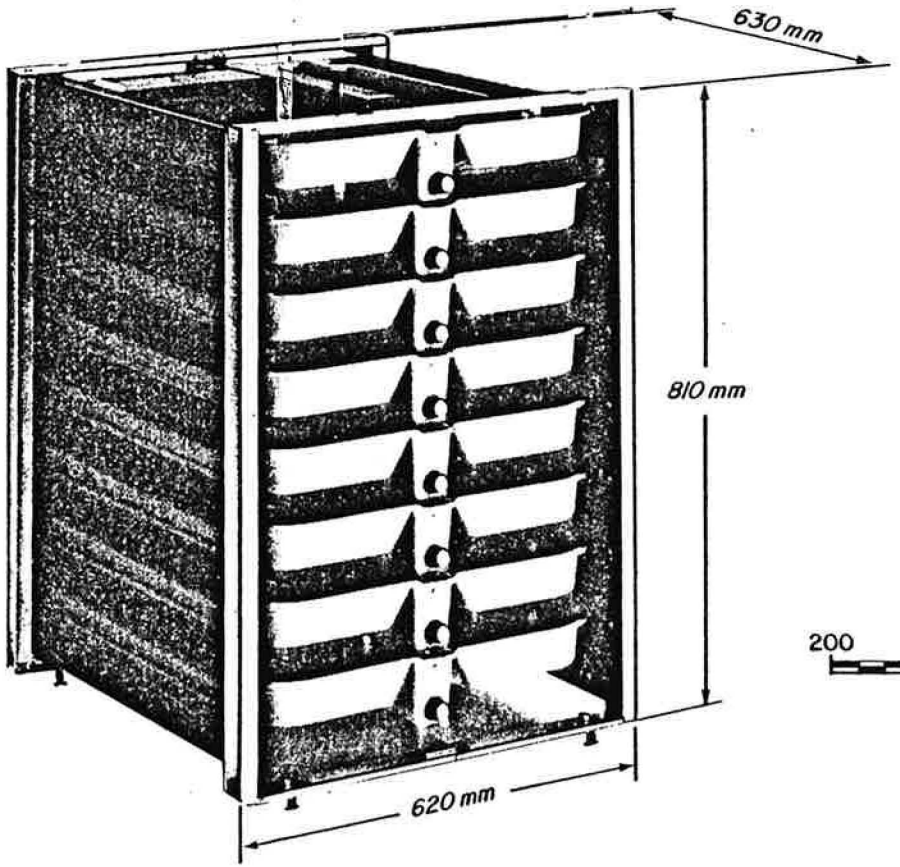


Figure 7
Picture of 1982/83 Pilot Interior





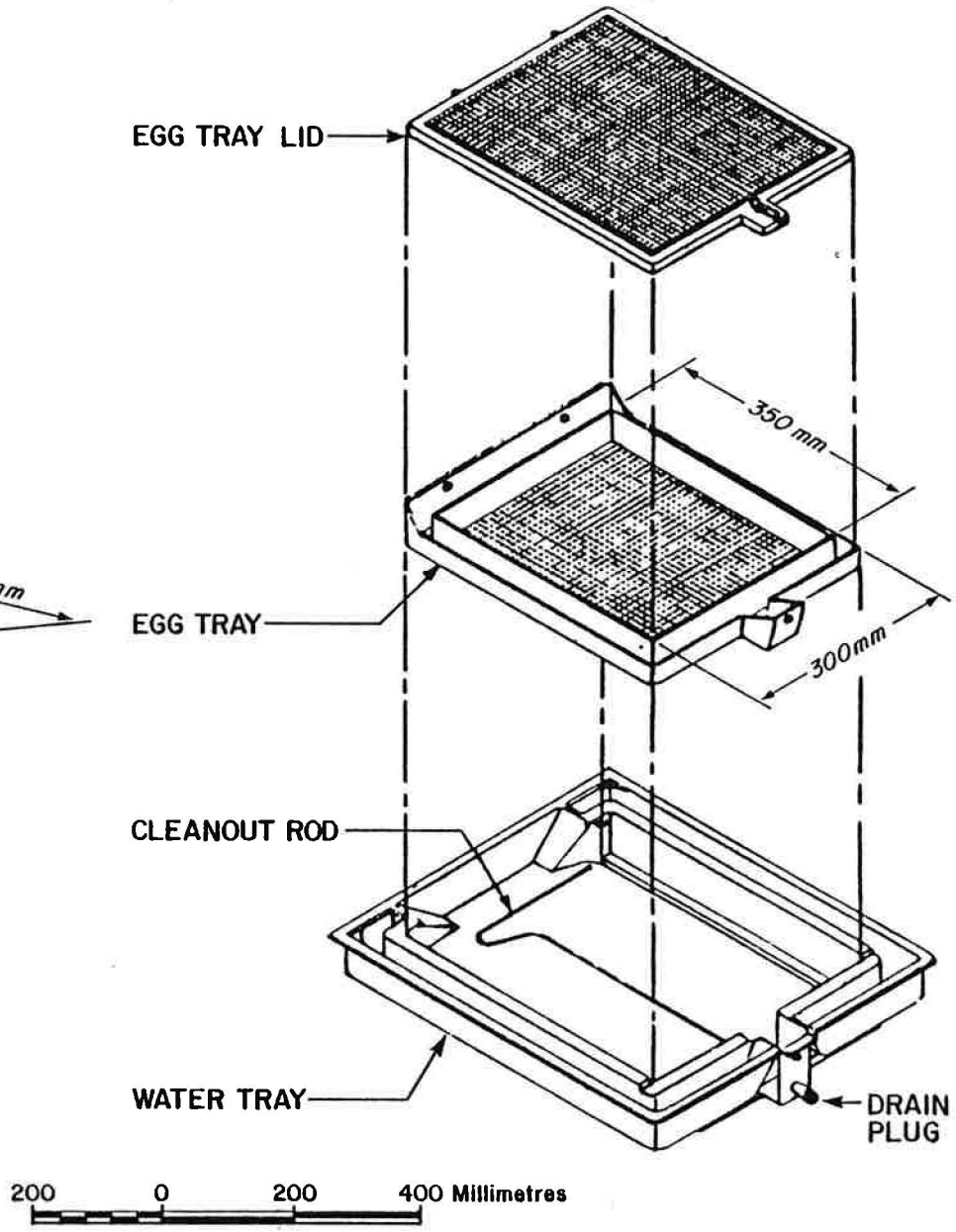
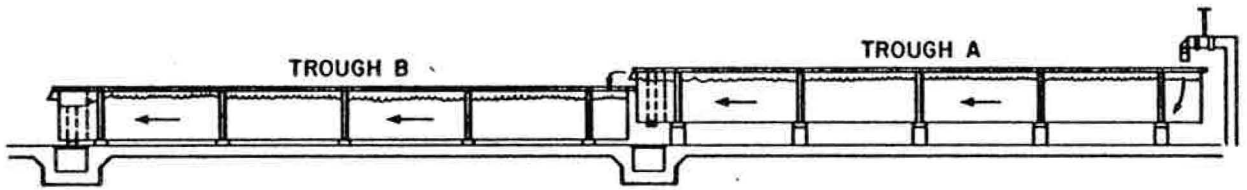


Figure 8 Vertical Tray Incubator



SIDE VIEW OF ARRANGEMENT

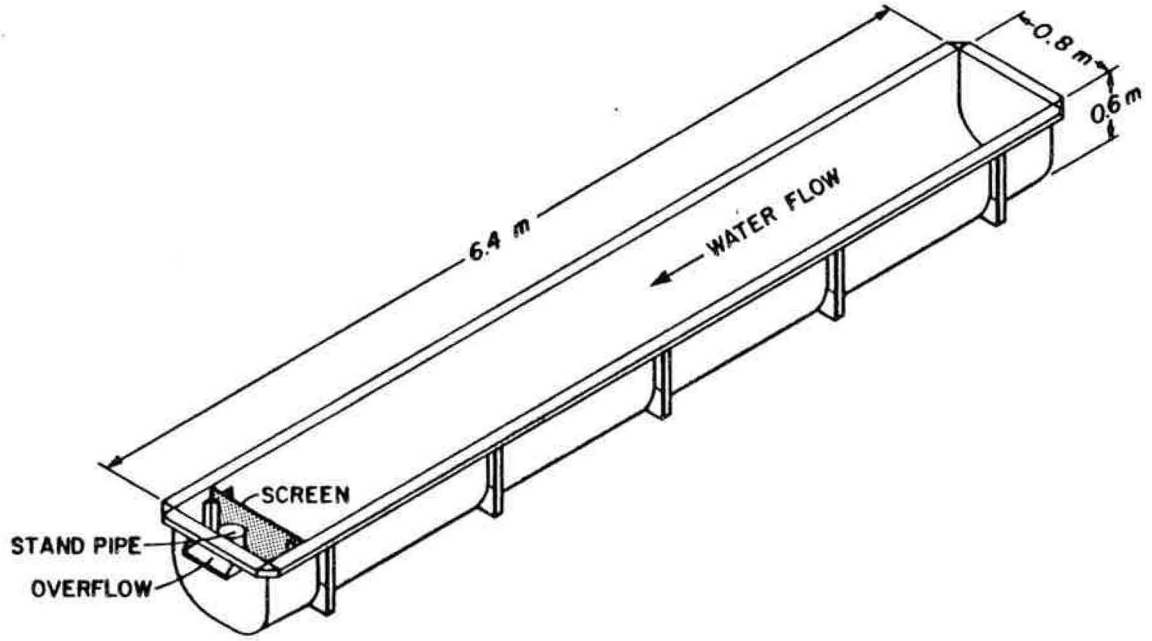


Figure 9 Capilano Style Rearing Trough

The single, small sand filter was replaced with two 1.2 m x 1.2 m x 1.2 m plywood boxes filled with 20 cm of pea gravel on the bottom and 30 cm of silica sand on the gravel (Figure 10). A prototype test showed that the 30 cm depth of sand would be sufficient to reduce the iron concentration considerably while maintaining the maximum flow of 530 LPM of flow required for filtered water rearing. Water from the head tank flowed into the top of each filter box, then percolated through the sand and into the filtered water supply manifold at the bottom. The gravel was placed on the bottom of each filter to prevent sand from entering the outlet, as it had during the first pilot. A high pressure line connected to the outflow manifolds allowed the filters to be backwashed.

