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Upwelling incubation boxes for Atlantic salmon *Salmo salar*

by

T. R. Porter and D. J. Meerburg
Research and Resource Services
Fisheries and Environment Canada
P.O. Box 5667
St. John's, Newfoundland A1C 5X1
Canada

INTRODUCTION

In the past 10 years there have been many investigations into use of egg incubation substrates for Pacific salmon (*Oncorhynchus* sp.), particularly in British Columbia and Alaska. Bams and Simpson (1977) provide an excellent description of various types of "deep substrate and shallow-matrix" incubators currently in use for experimental or mass fry production. A summary of pilot projects and a bibliography is included in their report. The primary objective of the substrate incubator is to produce fry of similar size to those produced in the natural environment. The direct relationship of the size of a fry to its swimming performance and ability to avoid predators was demonstrated for sockeye salmon (*O. nerka*) by Bams (1967). Mead and Woodall (1968) showed that salmon fry produced in natural streams on rugose substrate were larger in size than those produced in conventional hatcheries. Thus, hatchery fry are considered inferior to fry produced in the wild. There are several factors in hatcheries that lead to smaller size fry. Rearing alevins on flat surfaces such as in Heath incubator trays causes increased activity by alevins to satisfy its righting response (Bams 1969). High water velocities and daylight increases activity of alevins (Brannon 1965). This increased activity or energy expenditure results in a lower conversion of yolk to body tissue. Substrate incubators were designed to overcome these inefficiencies of hatcheries by providing a rugose substrate to (1) aid alevins in maintaining their upright position, (2) reduce ambient water velocity, and (3) eliminate exposure of the eggs and alevins to light.

The first deep-substrate incubator for Atlantic salmon eggs was constructed in 1975 at the spawning channel on the Exploits River, Newfoundland. This paper will describe the design of the incubators, the operations during 1975-76 and 1976-77, the environmental conditions during operations, and compare the quality of fry produced in a gravel substrate incubator with fry produced in an AstroTurf (plastic grass) Substrate incubator. Fry from the incubators are compared to those from the more natural conditions of a spawning channel.

DESIGN OF THE "EXPLOITS RIVER BOX"

Two incubators were constructed in parallel in the upper section of the artificial spawning channel (Fig. 1). There were two benefits achieved by choosing this location:

1. The water supply for the boxes could be gravity fed from the existing spawning channel head pond, and

2. The portion of the boxes submerged in the channel (1 m) would be partially insulated by the water flowing in the channel.

The "Exploits River Box" is essentially a variant of the deep-substrate incubators designed for Pacific salmon (Bams and Simpson 1977). Its outside dimensions are 4.79 x 2.07 x 1.92 m deep and is constructed of 15.2 cm concrete walls with 10.2 cm of rigid polyurethane insulation and a 1.9 cm (.75 inch) plywood liner (Fig. 2). The box is subdivided into three incubation compartments (0.91 x 1.52 x 1.37 m deep), one head compartment for inlet water and one overflow compartment. A false floor in the incubation compartments consist of 2.5 x 5.1 cm (1 x 2 inch) slats set on edge and spaced 1.3 cm apart. An insulated cover was placed over the box throughout the incubation period. A 5 to 8 cm layer of clean crushed gravel, 1.9 to 3.8 cm in diameter, was placed on the false floor. A 13 cm layer of pea gravel (0.5 to 1.5 cm) was then added to each box. The pea gravel acted both as a pressure layer and as a fry barrier. During the first year of operation the water supply was not filtered. However, prior to the 1976-77 incubation, a washed gravel filter (Fig. 3) was added to the intake system in the head pond (Fig. 1). The water flows from the head pond to each box and upwells through each incubation compartment (Fig. 4). Total rate of flow of water in each box was maintained at 284 ℓ/min.

The cost of each incubation box was approximately $10,000 (Canadian) in 1975. This price does not include the cost of the dam for the head pond; it was previously constructed for the spawning channel. If the boxes could have been built in a less remote area, construction costs would have been considerably less.

