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CHUM SALMON HATCHERY REARING
IN JAPAN, IN WASHINGTON

By Stephen B. Mathews
and Harry G. Senn

DIVISION OF MARINE RESOURCES
UNIVERSITY OF WASHINGTON 98195

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F O R E W O R D

In 1970, the Washington Sea Grant program initiated project NORFISH for the purpose of providing a channel between technical methods developed or studied at the University of Washington and the management agencies with marine resource problems on which those methods might have a bearing. In furtherance of that goal and in anticipation of possible increased chum salmon production in Washington State for commercial use, the authors of this report undertook a comparative study of chum production in Washington and Japan. Their findings are reported here.

A U T H O R S

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A C K N O W L E D G M E N T S

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CHUM SALMON HATCHERY REARING
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INTRODUCTION

In anticipation of increased chum production in Washington State hatcheries and because of a growing interest in the use of chums for private "fish ranching," we undertook a fact-gathering survey of Japan's successful chum salmon hatchery program on her northern island of Hokkaido.

Using an interpreter, we spent 10 days interviewing hatchery experts of the Japanese Fishery Agency (JFA), and visiting six hatcheries and three adult trapping sites. In addition, data on production techniques and successes, much of it unpublished (TABLE 1), were provided to us. All three trapping sites and the smallest of the hatcheries were operated by private fishermen cooperatives. The rest were run by the Hokkaido Salmon Hatchery, a branch of the JFA.

To fully understand all facets of the art of chum salmon rearing in Japan would require an extensive stay, for one would need to work during an entire cycle at a hatchery to observe all activities first hand. However, we believed that a substantial amount of useful information was obtained in our 10-day survey.

TABLE 1. Hokkaido Chum Salmon Hatcheries Visited

Location	Operator	Water source	Egg & fry capacity	Water available during incubation of eggs & fry (cfs)	Full water available during maximum rearing (cfs)
Chitose River	J.F.A.	spring	30 million	3.6	9.0
Near Tokachi River	J.F.A.	spring & river	50 million	3.6	6.0
Makubetsu River	J.F.A.	spring & river	32 million	3.0	12.0
Satsunai River	J.F.A.	spring & river	70 million	9.6	12.0
Hatchery under construction near Tokachi River	J.F.A.	spring	10 million	1.8	3.6
Small coastal stream near town of Hiroo	private	spring & river	2 million	not determined	not determined

OVERVIEW OF CHUM SALMON REARING

In Hokkaido

In total there are about 50 chum hatcheries on Hokkaido. Only three are privately operated; the rest are run by the JFA (Japanese Fishery Resource Conservation Association, 1966). The private industry works in very close cooperation with the government hatchery people. For example, most of the adult trapping for egg-taking is done by private fishermen's cooperatives. The cooperatives may take the eggs and fertilize and transport them to the government hatcheries, or may transport the adults live to the hatcheries. In return, they are allowed to sort and sell excess males along with all the spawned carcasses.

The hatcheries have several features in common: (1) a source of constant temperature (about 8°C), clear spring water to hatch the eggs and incubate the yolk-sac fry (river water may be added during the feeding phase); (2) a system of channels 2 m wide and gravel-lined (of varying constructional aspects discussed below) for planting eyed eggs shortly before hatching or newly hatched fry; and (3) a common flow-through principle, with the egg incubators at the head of the system, the yolk-sac fry incubators in the middle, and the rearing ponds for feeding at the down-stream end.

The total catch of chum salmon from Hokkaido rivers has averaged 3.89 million fish from 1952-1972, but has increased sharply in recent years to 6-8 million (TABLE 2). Catch figures include both the coastal portion, taken largely in traps near the river mouths, and the high seas portion taken by Japanese long-line and gillnet gear throughout many areas of the northeastern Pacific Ocean and adjoining seas where high seas fishing is not prohibited by treaties with the U.S., Canada and the U.S.S.R. The high seas catch figures are understandably rather imprecise estimates, inferred from high seas tagging results (personal communication, Dr. Tamotsu Yonemuri of the Far Seas Fishery Research Laboratory of the Japanese Fishery Agency at Shimizu).