Polyester aquarium floss was used as an additional filter medium. During incubation, floss was packed into the top tray of each of the filtered water incubator stacks. The floss was replaced every few days when it became clogged. Polyester floss also was sandwiched between two expanded aluminium screens in a box at the head end of one of the filtered-water Capilano troughs to supplement filtration of rearing water.

To improve the aeration of the well water, three more segments were added to the packed column aerator for the 1982/83 Pilot. The column was also enclosed in a wooden tower with louvered walls to provide some shelter from the wind and cold during the winter.

WATER QUALITY

Water samples were taken from the Stuart Pilot Hatchery during pumptesting April 8-10, 1980. Additional full-series samples were collected once during the 1981 Pilot and three times during the 1982/83 Pilot, mainly to monitor filter performance and iron concentrations in unfiltered water. The samples were collected in three plastic containers; a 200 mL bottle with 10 mL of nitric dichromate preservative for mercury analysis; a 200 mL bottle with 1 mL of nitric acid added for analysis of extractable metals; and a 2 L container for analysis of pH, nutrients, residues and other general parameters. Temperature, dissolved oxygen, tensiometer pressure and pH were measured *in situ*. The samples were delivered to the Department of Fisheries West Vancouver Water Quality Laboratory for analyses. Sample analysis followed the methods outlined in Environmental Protection Service (1979).

Nitrogen and total gas pressures were calculated from saturation measurements made with a Novatech model 300B tensionometer. Measurements were made on several occasions prior to the start-up of the Pilot and during the Pilot's

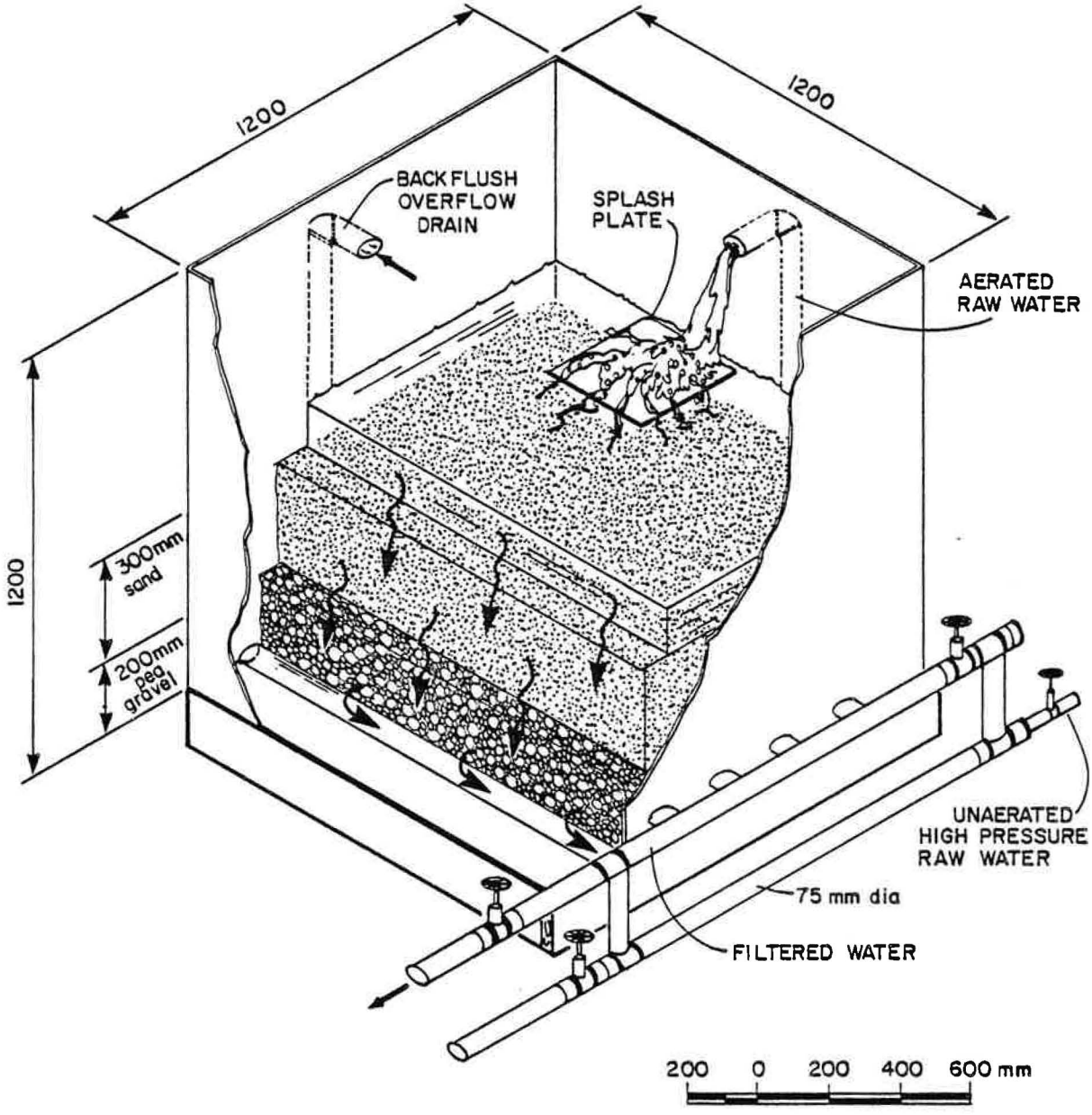


Figure 10 Cutaway of Filter for 1982/83 Stuart Pilot Hatchery

operation. Oxygen measurements were taken almost daily during the rearing studies of the two Pilots, using the modified Winkler technique (APHA, 1985).

Hatchery well water temperatures were monitored with a Ryan thermograph from November 1981 to March 1982 when the facility was not operating. The thermograph was set in a bucket fed by a bleed line inside the insulated wellhouse. Temperatures were measured daily with a handheld thermometer while the hatchery was in operation. In situ iron concentration tests were made daily with a portable analysis kit during the 1981 Pilot. For the 1982/83 Pilot, all the iron concentrations were determined from water samples sent to the West Vancouver Laboratory, because the portable analysis kit measurements were found to be inaccurate in 1981.

ADULT COLLECTION AND EGG TAKE

The 1981 Stuart Pilot used Slim Creek chinook fry transferred from the Penny Pilot Hatchery, so no adult collection, egg take or incubation were required.

Adult broodstock for the 1982/83 Pilot were collected by drifting 14 cm and 18 cm mesh-sized tangle nets through the spawning areas in the vicinity of Dog Creek above Six Mile Island on the Stuart River (Figure 1).

When ripe fish were captured, sperm was stripped first from live males into dry jars. Special care was taken to avoid mixing any water with the sperm. The sperm from each male was then poured into a separate Whirl-pak bag and placed on ice. Females were then killed with a blow to the head, the gill arches were severed and the fish were hung by the tail to bleed. After being wiped dry, the females were held over a dry plastic basin and the eggs were gently spilled into the basin from an incision made from the ovipositer to the anterior end of the body cavity. The eggs were stored in 2 L or 5 L containers, which were placed on ice in coolers and transported by boat and then truck to the hatchery.

At the hatchery site, 100 mL samples of eggs were taken and counted to determine the number of eggs per liter. The total volume of eggs was then measured to estimate the total numbers. This measurement of egg numbers was an approximation because it included the volume of the ovarian fluid with the eggs. A more accurate estimate of egg numbers was made after the eggs had water-hardened and again when they reached the eyed stage. However, the most accurate estimates were made from the subtraction of incubation and rearing mortalities from the

numbers tagged and released at the end of the rearing program. Fish numbers in this report are based on this latter method of estimation.

INCUBATION

Eggs were incubated at the Stuart Pilot in 1982/83 only.

At the hatchery, the eggs were divided into 1250 mL lots and the sperm from 3-5 males was mixed in. Water was added, then the mixture was allowed to stand 2-3 min before rinsing. The eggs were then poured into the incubator trays to water-harden for 5 min. The trays were then pulled out slightly, drained and filled with an Ovidine solution (13.5 mL Ovidine/L water) for 10 min to disinfect the eggs. The trays were then replaced to allow rinsing and initiation of incubation.

The eggs were divided into two groups. One group of about 10,000 eggs was placed in a flow of unfiltered water. The second group of about 62,000 eggs was placed in filtered water.