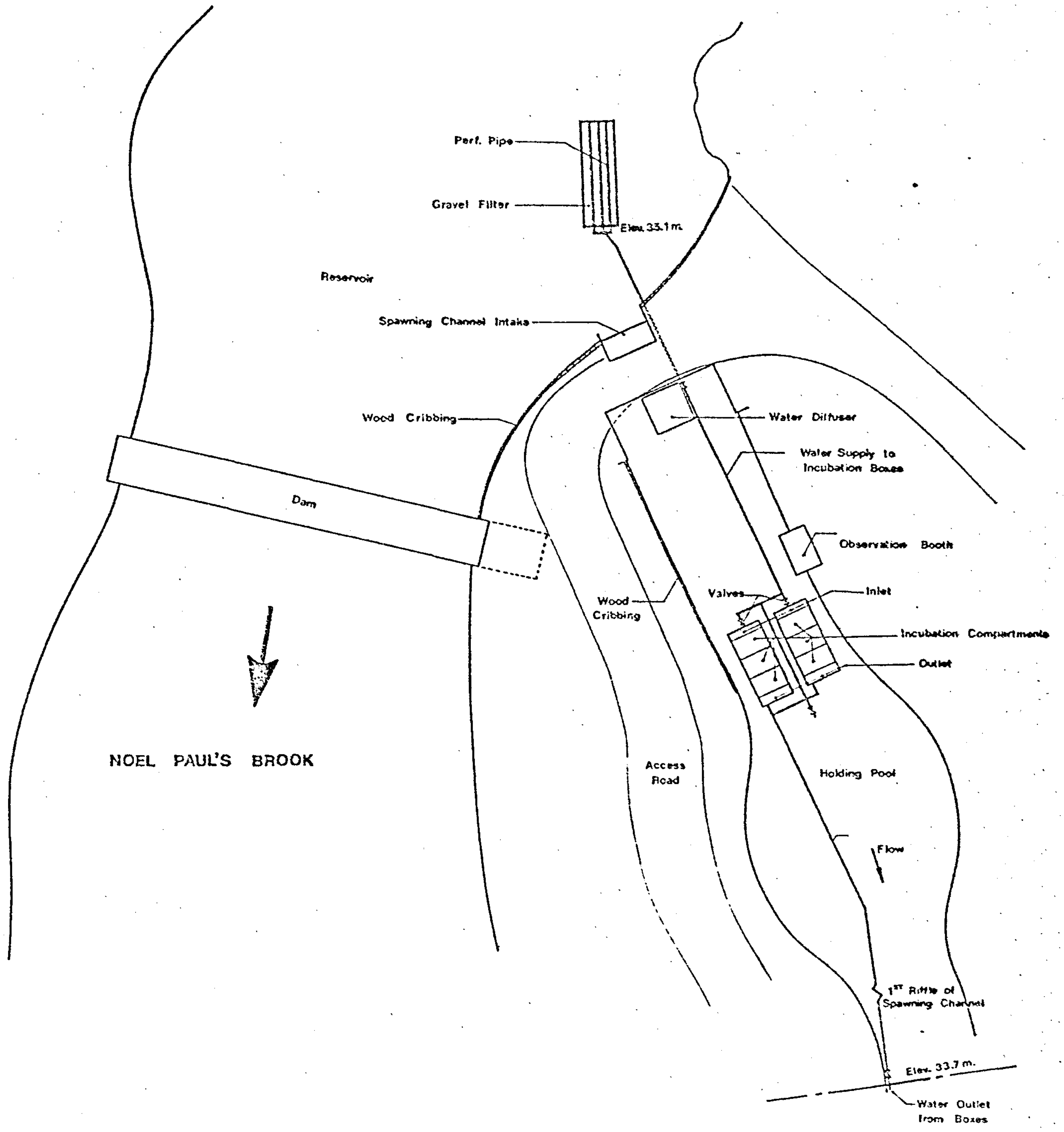

Fig. 1. Site plan of incubation boxes on Noel Paul's Brook, tributary of the Exploits River.