Most of the Hokkaido chum catch is attributed to hatchery production by the Hokkaido Salmon Hatchery staff. There is some natural spawning, and we saw several streams that appeared completely suitable for natural propagation. However, because of dam building, siltation, pollution, channelization, etc., weirs or seining sites have been placed near the mouths of most rivers where attempts are made to take as many eggs as possible. Thus, little spawning seems to be left to chance, a policy we cannot adequately assess from our limited observations, but which speaks for itself in one regard--high and increasing success.

Chum salmon in Hokkaido are predominantly 3 and 4 years old at maturity. The average age composition for five major streams in Hokkaido for the years 1950-57 was as follows (Sano, 1959):

2-year-olds	-	0.8%
3-year-olds	-	24.9%
4-year-olds	-	59.9%
5-year-olds	-	14.1%
6-year-olds	-	0.2%

TABLE 2. Catch and Spawning Escapement of Chum Salmon from Hokkaido* Rivers in Millions of Fish

Year	Spawning Escapement	Coastal Catch	High-Seas Catch	Total Run
1952	0.31	1.75	0.01	2.07
1953	0.21	2.00	0.05	2.26
1954	0.39	2.99	0.15	3.53
1955	0.29	2.12	0.23	2.64
1956	0.18	1.70	0.44	2.32
1957	0.45	2.17	0.10	2.72
1958	0.49	2.47	0.39	3.35
1959	0.35	1.43	0.21	1.99
1960	0.31	1.42	0.39	2.12
1961	0.43	2.51	0.09	3.03
1962	0.37	2.39	0.05	2.81
1963	0.36	2.41	0.24	4.01
1964	0.59	3.22	0.40	4.21
1965	0.81	3.94	0.22	4.97
1966	0.40	3.41	0.29	4.10
1967	0.59	3.91	0.27	4.77
1968	0.24	1.90	0.63	2.77
1969	0.58	3.60	0.68	4.86
1970	0.64	4.65	0.93	6.22
1971	0.85	6.81	0.81	8.52
1972	0.62	6.34	1.43	8.39
\bar{X}	0.45	3.05	0.38	3.89

*Chum salmon are also produced on the northern portion of the main island of Honshu in amounts approximately 20%-25% of Hokkaido production.

Source: personal communication, Hokkaido Salmon Hatchery Staff (JFA).

The average weight in inshore catches of Hokkaido was reported to be 3.2 kilograms (7.0 lbs.) for years 1946-64 by the Japan Fishery Resource Conservation Association, 1966 (JFRCA). Although not specifically stated in this source, we believe this to be a dressed weight figure. We judged that the average round weight of adults we saw was 9-10 pounds, quite similar to Washington chums.

Major adult chum runs enter Hokkaido rivers from early September to January (JFRCA, op. cit.). The timing varies by locality and river, but generally speaking the peak months are October and November.

In Washington

Hatchery rearing of chum salmon (*Oncorhynchus keta*) in Washington has received relatively little attention compared to chinook and coho salmon efforts. The reasons have been several. Until recently chum salmon were not commercially valued as highly as chinook or coho. Also, chum salmon are not a prime sport fish since their ocean migration takes them far offshore, where they are inaccessible to coastal fisheries, and they do not take hook-and-line very readily during their spawning migration. Finally, experimental rearing of chums which has been done for many years in the U.S. had not, until quite recently, been very successful.

The recent successes of experimental chum rearing at a hatchery in Puget Sound (Hood Canal) and at a channel on the Big Qualicum River in British Columbia have been encouraging.

Also, there are several other reasons why a rapidly expanding chum hatchery program may be needed. For one thing, natural production of chums has fallen to a very low ebb in Puget Sound, Grays Harbor, Willapa Bay and the Columbia River, in spite of stringent fishery regulations to maintain spawning abundance. The main reason for the decline is thought to be greater amplitude of flood runoff and land clearing, causing increased siltation.