The flows were set at 15 LPM per incubator stack. The flows were tested and reset as required every two weeks by pulling the top tray plug and recording the time required for the water to fill a 15 L bucket. The incubator tray stacks were covered with a double layer of black plastic to keep the eggs in darkness.

After the eggs had accumulated at least 300 accumulated thermal units (ATU in °C days) to ensure that they had reached the eyed stage, they were shocked by dropping them into 5 cm of water from a height of 0.6 m. The dead, white eggs were picked out 30 min later with blunt forceps. At this time, six 100 mL samples of eggs were counted so that the total number of dead and live eggs could be estimated from volumetric measurements. Representative samples of dead eggs were cleared in vinegar to determine fertilization rate. Each group of eggs and alevins was picked on three other occasions during incubation: on October 28, 1-2 wks before hatching started; when 100% of the hatch was completed, (November 17-18 for the filtered group and November 26-27 for the unfiltered group); and just before ponding, December 25-27 for the filtered group and January 14 for the unfiltered group. The numerous egg picks allowed the survivals of the two groups to be assessed throughout incubation.

REARING

1981 Pilot

In order to carry out rearing studies during the summer of 1981, 3,850 1.0 g fry were transported in plastic bags set on ice in plastic garbage pails by truck from the Penny Pilot Hatchery. Nine hundred fry died from asphyxiation in the 6 hr that it took to transport and plant the fry into the rearing tubs at the Stuart Pilot. The remainder of the fry were divided into nine lots of 327 fry per tub. For the first few days all the fry were held in aerated, unfiltered water. After 5 days, one group was transferred to filtered water, another group to unfiltered water, and a third group to unfiltered water with approximately 5 mg/L of ferrous sulphate added by Mariotte bottle.

Fry were fed Oregon moist pellets (OMP) according to the recommendations for amount, pellet size and frequency recommended in the manufacturer's feeding chart. Flow to each of the nine tubs was initially set at 0.5 LPM, increasing to up to 1.0 LPM as the fry grew in size.

Once every week, 30 fry from each group were anaesthetized in 2-phenoxyethanol (0.4 mL/L), individually weighed to the nearest 0.01 g on a Dial-o-gram balance and measured for nose-fork length to the nearest millimeter.

After 34 days of operation, the iron concentration of the unfiltered group's water was increased to the same level as the iron-added group to compare the oxygen consumptions of the two groups. Oxygen levels were monitored daily in the three systems during this 14 day experiment.

1982/83 Pilot

When the 1982/83 brood in the incubator trays reached the swim-up stage, they were transferred to three Capilano troughs. Five thousand fry that had been incubated on filtered water were placed in one trough supplied with unfiltered water. The remainder of the fry that had been incubated on filtered water were placed in a trough supplied with filtered water. The fry that were incubated on unfiltered water were placed in a trough supplied with filtered water for 40 days then switched to unfiltered water. The flows varied between 114 to 227 LPM per trough depending on the number and size of fry in it.

At ponding, fry were fed a 50/50 mixture of OMP starter mash and 0.8 mm pellets for three days. On the fourth day a 25/75 mixture of starter mash and 0.8 mm pellets was used. Thereafter, the fry were fed only pellets. Pellet size and feeding frequency were according to the OMP feeding chart. The amount fed was 110% of the level recommended in the chart, to ensure satiation.

Once every two weeks, 50-100 fry from each of the troughs were anesthetized and measured as in the 1981 Pilot. Condition factors (K) for each sample were calculated from the weight (W) in grams and the length (L) in centimeters according to:

$$K = \frac{100W}{L^3}$$

Growth rate (b) was calculated as percent size increase per day by the formula:

$$b = \frac{(\ln S_i - \ln S_o)}{(T_i - T_o)} \times 100$$

where ln is the natural logarithm, S_i is the final fry size, S_o is the initial fry size and T_i-T_o is the rearing period in days.

FRY TAGGING

The small number of fry raised during the 1981 Pilot were returned unmarked to the donor stream, Slim Creek.

The chinook fry produced during the 1982/83 Pilot were adipose fin clipped and tagged with binary-coded wire nose tags (CWT) in order to assess adult return success of fry reared in the Fort St. James water, and more generally to provide information on the fisheries contribution of Stuart River chinooks.

The fish were tagged when they reached a mean weight of 3 g. Half of each experimental group was taken randomly, pooled and tagged with one code and the remaining half was tagged with another code.

The fry were anesthetized with MS 222, adiposed fin clipped and coded wire tagged. Samples of 200 fry were re-run through the quality control device after

being held for 24 hours' to check for tag retention. Tagging was completed over a three day period by an eight person crew with two tagging machines.

After tagging, all the fry were reared on unfiltered groundwater until they were released. One group of tagged fry was released shortly after tagging at close to 3 g in size. The other group was raised to almost 5 g before release so that the survival of the two different times and sizes of release could be compared. The fry were transported by helicopter in a 300 L monsoon bucket to the Dog Creek egg-take site on the Stuart River for release.

TAG RECOVERY

Preliminary data on the recovery of the Stuart Pilot tags from adult salmon was obtained from the Mark Recovery Program (MRP) computer data base, which includes data from all the commercial and some sport fisheries on the eastern Pacific coast, from Alaska to California (Bailey et al., 1984). For the MRP, a proportion of each fishery is sampled and each fish found with no adipose fin has its head severed for dissection to obtain the coded wire tag embedded in its nose cartilage. The number of tags of each code actually "observed" is divided by the sampling rate to give the number of tagged fish "estimated" to have been caught. For most tagged groups, the "estimated" value is divided by the tagged-to-total release ratio to give an "expanded" estimate of tag recoveries. However, since most of the Stuart Pilot untagged releases were fish that were too small to tag, and therefore presumably less fit to survive, only the "estimated" tag recoveries were used for this report. The recovery data used was drawn from the MRP data base in June 1987, and includes all recoveries recorded for the two Stuart Pilot tag codes up to and including the 1986 fisheries.

Scales are also taken from MRP samples and the available plates were inspected to determine the juvenile life history of the Stuart Pilot releases compared to wild juveniles from the Stuart River.

RESULTS

WATER QUALITY

The four water samples taken from the Fort St. James aquifer prior to the construction of the Pilot indicated that ammonia, iron and total alkalinity were high (Table 1). Total alkalinity measurements slightly exceed the recommended upper limit of 300 mg/L on several occasions, but it was thought that fish would not be affected by these levels. Total ammonia was also high, but below the toxic level of 1.3 mg/L recommended by Taylor and Pierce (1987), even though the equilibrium of ammonia and ammonium would favour the more toxic un-ionized ammonia due to the high pH (Sigma, 1983).

Iron levels in samples collected from the Fort St. James aquifer from 1958 to April 1983 ranged from 0.22 mg/L to 1.70 mg/L, and averaged 0.55 mg/L.

Water samples collected during pumptesting of the hatchery well in April 1980 showed that the water contained very little dissolved oxygen (less than 1 mg/L) and a high partial pressure of dissolved nitrogen (130% of saturation). All other parameters fell within the recommended limits for intensive culture of salmonids.

Aeration

The six-segment, 200 mm diameter packed column aerator installed in the 1981 Pilot improved the high dissolved nitrogen and low dissolved oxygen levels. The column reduced nitrogen gas to an average of 106.7% of saturation and increased the oxygen levels to an average of 94.1%, which resulted in total gas pressures (TGP) of 103.7% (Table 2). Although the rearing chinook did not show overt symptoms of gas bubble disease, the nitrogen and TGP were above the recommended safe levels. The addition of three segments to the column for the 1982/83 Pilot reduced nitrogen to 103% and TGP to 100.6% of saturation.

Table 1 - Water Quality Values for Well at Stuart Pilot Hatchery (below detection limits - 0)