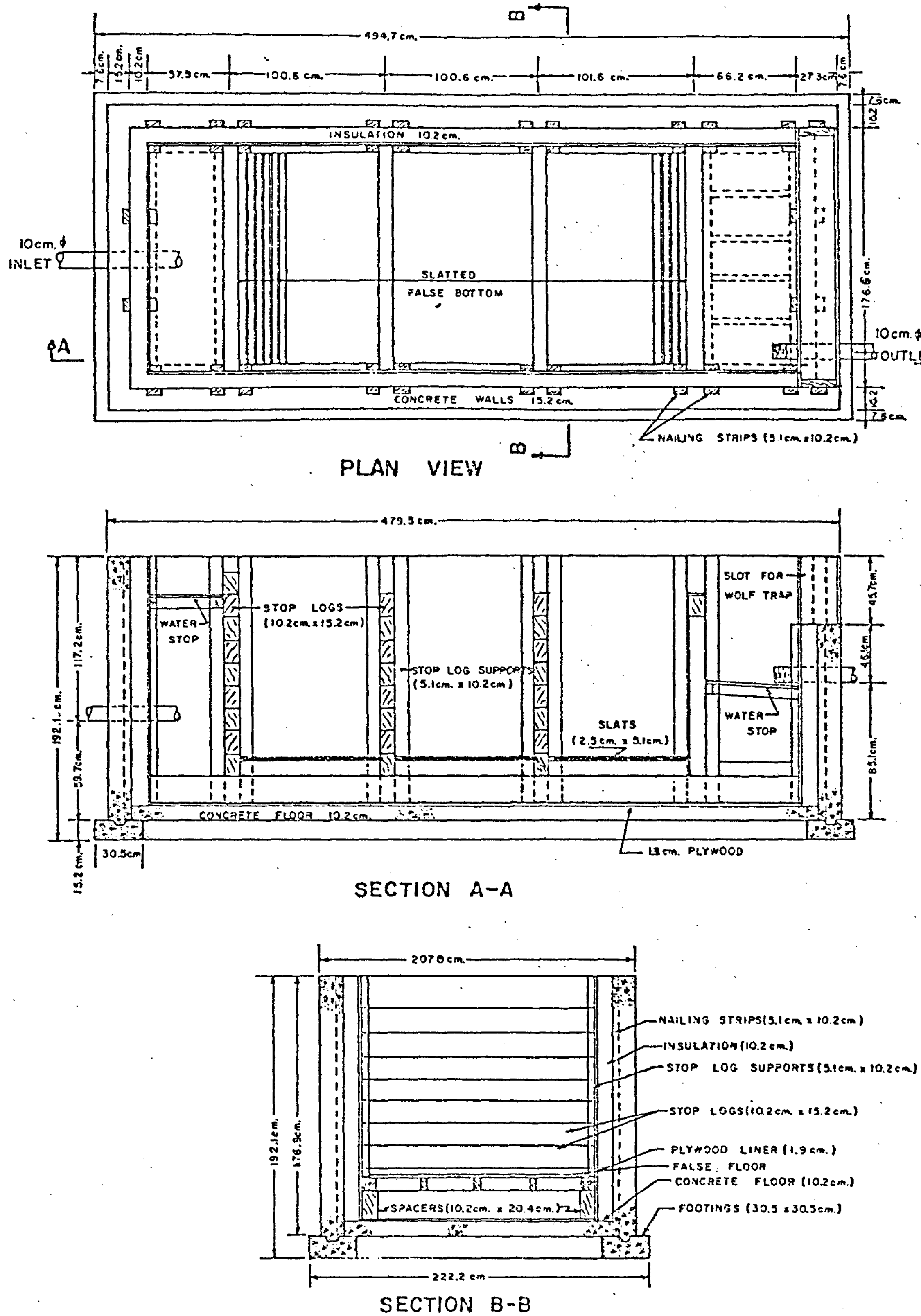

Fig. 2. Diagram of the "Exploits River Box".