Parameters	Recommended	Apr. 08/80 4.5 hr Well #2	Apr. 09/80 16.5 hr Well #2	Apr. 09/90 26 hr Well #2	Apr. 10/80 41 hr Well #2	Jun. 10/82 Stuart Pilot WL	Apr. 09/80 Village Well	Apr. 09/80 Private Well	Jun. 06/79 FS James City Well
Alkalinity - Total	20-300	314	320	308	315	308	320	282	310
Ammonia	<.002	.1657	.164	.17	.169	.173	.132	0	.11
Chloride	<170	1.24	1.24	1.3	1.57	1.2	1.39	.9	.0088
Conductivity Field	150-2000	430	428	443	446		420	385	
Conductivity Lab	150-2000	650	660	660	660	655	639	540	630
Dissolved O2-ppm	>6-8	1.1	1.4	.4	.4		1	1.2	0
Dissolved O2-%sat	100%	10.4	13.1	3.7	3.6		9.1	10.6	
Dissolved Gas Tot	<103%	104.1	104.3	103.7	104.1		105	102.9	
Dissolved Nitrogen	<102%	129	128.6	130.3	130.8		130.5	127.4	
Hardness	20-400	346	339	339	337	337	340	297	333
Nitrite	<.012	.0054	0	.0071	.0077	0	.0055	.0098	0
Nitrate	<.12	0	.0161	.0126	.0188	0	.0121	.0703	0
pH-Field	6.8-8.5	7.3	7.8	7.7	7.5		7.6	7.1	
pH-Lab	6.8-8.5	8	8.1	7.8	7.7	7.9	8	7.5	8
Phosphate	<.05	.1403	.036	.0279	.0278	.03	.0268	.0069	.0235
Residue-Filterable	70-400	422	424	424	420	447	400	316	406
Residue-Nonfilterable	<3	187	0	0	0	5	0	0	0
Silica	<10-60	11.6	11.8	11.8	11.7	12.1	11.8	7.05	11.8
Sulphate	<90	62.5	58.3	66.5	69.2	60.5	48.2	17.6	46.5
Taste	OK	DISTINCT MINERAL TASTE ----------							
Temperature	4-18C	8.6	8.4	8.6	8.6		7.3	5.9	9.25
Turbidity	1-60	31	4.9	4.2	4.4	9	7.3	0	4.6
METALS									
Al-Aluminum	<.1	.352	0	0	0	0	0	0	0
As-Arsenic	<.5	0	0	0	0	0	0	0	0
Ba-Barium	<1	.142	.0881	.0745	.0624	.057	.0641	.127	.0532
Ca-Calcium	4-150	45.5	43.1	43.3	42.8	40	54.2	76.2	48.6
Cd-Cadmium	<.0004	0	0	0	0	0	0	0	0
Co-Cobalt		0	0	0	0	0	0	0	0
Cr-Chromium	<.01	0	0	0	0	0	0	0	0
Cu-Copper	<.006	0	0	0	0	0	0	0	0
Fe-Iron	<.3	1.7	.383	.365	.351	2.2	.613	.021	.669
Hg-Mercury	<.00005	0	0	0	0	0	0	.00033	0
K-Potassium		3.76	3.59	3.53	3.49	3.58	3.08	1.22	3.15
Mg-Magnesium	<10	56.5	56.3	56.1	56	56.4	49.7	26	51.4
Mn-Manganese	<.05	.0996	.02	.0197	.0187	.013	.0293	0	.031
Mo-Molybdenum		0	0	0	0	.009	0	0	0
Na-Sodium		16.9	20.3	20.2	18.5	19	14.6	6.01	6.35
P-Phosphorus		0	0	0	0	0	0	0	0
Pb-Lead	<.01	0	0	0	0	0	0	0	0
Si-Silicon	<10-60	11.8	12.1	12	11.7	12.7	12.1	6.85	11
Sn-Tin		0	0	.2	.22	0	0	.22	0
Zn-Zinc	<.005	.0034	.002	.0015	.0016	0	.0016	.0028	0

NOTE: Underlined values are outside the recommended limits for fish culture.

Table 2. Stuart Pilot Hatchery dissolved gas pressures.

Date	Sample Location	Temp. (°C)	$\%O_2$ Saturation	$\%N_2$ Saturation	%TGP Saturation
April 1980	unaerated	8.6	7.1	129.7	104.1
June 1981	aerated (6-seg.col.)	9.0	94.1	106.7	103.7
Dec. 22 1982	unaerated	9.0	4.8	146.9	117.1
	aerated (9-seg.col.)	9.0	92.2	103.0	100.6

During the winter of 1982/83, aerator performance decreased when air temperatures fell below -18°C, due to ice buildup on the outside of the tower housing from water splashing out between the segments. Ice buildup and the resultant poor ventilation caused oxygen levels to fall to 82% and nitrogen levels to increase to 106% when measured on Dec. 22, 1982. To maintain aerator performance, the ice was cleared from the column daily during cold weather thereafter.

Filtration

In the 1981 Pilot, the 1.4 m^3 retention tank and the 0.4 m^2 silica sand filter worked well. The iron concentration of 3 LPM of water was reduced from 0.45 mg/L to 0.02 mg/L, which was well below the recommended level of 0.3 mg/L for salmonid culture. The retention tank reduced the iron concentration by only 0.09 mg/L by sedimentation, but it allowed the iron time to precipitate to form large enough particles to be captured by the silica sand filter. One problem with this filter was that some sand leaked into the outlet pipe and thus into the rearing troughs.

The two larger filters used for the 1982/83 Pilot, each with a surface area of 1.4 m^2, did not adequately reduce iron concentrations in the water supply to below the recommended level of 0.3 mg/L (Table 3). The filters could not be

Table 3. Iron concentrations of the Stuart Pilot Hatchery.

Date	Source	Concentration (mg/L)
1960	Fort St. James well (site unknown)	0.91
1980	Hatchery well pumptest (raw well water)	0.43
	1981 Pilot Hatchery	
June 25, 1981	pre-aeration	0.45
	head tank	0.45
	unfiltered rearing water	0.49
	filtered rearing water	0.02
	iron added rearing water	5.85
	1982/83 Pilot Hatchery	
Oct 16-24	sand filtered incubation water	0.64 (avg.)
Oct 24	unfiltered incubation water	0.40 (avg.)
Nov. 22-28	sand filtered incubation water	0.36 (avg.)
Nov. 22-28	poly floss + sand filtered inc. water	0.13 (avg.)
Nov. 22-28	unfiltered incubation water	0.43 (avg.)
Feb 12-15	unfiltered rearing water	0.49 (avg.)
Feb. 12-15	filtered rearing water	0.47 (avg.)
April 11-17	unfiltered rearing water	0.53 (avg.)

improved through the addition of more silica sand because the flows would then not be sufficient to supply the hatchery.

As a simple filter supplement, polyester aquarium floss was placed in the first tray of every incubator stack. The polyester floss reduced unfiltered aerated water iron levels from 0.5 mg/L to 0.13 mg/L. The polyester floss had to be replaced every few days, making it labor intensive, although not particularly costly.

During the rearing program, water was first filtered through the silica sand filters then through the polyester floss filter. Filtered water sampled February 12-15 during the middle of the rearing program contained an average of 0.47 mg/L of iron, only 0.02 mg/L less than the unfiltered water. At the beginning of the rearing program when flows were less, it was estimated that the filtered water contained between 0.2 to 0.3 mg/L of iron, although no measurements were made.

Water Temperature

In 1969 and 1979, water temperatures of the new city well were 9°C and 9.25°C respectively (A. Playfair, pers. comm.); the time of year when measurement was made is not known. A Ryan thermograph recorded an average temperature of 8.7°C, a maximum of 8.9°C and minimum of 8.4°C from October 1981 to March 1982 in a bucket fed from the hatchery hatchery well. When the 1982/83 Pilot was operating, the daily water temperature remained at 9°C from early December to late February.

EGGTAKE AND INCUBATION

About 72,000 eggs were taken between September 16-19 for the 1982/83 Pilot (Table 4). An estimated 97% of the eggs were successfully fertilized. If the numbers of unfertilized eggs are excluded, the unfiltered group (0.5 mg/L average iron concentration) had a mortality rate of 0.5% to the eyed stage compared to 1.1% for the filtered group (0.1-0.2 mg/L iron). The filtered group had higher losses due to fungal growth spreading from dead eggs to live eggs. It is possible that the iron floc inhibited the growth of fungus on the eggs of the unfiltered group. From the eyed stage to just prior to hatching (October 28), the filtered group had 1.2% mortalities compared to 2.1% for the unfiltered group. The iron floc possibly caused some mortalities in the unfiltered group by inhibiting oxygen transport for the eggs as their metabolic activity increased.

The unfiltered group took 10-11 days longer than the filtered group for 100% of the eggs to hatch (Table 5). The unfiltered group was switched to filtered water on November 15 for the balance of the incubation period because of the high mortalities. After hatching was complete, the filtered group had 6.9% mortalities compared to 60.8% mortalities for the unfiltered group. Of the mortalities in the unfiltered group, about 15% were eggs that did not hatch, 15-25% were embryos that died during the hatching process and 60-70% were alevins that died after the hatching process was completed.

On the final egg pick just prior to ponding, the mortalities in the unfiltered group remained high at 21.1%, but were greatly reduced from the previous pick. The filtered group had only 0.6% mortalities at the final egg pick. The overall mortality during incubation, excluding unfertilized eggs, was 74.3% for the unfiltered group and 11.9% for the filtered group. Mortality in the unfiltered group no doubt would have been even higher if they had been left on unfiltered water for the last 10 days of incubation.

Table 4. Incubation Survival at the 1982/83 Stuart Pilot Hatchery

	Filtered Group			Unfiltered Group			Total	
	Dead	Live	% survival	Dead	Live	% survival	Dead	Live
Eggs taken		61,926			10,355			72,281
Fertilization Inventory	1,564	60,362	97.5	575	9,780	94.2	2,139	70,142
Viable eggs								
Eyed	691	59,671	98.9	48	9,732	99.5	739	70,142
1 week prehatch	737	58,934	98.8	208	9,524	97.9	945	68,458
100% hatch	4,064	54,870	93.1	5,788	3,736	39.2	9,852	58,606
Ponding	342	54,528	99.4	790	2,946	78.9	1,132	57,474
Total	7,398	54,528	86.6	7,409	2,946	28.5	14,807	57,474

Table 5. Incubation Timing Summary for the 1982/83 Stuart Pilot Hatchery

	Filtered group			Unfiltered Groups		
	Date	Days	ATU	Date	Days	ATU
Egg-take	Sept 16-19			Sept 16-17		
Eyed Stage	Oct 18-21	32	297-306	Oct 18-21	32-34	297-306
10% hatch	Nov 6-10	51	459-468	Nov 10-12	55-56	495-504
50% hatch	Nov 9-16	54-58	486-522	Nov 15-16	60-62	540-558
90% hatch	Nov 13-17	50-59	522-531	Nov 21-23	66-67	594-603
100% hatch	Nov 15-18	60-61	540-549	Nov 26-27	71-72	639-648
Ponding	Dec 25-27	100-101	900-909	Jan 14	119-120	1071-1080

The unfiltered group also continued to be much slower developing and were not ready for ponding until over two weeks after the filtered group was ponded (Table 5). Alevins initially incubated on unfiltered water were more lethargic, but otherwise appeared normal.

REARING

1981 Pilot

During the 55 day rearing program, the majority of mortalities were fish that jumped out of the small rearing tubs onto the ground. If the jumpers are excluded, the survival for all three groups was about 99%, with no significant difference in survivals between groups (Table 6). Iron concentrations from 0.02 mg/L (for the filtered group) up to 5.85 mg/L (for the iron added group) thus did not appear to affect the survival of chinook fry reared from 1.3-3.0 g in size. Although there was no difference in the mortalities between the three groups, the fry reared in iron-added water appeared stressed. Typical actions of fry in the iron-added water were:

(i) swimming nearer the surface and directing their bodies more towards the water inlet;
(ii) lethargic;
(iii) poor feeding;
(iv) intermittently beating the water surface.

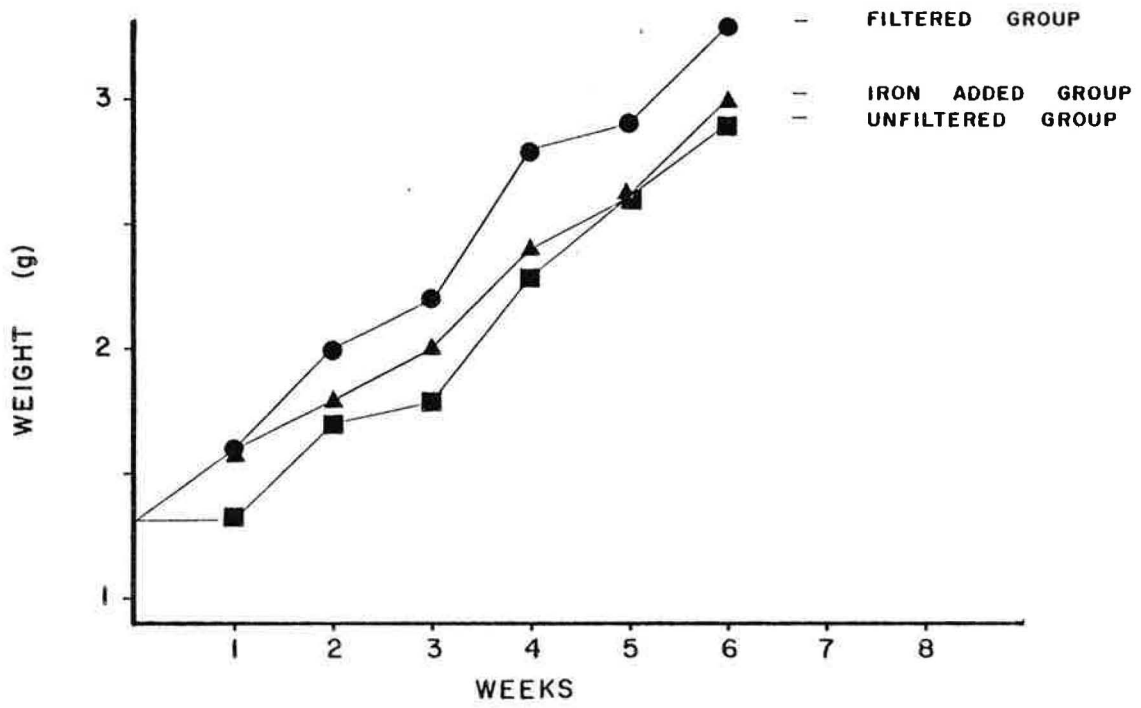
Larger fish appeared more tolerant of the high iron levels. There did not appear to be any differences in the behaviour of fry reared on filtered versus unfiltered water.

Table 6. Rearing Survivals at the 1981 Stuart Pilot Hatchery.

Group	Total Fish Initially	Mortalities		Natural Survival Percent	Total Survival
		Jumpers	Natural		
Filtered	999	54	6	99.4%	93.9%
Unfiltered	984	38	13	98.7%	94.8%
Iron added	975	32	9	99.1%	95.8%

The increase in average weight for the three groups of fry during the rearing program is shown in Figure 11. A single-factor analysis of variance, carried

Figure 11 Growth of Chinook Fry in the 1981 Stuart Pilot Hatchery



out on the pooled weight samples of the three groups indicated that the mean weights of the three groups were significantly different ($p<.05$). The Neuman-Keuls multiple range test (Zar, 1974) showed that there was no significant difference ($p=0.05$) between the weights of fry of the unfiltered group and the iron-added group ($q=2.75$), but that the weights of fry of the unfiltered and iron-added groups were significantly different than the filtered group.

These tests indicated that iron concentrations of 0.5 mg/L or greater slowed the growth of the chinook fry to a significant extent.

During the last 14 days of rearing, the iron concentration of the unfiltered system (0.5 mg/L) was increased to that of the iron added system (5.9 mg/L). After iron was added to the unfiltered system, the outflow oxygen consumption of that group averaged 6.7 mg/L, which was 1.4 mg/L higher than that of the original iron-added group and 1.6 mg/L higher than the filtered group (Table 8).

Table 8. Oxygen Consumption of Iron Stress Test.

Group	Oxygen Consumption* (mg/L)	Estimated Iron (mg/L)
filtered	5.1	0.02
high iron (acclimated for 39 days)	5.3	5.85
Unfiltered to high iron (unacclimated)	6.7	5.85

* O_2 consumption = difference between O_2 in influent and effluent flows.

1982/83 Pilot

On December 25-27, the 55,000 juveniles that survived incubation on filtered water were split into two groups; one group of 5,000 fry was reared in unfiltered water and the rest were reared in filtered water. The 2,946 fry that remained from the unfiltered incubation group were ponded 2.5 weeks later on January 14 into a trough supplied with filtered water. These fry were later switched to unfiltered water on February 24.

The iron concentration in the unfiltered water was approximately 0.5 mg/L. Although no measurements of iron concentrations of the filtered water were made until February 12-15, it was estimated that the iron concentration was 0.2-0.3 mg/L at the beginning of the rearing program and increased to 0.5 mg/L by February 12-15 in the filtered water.

There was only a slight difference in mortalities between the filtered-water-incubated/filtered-water-reared (FIFR) group and the filtered-water-incubated/unfiltered-water-reared (FIUR) group. To the 1 g stage, reached by about February 8 by both groups, the FIFR group had 1.4% mortalities and the FIUR group had 3.9% mortalities (Table 9). The majority of mortalities in both groups were fish with abnormalities (scoliosis and pinheading) that failed to develop into free-swimming fry. The unfiltered-water-incubated/filtered-water-reared (UIFR) group had 3.2% mortalities to the 1 g stage, similar to the FIUR group. From the 1 g to the 2 g stage, the mortalities in the FIFR group and the FIUR group were both 0.8%. The UIFR group had slightly higher mortalities at 1.8%. As the fry grew from 2 g to 3.5 g the FIFR group had slightly higher rearing mortalities (2.5%) than the FIUR group (1.5%) possibly due to their higher rearing density. The overall mortalities during rearing were considered low for all three groups: the FIFR group had 4.6% mortalities to the 3.5 g size; the FIUR group had 6.1% mortalities to the 3.5 g size; and the UIFR group had 5.3% mortalities to the 2 g size (Table 9).

Table 9. Rearing Survivals at the 1982/83 Stuart Pilot Hatchery

Stage	FIFR Filtered Rearing Filtered Incubation			FIUR Unfiltered Rearing Filtered Incubation			UIFR Filtered Rearing Unfiltered Incubation			All Groups
	Dead	Cum* Dead	Live (survival)	Dead	Cum* Dead	Live (survival)	Dead	Cum* Dead	Live (survival)	Live (survival)
Ponding	0	0	49,524	0	0	5,004	0	0	2,946	57,474 (100%)
Initial Rearing to 1g	691	691	48,833 (98.6%)	195	195	4,809 (96.1%)	95	95	2,851 (96.7%)	56,493 (98.3%)
Intermediate Rearing to 2 g	363	1,054	48,470 (97.9%)	37	232	4,772 (95.4%)	62	157	2,789	56,031 (97.5%)
Intermediate Rearing to 3.5 g	1,219	2,273	47,251 (95.4%)	72	304	4,700 (93.9%)				54,740 (95.2%)
Final Rearing to Release (Smolt)										53,687 (93.4%)

* = Cumulative

Growth to the 1 g stage was similar for all three groups with an average daily growth rate of 2.8%. Once over 1 g in weight, the FIUR group gained weight at a slightly faster rate than either the FIFR group or the UIFR group. Daily growth rates were 2.7 ± 0.7% for the FIUR group, 2.6 ± 0.7% for the FIFR group and 2.2% for the UIFR group. While the weights of the FIUR group were generally larger after the 1 g stage, the lengths of the FIFR and FIUR group were similar (Figure 12), so the FIUR generally had higher condition factors (Table 10, Figure 13). The higher rearing densities of the FIFR group may have caused this difference.