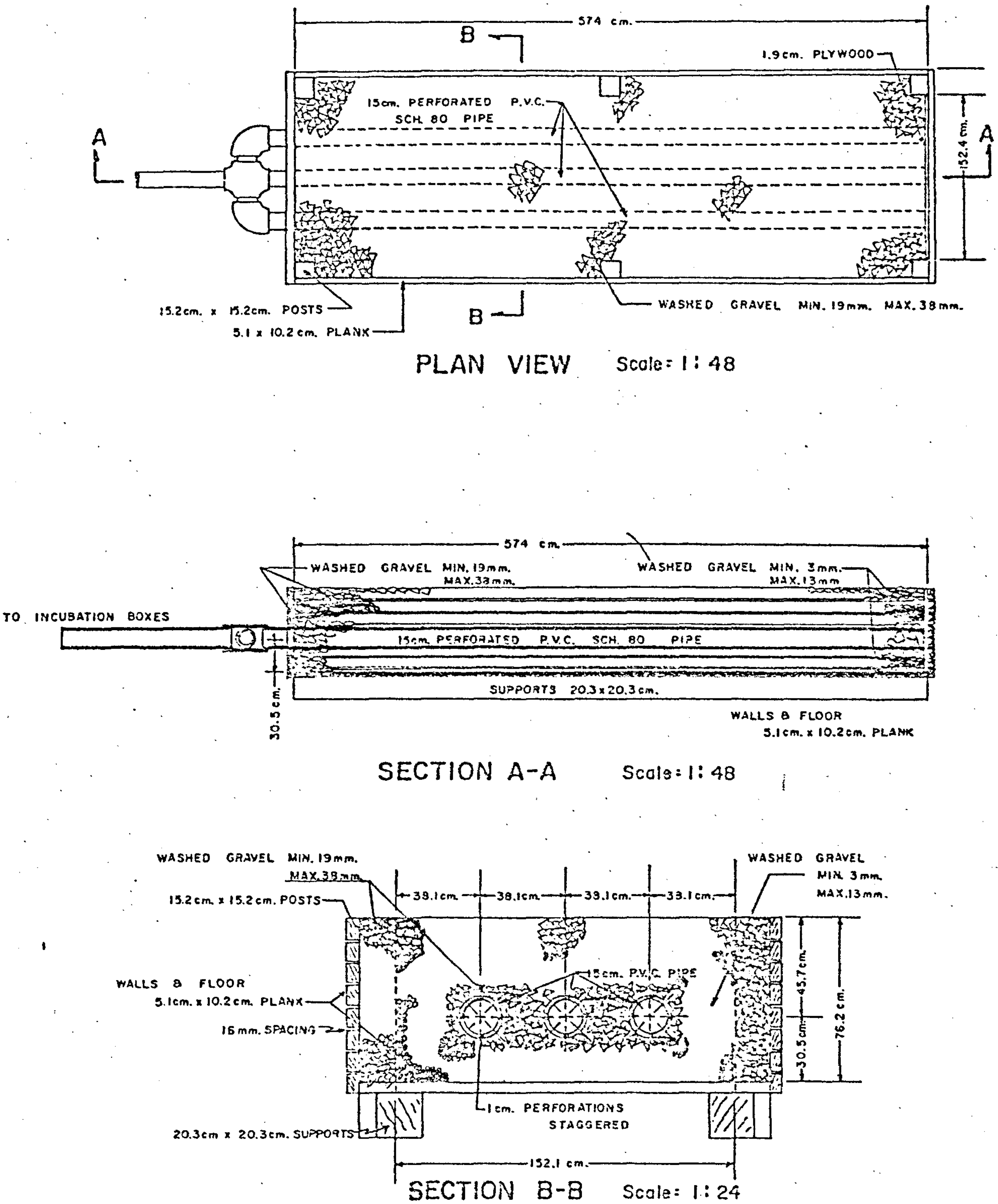

Fig. 3. Diagram of the gravel filter.