The efficiency which food was converted to biomass throughout the rearing program is presented in Table 11. Due to the slowness in initiation of feeding, all three groups had low conversion efficiencies varying between 19 to 27% for the first several weeks. Conversion efficiency subsequently increased to about 50%. The FIUR group had the highest overall efficiency of 52.4%, however, the FIFR group was fed an additional 9.4% above the satiation level according to the OMP feed chart because of an overestimation in the number of fry. If the excess food is subtracted from the total amount fed, the overall conversion efficiency for the FIFR group would be 52.7%, similar to that of the FIUR group. The UIFR group, with an overall conversion efficiency of 42.1%, was lower than the other two groups.

FRY TAGGING

Of the 54,941 fry reared in the 1982/83 pilot, 49,866 were successfully tagged, 3,131 rejected their tags, and 1,944 pinheads and small fry were not tagged (Table 12). Problems with the CWT injector units resulted in lower-than-normal tag retentions. The group tagged with code 2-23-60 were reared for an extra 20 days prior to release, to produce a larger size and later release group for survival comparisons. The growth rate after tagging decreased to 1.5% per day from 2.8% before tagging, possibly from the stress caused by tagging.

Figure 12 Growth of Chinook Fry in the 1982/83 Stuart Pilot Hatchery

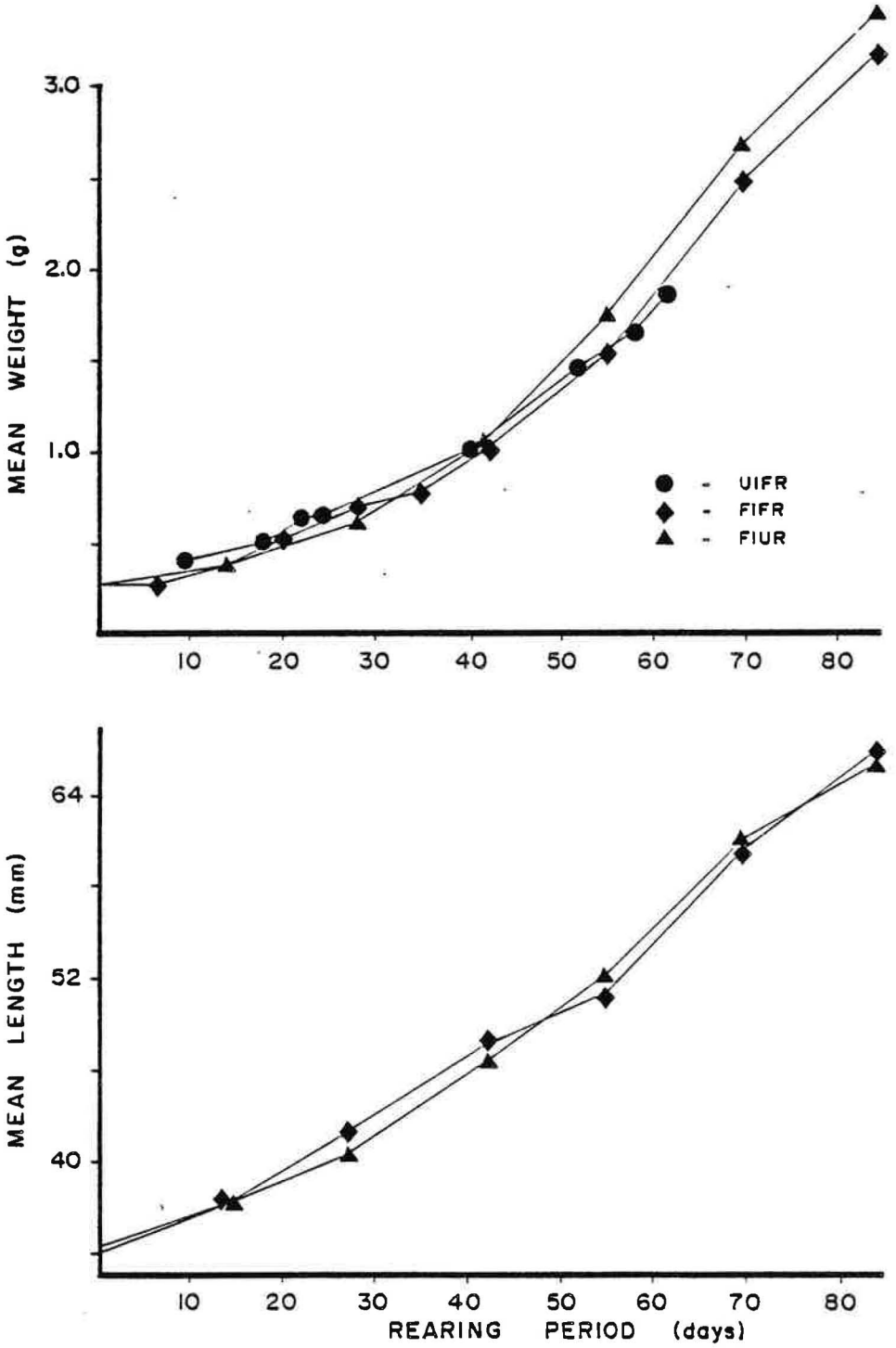


Table 10. Chinook Fry quality at the 1982/83 Stuart Pilot Hatchery.

		Filtered Group			Unfiltered Group		
Date	Days Reared	Length (mm)	Weight (g)	K*	Length (mm)	Weight (g)	K*
Dec 28	0	34.0	0.32	0.814	34.1	0.32	0.807
Jan 3	6		0.33				
Jan 10	13	36.3	0.41	0.857	36.3	0.41	0.857
Jan 17	20		0.55				
Jan 25	28	41.8	0.71	0.972	40.9	0.66	0.965
Feb 1	35		0.78				
Feb 8	42	47.8	1.07	0.980	46.7	1.09	1.070
Feb 21	55	52.9	1.57	1.061	54.4	1.80	1.118
Mar 7	69	60.9	2.49	1.102	61.1	2.69	1.179
Mar 21	83	66.7	3.20	1.078	66.6	3.37	1.141

*K = condition factor = $100W/L^3$ W = weight in g; L = length in cm (10 x mm)

Figure 13 Condition Factors of Chinook Fry in the 1982/83 Stuart Pilot Hatchery

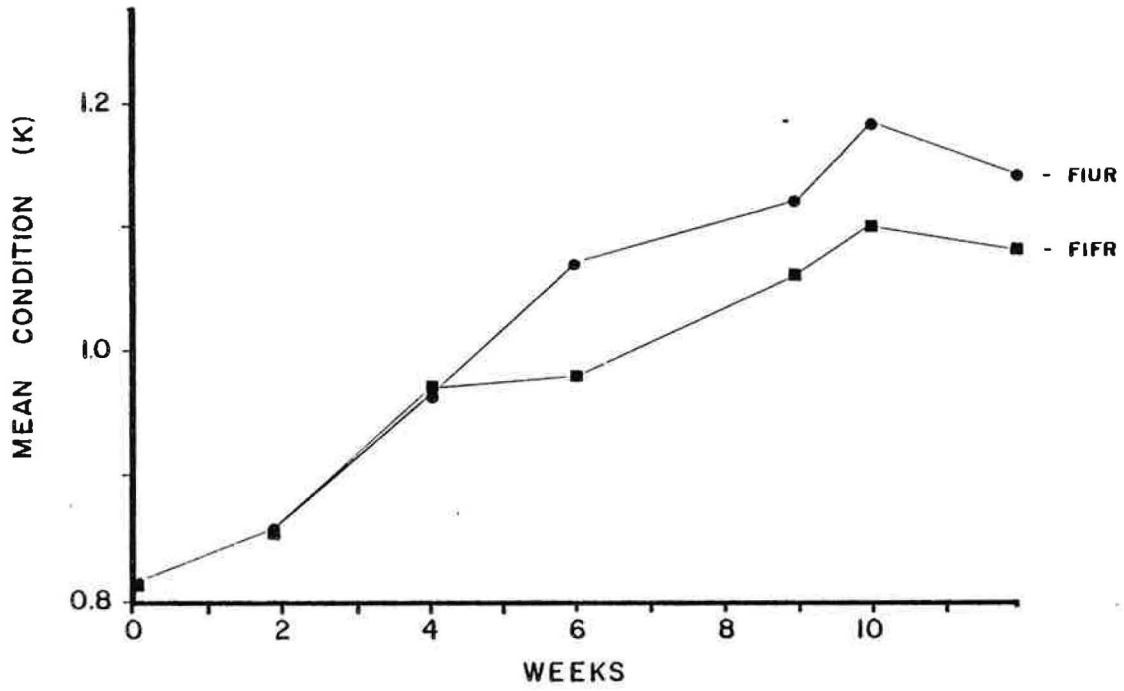


Table 11. Food Conversion Efficiency During the 1982/83 Stuart Pilot.

		F I F R GROUP			F I U R GROUP				U I F R GROUP		
Period	Days	Amount OMP Fed (kg)	Biomass Increase (kg)	Conversion Efficiency	Amount OMP Fed (kg)	Biomass Increase (kg)	Conversion Efficiency	Period	Days	Amount OMP Fed (kg)	Biomass Increase (kg)	Conversion Efficiency
Dec 28 - Jan 9	0-13	20.1	3.782	18.8%	1.9	0.447	23.5%	Jan 14 - 23	0-9	0.72	.19	26.9%
Jan 10 - Jan 24	14-27	31.1	15.073	48.5%	2.8	1.217	43.3%	Jan 23 - 31	10-17	0.88	.32	35.9%
Jan 25 - Feb 7	28-42	39.0	17.548	45.0%	3.6	2.079	58.2%	Jan 31 - Feb 8	18-25	0.96	.25	25.5%
Feb 8 - Feb 20	43-54	49.7	25.706	51.7%	4.5	3.386	75.4%	Feb 8 - Feb 21	26-38	1.85	1.26	68.1%
Feb 21 - Mar 6	55-68	67.7	41.822	61.5%	6.5	4.247	65.2%	Feb 21 - Mar 6	39-51	2.64	1.31	49.6%
Mar 7 - Mar 20	69-82	83.3	32.247	38.7%	8.3	3.112	37.3%	Mar 6 - Mar 19	52-64	3.18	.90	28.4%
								Mar 19 - Mar 26	64-71	1.89	.89	47.0%
Dec 28 - Mar 20		291.1	136.178	46.7%	27.6	14.488	52.4%	Jan 14 - Mar 26		12.1	7.1	42.1%

Table 12. Coded Wire Tagging Summary.

Tag Code	Release Date	Total No. Tagged	Tag Retention	Total valid Tags	Weight at release (g)
2-23-60	April 26	25,459	93.7%	23,860	4.6 g
2-23-61	April 6	27,538	96.0%	26,000	3.3 g

TAG RECOVERY

Of the nearly 50,000 tags released from the Stuart Pilot Hatchery, 76 are estimated to have been caught in 1985 and 1986 (Table 13). This preliminary recovery data for the two different Stuart Pilot tag codes showed that the larger fish survival slightly better (0.17%) than the smaller fish (0.14%). These survivals are low compared to the coastal hatchery biostandard of 1-1.5%, but much higher than the survivals of similar broods from other Fraser River facilities (Table 13).

Thirteen of the 76 MRP recoveries were sampled for scale aging, but only eight of those scale books could be found, with only three scales in good enough condition to be aged. Those three fish, two from tag code 2-23-61 and one from tag code 2-23-60, were all aged 4_1 and had entered sea soon after release. It appeared from the scales that the earlier, smaller release group underwent a rapid transition from fresh to salt water, whereas the later, larger release seemed to have spent more time in the estuary before fully committing to sea water (Y. Yole, pers. comm.). However, it is obviously not possible to draw any broad conclusions from only three pieces of data. A chinook spawner survey in 1980 on the Stuart River indicated that virtually all (97.7%) of the fish sampled had spent two winters in freshwater before smolting (age 3_2, 4_2, 5_2 or 6_2), as is apparently the norm for Upper Fraser chinook stocks (Shepherd et al., 1986).

Table 13. Tag Recoveries from the Stuart Pilot and other Fraser River Facilities

Facility Name	Brood Year	Number Tagged	Release Size (g)	Fishery Returns of Coded Tags (estimated by year) 83	84	85	86	Fishery Returns to Date	Survival** to Date (%)
Stuart Pilot	1982a*	23822	4.6			5	36	41	0.17
	1982b	25918	3.3			7	28	35	0.14
	total	49740				12	64	76	0.15
Quesnel	1981	55577	2.2-5.0		5	7	5	17	0.03
	1982	1153005	1.3-3.4			14	32	46	0.004
	1983	388492	4.4-6.5			12	32	44	0.01
Penny Pilot	1981	118688				3	4	7	0.006
Loon	1981	74790	1.3-3.3	4	49	23	0	76	0.10
	1982	28683	3.9			8	4	12	0.04
	1983	56062	2.6-3.4				22	22	0.04
Birkenhead	1981	35050	3.4		8	4	2	14	0.04
	1982	114596	1.4-3.5				2	2	0.002
	1983	83296	2.4-3.3				12	12	0.01

* Stuart Pilot Codes - 1982a = 022360
1982b = 022361

** Note that returns only include MRP fishery data and not returns from:

1. high seas fisheries
2. native food fisheries
3. post 1986 fisheries
4. unsampled sport and commercial fisheries
5. poaching
6. escapements

DISCUSSION

WATER QUALITY

The well for the Stuart Pilot facility provided relatively warm and stable temperatures of 8°-9°C. A nine-segment packed column aerator improved the dissolved oxygen and nitrogen concentrations to levels that were within the limits recommended for salmonid culture. The main problem with the aeration system was that air temperatures below -18°C caused ice to form on the outside of the column and reduced the circulation of air. This problem could be dealt with by building a better shelter around the column and by reducing splash.

In the 1981 Pilot, the 0.4 m^2 silica sand filter worked well to reduce the iron concentration of 3 LPM from 0.45 mg/L to 0.02 mg/L. Although larger silica sand filters were constructed for the 1982/83 Pilot, they did not effectively filter the much larger flows required. The addition of polyester floss to the top tray of each incubator stack reduced the iron concentration during incubation to below 0.3 mg/L, but was not as effective as the first silica sand filter. During early rearing, the polyester floss filter used in conjunction with the silica sand filters reduced the iron concentration to an estimated 0.2 - 0.3 mg/L, but during the latter stages of rearing the flows were too high to be effectively filtered in this method.

Filter performance was correlated more to the amount of water flow than to iron concentrations or filter design. Even water that appeared very clear directly after coming out of the filter could be seen to develop a red coloration in a few seconds. It is suggested that the reason that the filters did not work well at high flows is because the water was not retained long enough post-aeration to allow the iron to react with the oxygen to form precipitates. For the 1.44 m^3 head tank, retention time was 24 min at 60 LPM, but only 2.7 min at 530 LPM. Thus, the higher the flow, the shorter the retention time in the head tank and piping before the water reached the filter and the less of the iron that would have had time to form into large enough particles to be filtered.

The next step to try to achieve better filtration at the Stuart facility would be to provide a larger retention tank post-aeration and to provide excessive oxygenation at least for the incubation water, by bubbling air into the retention tank or dripping in an oxidizing agent like potassium permanganate. A 45 m^3 tank (3 m high by 4.5 m diameter) would give 30 min retention to 1500 LPM, enough to incubate 4 million eggs, which could be reared in the 10,000 LPM available from the Stuart well (retention time of 4.5 min).

INCUBATION

The incubation studies at the 1982/83 Stuart Pilot indicate that iron levels of about 0.5 mg/L have a deleterious effect on juvenile chinook in this water, particularly at the hatching and early alevin stages, causing severe post-hatch mortalities. It is probable that 100% of the unfiltered group alevins would have died had they remained in unfiltered water. The group of eggs incubated on filtered water with iron concentrations of 0.1-0.2 mg/L had few mortalities.

Other researchers have found that newly hatched alevins are the life-stage most affected by high iron concentrations. At the Abernathy Experimental Hatchery in Washington State, chinook eggs were not affected by iron concentrations of 2.2 mg/L until the time of hatching (Sigma, 1983). However, within 24 hr of hatching, this level of iron caused extensive mortalities by clogging gills and impairing respiration. At iron concentrations of 0.3-1.0 mg/L, few post-hatch mortalities occurred and at concentrations below 0.3 mg/L, the iron did not cause any mortality. Smith and Sykora (1976) found that iron concentrations of 0.75, 1.5 and 3.0 mg/L did not affect coho and brook trout egg hatchability or alevin survival. Concentrations of 6.0 and 12 mg/L did not affect egg hatchability, but increased the mortalities after hatching. However, the bioassay method used by Smith and Sykora provided a radically different environment for the eggs than occurs in standard hatching trays.

Chinook appear to have a low tolerance to iron compared to coho and brook trout. The safe upper limit of iron concentration for chinook fry incubation at the Stuart Pilot lies between the 0.1 and 0.5 mg/L. More studies are needed to define the upper limit more precisely.

Although the newly hatched alevins are the most susceptible stage, 10-15% of the Stuart unfiltered group mortalities at the post-hatch egg pick were eggs that did not hatch. At the Big Qualicum Hatchery in B.C., chum salmon eggs were incubated on groundwater containing 2.8 mg/L of iron. Many of the eggs died before hatching and all the eggs that did hatch died within 48 hr, being covered with a thick coating of iron floc. Smith et al. (1973), studying the effect of various levels of iron hydroxide on the eggs of fathead minnows, found that the highest numbers of eggs hatched in concentrations of 0 and 50 mg/L and the lowest numbers hatched in 1.5 mg/L. It was found that the particle size of the iron precipitate increased with increasing iron concentration. The average particle size was 2.04 μm in diameter at of 1.5 mg/L iron and 5.36 μm in at 50 mg/L iron. The larger particle sizes of the high iron water may have prevented

penetration and clogging of the 1.3 μm diameter pores of the egg chorion. At lower concentrations of iron, the particles are finer and can more easily clog egg pores. In the 1982/83 Stuart Pilot incubation studies, it appears that the iron particles in the unfiltered water were small enough to interfere with the pre-hatch egg respiration, since 6% - 25% of the eggs died in the last 2 wk before hatching.