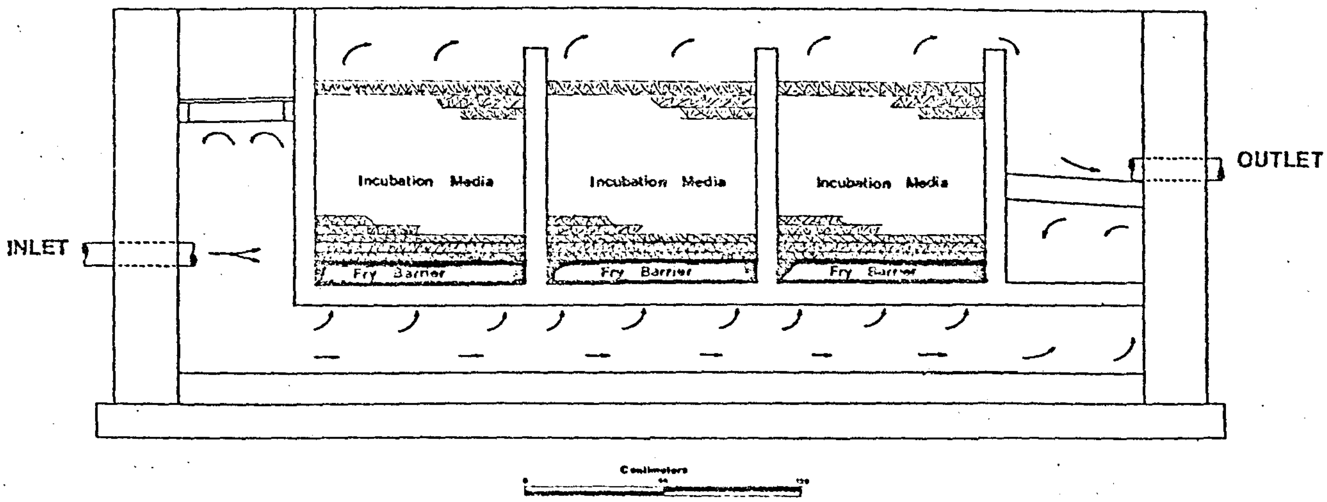

Fig. 4. Flow pattern through the incubation box.

EXPERIMENTAL DESIGN AND OPERATIONS

In the initial brood year (1975) of operations, washed, crushed gravel (1.9 to 3.8 cm) was used as the substrate in one incubation box and AstroTurf (Marine surface FH.01 by Monsanto) was used in the other. For the 1976 brood year, AstroTurf was used in both boxes. The AstroTurf was cut to fit each compartment then perforated with 1.8 cm holes at 7.6 cm centers. The perforations were made to ease fry emergence. Atlantic salmon were stripped of eggs and sperm and fertilization occurred by the dry method (Leitritz 1969) in late October and early November. The eggs were washed, water hardened for two hours, counted by the displacement method and seeded in the boxes. In the gravel incubator a 5 cm layer of gravel was placed over the pea gravel followed by 10,000 to 12,000 eggs which were uniformly distributed over the gravel in each compartment. The addition of layers of gravel and eggs was repeated until 15 layers of eggs were seeded in the box. The top layer of eggs was also covered with 5 cm of gravel. The procedure for seeding the AstroTurf was similar to that for seeding the gravel. A layer of turf was placed on the pea gravel and a small quantity of incubation gravel was sparsely scattered over the turf to hold it flat against the pea gravel. A layer of 10,000 to 12,000 eggs was then uniformly distributed on the AstroTurf in each compartment. This procedure was repeated for 14 to 18 layers. The top layer of eggs was covered with a layer of AstroTurf and 3 to 5 cm of gravel.

The gravel filter was back-flushed with the use of a large pump at regular weekly intervals to prevent the accumulation of silt. Air and water temperatures were recorded throughout both incubation periods. In 1976-77 dissolved oxygen concentration of the outlet water was determined five times a week using the modified Winkler technique.

Prior to fry emergence, light-proof enclosures were built on top of incubators and equipped with electric lights. The lights were illuminated to reduce emergence prior to yolk sac absorption. Fry were enumerated as they moved from each incubator. No attempt was made to collect fry from each compartment. A sample ($\geq$ 20) of the emergent fry was taken daily from each incubation box and spawning channel. The weight and length of each fry was measured. The developmental condition factor (K_D) was calculated using the formula (Bams 1970).

$$K_D = \frac{10 \sqrt[3]{\text{weight in mg}}}{\text{length in mm}}$$

RESULTS

The density of eggs in the gravel incubator was 152,000/m^3 of substrate. This is less than 50% of density seeded in the AstroTurf incubators. The density of eggs per layer in each box for the 1975 brood year was 8000 eggs/m^2 compared to 9000 eggs/m^2 for the 1976 brood year (Table 1). The rate water flowed through each box was relatively constant for both years; however, the volume of water used per 1000 eggs being dependent upon the egg densities, ranged from 0.7ℓ/min to 0.6ℓ/min. In the 1976 egg stripping, the fertilization success was checked and found to be 95.4%.

The periods of fry emergence in both boxes were May 31 to June 24 and June 10 to July 8 for 1976 and 1977 respectively. For the first week of emergence, in both incubators, the fry were premature (yolk sacs not completely absorbed). Hence, lights over the boxes were turned on for 7 to 8 days, which effectively delayed emergence until the yolk sacs were absorbed. The pattern of fry emergence from each box for 1976 and 1977 were similar.

Comparisons of unpreserved fry between sample locations and years (Table 2) indicated the following significant differences ($t^{.05}$): (1) those from the gravel box were longer, heavier and had a higher condition factor compared to both the AstroTurf and the channel, (2) fry from the AstroTurf in 1977 were longer, and because of this, had lower condition factors compared to 1976, and (3) fry from the channel in 1977 were longer than in 1976. The weight of fry was not significantly different between 1976 and 1977 from any location.

During the enumeration of fry from the boxes in 1976, technical difficulties were encountered and only a partial count of fry was obtained (Table 3). The fry that escaped uncounted were later captured in the wolfe traps in the spawning channel. Using this information the minimum survival from fertilization of the eggs to fry emergence was estimated to be 82% (Table 3). Green egg to fry survivals during the 1976-77 incubation period was 83% and 84% for each of the two boxes (Table 3). Allowing 4.6% for unfertilized eggs, the survival from green fertilized eggs to fry emergence would be 87% and 89%.

During egg incubation in both years the boxes were subjected to air temperatures that ranged from -24 C to 22C. Table 4 shows the mean temperature, dissolved oxygen concentrations and percent saturation of the water in the incubation boxes for five stages of egg development from November 1976 to July 1977. The temperature and dissolved oxygen concentrations remained relatively stable during the pre-eyed stage of development. As the water temperature increased, so did the rate of embryo development. This was concurrent with a decrease in oxygen levels. The percent oxygen saturation dropped from 98.3% at prehatching to 77.5% during the stage from hatching to first emergence (Table 4).

Table 1. Egg densities per m^3 and m^2 of substrate and flow of water for each incubation box.

Incubator substrate		Brook year	No. of eggs (,000s)	Density		Water	
				eggs/m^3 (,000s)	eggs/m^2 (,000s)	ℓ/min	ℓ/min/ 1000 eggs
Gravel		1975	432	152	8	284	0.7
AstroTurf		1975	486	420	8	284	0.6
AstroTurf	(I)	1976	504	457	9	284	0.6
AstroTurf	(II)	1976	472	460	9	284	0.6

Table 2. Mean ± standard deviation for the length, weight and developmental condition factor (K_D) of fry from the incubators and spawning channel in 1976 and 1977.

Substrate	Length (cm)		Weight (g)		K_D	
	1976	1977	1976	1977	1976	1977
Gravel	2.75±.06	-	0.17±.02	-	2.01±.07	-
AstroTurf	2.70±.05	2.75±.09	0.16±.01	0.16±3.02	2.00±.05	1.95±.06
Spawning channel	2.70±.05	2.76±.14	0.16±.01	0.16±.02	1.98±.06	1.96±.06

Table 3. Survival of eggs from fertilization to fry emergence. Number in parenthesis is percent survival of fertilized eggs only.