The rate of development of the filtered group eggs was faster than those of the unfiltered group at the Stuart Pilot. The slower development of the unfiltered group was possibly caused by reduced metabolite transfer caused by clogging of the egg pores. Brenner and Cooper (1978) did not find any difference in the rate of development of coho eggs incubated in 10°C water with iron concentrations of 0 and 3.0 mg/L. Smith and Sykora (1976) did not find any differences in hatching times of brook trout eggs or coho eggs incubated in concentrations of ferric hydroxide of up 12 mg/L. However, the standard bioassay method of evaluating iron toxicity is different than the real-life tests used at the Stuart Pilot. Smith and Sykora (1976) provided their iron-enriched water 1.5 hrs of retention in an aerated aquarium before presenting it to the fish, also in a turbulently aerated aquarium. The water in a production facility, as at the Stuart Pilot, could not practically be retained for such a long time before being passed to the fish, due to the high flows used in hatcheries. Criteria developed from an aquarium test or from hatchery tests may not be relevant to wild streams, again because the conditions are very different. It is clear, however, that hatchery-incubated salmon eggs require sufficient filtration of iron-rich water to reduce the iron concentration to well less than 0.1 mg/L, with even lower levels (0.02 mg/L) being preferred.

REARING

In the 1981 Pilot, no significant differences were found between the mortalities of fry reared from 1 to 3 g in filtered water (0.02 mg Fe/L), in unfiltered water (0.5 mg Fe/L), and high iron water (5.8 mg Fe/L). The fry in the filtered water grew in weight at a slightly faster rate.

Similarly, in the 1982/83 pilot, there were no significant differences between the mortalities of the groups. Unlike the 1981 pilot, the unfiltered group had higher growth and condition factors than the filtered group. One reason for this result is that the 1982/83 filters were not very effective in reducing the iron concentration of the filtered water during rearing so the differences in

iron concentrations between the groups were small (e.g. a difference of only 0.02 mg/L on February 12-15, during the middle of the rearing program). In addition, the filtered group fry were reared at higher densities, which could have stressed the fish and suppressed growth. Therefore the iron concentration in the unfiltered water may have the potential to slightly retard the growth of chinook fry, as had occurred in the short term rearing experiment in 1981. This outcome would be more in keeping with the results of Smith and Sykora (1976), who found that iron concentrations of 3.0 mg/L and over reduced the growth of coho fry reared for 90 days from the time of hatching, without increasing mortalities. The growth of fry reared in concentrations of less than 1.5 mg/L was not reduced over the control.

Chinook fry were tolerant of iron levels of up to 5 mg/L during rearing from 1.0 to 3.5 g, although the fry appeared stressed and oxygen consumption was greater for the high iron group than for the filtered group. Some acclimation to higher iron levels was demonstrated when fish newly introduced into high-iron water showed greater oxygen consumption than fish that had been in high-iron water for some time.

TAG RETURNS

The most striking feature of the tag return data for the Stuart Pilot is that survivals appear to be up to an order of magnitude greater than for other upper Fraser River facilities. Some of this higher survival might be related to the relatively large size of the Stuart releases, which appears to have induced these fish to smolt in their first year. Whether smaller fish that stay to overwinter in fresh water have trouble adjusting to the wild environment and food sources, or whether predators or diseases victimize most of the hatchery fish heading to sea can only be speculated upon.

The hardness of the Stuart Pilot supply water, perhaps in combination with the high iron content, may also have contributed to the high survival of these fish. A relatively high content of dissolved solids is known to be beneficial to fish by reducing the requirement for osmotic pumping to maintain internal ion levels, and by providing trace concentrations of elements that may be missing in food items but needed for metabolism. By the same token, some workers have added low concentrations of iron directly to iron-poor rearing water in aquarium studies, resulting in increased health and growth of the

fish. Once the Stuart water had been filtered to the extent that gill abrasion from iron particles was not significant, the remaining iron content may have actually been beneficial to the health of the salmon.

From this limited study, it appears that the characteristics of the Stuart Pilot water supply, whether the warm temperature, high hardness or iron content, was certainly not shown to have decreased the survival to adult of chinook salmon, and may have, individually or in combination, significantly increased survival rates.

CONCLUSIONS

The operation of the Stuart Pilot Hatchery has increased our understanding of the impact of iron-rich water on the culture of chinook salmon by responding to the four objectives commented on below.

1. To conduct bioassays on incubating and rearing chinook salmon to determine the degree of iron-removal treatment necessary to provide suitable water for fish culture.

   The exact criteria for iron removal were not defined directly, however, considerable iron removal (to a total iron concentration of about 0.1 mg/L) is necessary for successful incubation. Rearing does not necessarily require iron removal but growth rates would be higher if iron were kept below the ambient level of 0.5 mg/L.

2. To examine sublethal effects of various iron concentrations on incubating and rearing chinook salmon.

   Sublethal effects included much slower development and reduced hatchability during incubation, and slower growth and higher condition factors during rearing for the higher-iron groups. Overall survival to adult seems to be relatively high for fish reared in the Stuart Pilot water, which may be attributable to the warm temperature, the high ionic content, metabolic enrichment of iron or a combination of these factors.

3. To develop and assess a simple filtration system to effectively decrease the iron floc in the hatchery water.

   The sand filters that were used provided adequate filtration only at very low flows due to the time required for the iron in solution to precipitate out after aeration. A future facility at this site should include a reaction chamber of sufficient volume to allow at least 20 min of retention time before the water is filtered, especially for flows to incubation.

4. To release tagged fish of two sizes to determine overall and comparative survival to adult.

The larger release size survived slightly better than the smaller sized group and both groups survived much better than releases of all sizes from the four other upper Fraser River facilities that also released fish in 1983. The scale samples obtained indicated sub-one smolting for the Stuart Pilot fish, in contrast to the sub-two smolting common to Stuart River wild fish.

It is concluded that the Stuart Pilot Hatchery would prove to be a good site for a major enhancement facility to serve local chinook salmon stocks, as long as the well water is well aerated and thoroughly filtered during incubation, with some filtering of rearing water as well. A larger size (5g) smolt release is also indicated.

SUMMARY

1. The Stuart Pilot Hatchery was built to test the suitability of the water from the Fort St. James aquifer for a chinook salmon hatchery.

2. Land for the hatchery was leased in the Village of Fort St. James and a well was drilled on the site in 1979. The water from the well was found to contain iron concentrations that slightly exceeded (0.5 mg/L) the recommended levels for fish culture (0.3 mg/L) and the water was low in dissolved oxygen (7%) and high in dissolved nitrogen (130%). The water temperatures were relatively warm and stable (9°C).

3. In June 1981 a small Pilot was constructed to test the suitability of the water for salmon culture. Of special interest was the effect of the iron on chinook rearing because of the lack of information on the subject. The facilities consisted of a six-segment packed column aerator, a filtration system and a number of small rearing tubs. The rearing tubs were divided into three groups and plumbed into either filtered water (0.02 mg/L iron), unfiltered water (0.5 mg/L iron) or unfiltered water with iron added (5.8 mg/L iron).

4. Four thousand 1 g fry were obtained from the Penny Pilot Hatchery. The fry that survived the trip were split equally between the three systems. It was found that chinook fry mortalities were similar for all groups of fry reared to over 3 g in the three concentrations of iron. However, fry growth was slightly slower for fry reared in the unfiltered and iron-added water. Fry reared in the iron-added water consumed more oxygen than the filtered water group. Fry appeared to acclimate to the iron-added water because oxygen consumption was lower for fry that were reared in the iron added water compared to fry that were recently placed in iron-added water.

5. Aeration was improved, incubation capacity was added and the rearing facilities were increased in size for the second Pilot in 1982/83.

6. In the 1982/83 Pilot, it was found that Stuart River chinook eggs could be raised on the unfiltered well water with few mortalities to a point several weeks before hatching. Some mortalities occurred just before hatching because the iron precipitate covering the eggs inhibited oxygen transfer across the egg membrane at a time of increasing oxygen demand. Almost

total mortality occurred during and just after hatching because the iron precipitate clogged the alevin's gills. Fry incubated on filtered water containing 0.1-0.2 mg/L of iron had 88% survival from fertilization to ponding. The eggs incubated on unfiltered water took 2.5 wk longer to develop than fry incubated on unfiltered water.

7. Fry reared to 3 g on unfiltered water had similar survivals to fry reared on filtered water (94% and 95%, respectively). The fry reared in unfiltered water had higher growth rates, contrary to the 1981 pilot results. However, in the 1982/83 pilot, the filters were not very effective in filtering the rearing water, so there was little difference in the iron concentrations of the two groups. Also the fry reared in filtered water were reared at higher densities, which may have slowed their growth.

8. Adult returns to the fishery of tagged Stuart Pilot fish indicated a higher survival (0.14-0.17%) than other upper Fraser River chinook hatcheries (0.006-0.1%).

9. In conclusion, the Stuart Pilot Facility could be expanded to a major facility to service area chinook stocks as long as the incubation water were adequately filtered. Filtration of rearing water would also be beneficial.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the assistance of the following people on the Stuart Pilot Project:

- for construction of the facility: the late S. Watanabe, Lucky Digging, Westerguard Construction and Jazz Plumbing of Fort St. James.

- for supervising the project; R. Dickson and B.G. Shepherd

- for data on adult returns: N. Williscroft, Y. Yole

- for reviewing the manuscript; F.K. Sandercock, C.N. MacKinnon and B.G. Shepherd

- for helping with operation; A. Dionne, J. Smith and A. Playfair.

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