Brood year	Substrate		No. of eggs (,000s)	No. of fertile eggs (,000s)	No. of fry (,000s)	Survival (%)
1975	Gravel		432	-	311[a]	82[b]
1975	AstroTurf		486	-	397[a]	
1976	AstroTurf	(I)	504	481	417	83 (87)
1976	AstroTurf	(II)	472	451	399	84 (89)

a - partial count
b - estimated

Table 4. Mean temperature, oxygen concentration, and percent oxygen saturation of water in incubation boxes for five periods of egg development during 1976-77.

	Fertilization to eyed Nov.1 - Mar.16	Eyed to hatching Mar.17 - May 25	Hatching to 1st emergence May 26 - June 10	1st emergence to peak June 11 - June 22	Peak to end of emergence June 23 -July 2
Temp. C $\pm$ SD	0.3 $\pm$ .1	2.2 $\pm$ 1.5	9.4 $\pm$ 3.0	14.8 $\pm$ 1.1	17.2 $\pm$ 2.6
Oxygen mg/ $\pm$ SD	13.6 $\pm$ .2	13.1 $\pm$ .7	10.1 $\pm$ 1.1	8.0 $\pm$ .5	8.7 $\pm$ 0.5
% saturation	97.1	98.3	77.5	81.2	93.1

DISCUSSION

The use of upwelling deep substrate incubators, such as the "Exploits River" box, was proven to be successful for producing good quality Atlantic salmon fry. The boxes are relatively inexpensive to construct and require minimum maintenance. Throughout incubation it was necessary, on occasion, to adjust the flow through the boxes to compensate for fluctuations in head pressure of the water supply. Silting was a problem during both years of operations, although to a lesser extent during the second year. The gravel substrate appeared to accumulate more silt than the AstroTurf and several times the volume of water passing through the box had to be increased to flush the silt away.

The preparation of the gravel substrate was considerably more labour intensive than the AstroTurf . The gravel had to be sifted to separate the pea gravel and washed thoroughly. All handling of the gravel was done manually using a shovel. AstroTurf required very little preparation. Scrubbing with soap and water and washing with a hose was sufficient to prepare the turf for re-use.

The statistically significant larger size and higher K_D for fry from the gravel incubator is not considered to indicate a biologically significant difference in fry quality. The difference in K_D is so small that performance tests are necessary to show true biological differences. Also, the differences in mean length and weight (Table 3) of the fry are so small that it is beyond the accuracy of the field measuring techniques. The large sample sizes enable a statistical difference to be shown.

The mean survival (83.5%) for green eggs incubated in AstroTurf to fry emergence is excellent considering that the incubators were exposed to extreme cold and silting and operated with low head pressure. This percent survival is higher than the 75% obtained for pink salmon (O. gorbuscha) fry by Bams (1973) and the 74% obtained for Sockeye salmon by Ginetz (1976) when green eggs were incubated in gravel incubators.

The density of eggs per m^3 of substrate can be projected to indicate the relative densities of alevins. Thus, assuming that the percent survival of the eggs to hatching was the same for both substrates, the density of the alevins was 164% to 203% higher in the AstroTurf (Table 1). Although the maximum density of eggs or alevins that can be successfully incubated to produce a good quality fry cannot be extrapolated from these data, it can be stated that a high percent survival and high quality of fry was produced at $460{,}000/m^3$ or 9000 eggs/m^2.

Premature emergence of fry is a problem that has been assóciated with incubation in plastic substrates (Bams and Simpson 1977). For the 1975 brood year, initial emergence of Atlantic salmon fry occurred on the same day from both the gravel and the AstroTurf ; indicating that the factors causing premature emergence were occurring in both types of substrate incubators. It is postulated that the premature emergence was caused by either the silting or crowding of the alevins. Although premature emergence is of concern, it is not considered to be a serious problem for operation of the boxes. By exposing the surface of the incubator substrate to continuous light, when premature emergence commences, the emergence can be delayed until the yolk sac has been absorbed.

The 1.8 cm perforations in the AstroTurf are considered to be important in easing the spatial distribution of the alevins in the gravel and easing fry emergence. This provides a potential reduction in energy expenditure.

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