Second, the commercial value of chums has risen sharply. The price per pound has recently averaged about 25 percent less than for coho. But since an adult chum averages about 30 percent heavier than an adult coho, the two species have a comparable commercial value on a fish basis.

A third factor is the realization through marking and tagging studies that many of the chinook and coho from Washington hatcheries migrate northward into Canadian waters and are caught there by Canadian troll, net and sport fisheries. Chums could contribute at a higher rate to Washington fisheries than chinook and coho since they would not enter the interim hook-and-line fisheries in any numbers. Nor would they be as susceptible to Canadian net fisheries in the outer Strait of Juan de Fuca, since they return later in the fall than chinook or coho when stormy weather would limit to some extent these fisheries.

A final factor that intensifies the need for a hatchery chum program is the recent decision of U.S. District Judge George Boldt, providing Indian fisheries a very substantially greater share of the Washington salmon harvest, with a corresponding decrease in the share to non-Indian commercial and sport fishermen. Perhaps the fairest, most effective, and least expensive way to compensate the established fisheries for their loss, and at the same time help the Indian fisheries, is to increase the size of the runs by artificial means to the point that the Indian fisheries can take their larger share (up to 50%) while the non-Indian catch is maintained at its pre-Boldt level (or perhaps increased). Chinook and coho hatchery production can be increased to provide such enhancement for the hook-and-line fisheries, but with only limited ability by the state of

Washington to regulate the ocean catches of these species, chinook and coho cannot be strongly relied upon to enhance the net fisheries. Thus, an artificial enhancement program of one of the three net species--chum, pink or sockeye--is needed.

The chum may be the best suited species for the state of Washington to consider. Sockeye are very difficult to propagate artificially and it would be unlikely we could duplicate the success of sockeye salmon spawning channels in Canada, where large, fertile rearing lakes, inexpensive riverside land and high volumes of silt-free water are readily available. Limited hatchery success with pink salmon has been achieved both in the U.S. and Japan, but the relatively low commercial value of pinks makes this an economically inefficient species to stress. Furthermore, pinks could be expected to enhance fisheries only on odd-numbered years for some indefinite time period that it might take to establish even-year runs.

In terms of biological characteristics, Washington's chum stocks are quite similar to those of Hokkaido. The age composition fluctuates considerably by year and river system, but is mainly 3- and 4-year-olds (Pratt, 1974). The major hatchery stock at Hoodspout has the following age composition:

3-year-olds	-	35%
4-year-olds	-	60%
5-year-olds	-	5%

The peak of spawning for most runs is late November, although there are important early races, particularly in southern Puget Sound and Hood Canal, that peak in late September. There is also a fine late run in the Nisqually River which peaks in January.

The average round weight in the fisheries is about 10 pounds (Pratt, 1974).

With this background we turn now to each separate facet of hatchery operation, describing it as we saw it on Hokkaido and then offering a comparison with the Washington State experience.

TRAPPING OF ADULTS

In Hokkaido

To obtain eggs for the hatchery systems, adult chum salmon are trapped in streams using seines, river racks and traps, fish wheels, dip nets, and gill nets. There are about 78 such trapping sites in Hokkaido. Approximately 250,000 females are required to maintain their 500 million fry production and twice this amount would be required to meet the JFA goal of 1 billion. TABLE 3 shows the numbers of adults trapped and spawned and the number of eggs taken.

River racks or barriers and hatchery holding areas are constructed from milled lumber, uncut timbers, or bamboo poles spaced to pass water but to stop upstream movement of adult salmon (Plate 1). These are built in combination with a "v" throated box trap. At the Chitose River rack a fish wheel of the type developed in Maine during the late 19th century is used to brail fish, diverting them into a large partitioned holding pen within the river where sorting can take place (Plate 2). Day and Moore (1959) pointed out the similarity of such a trapping device and other features of Japanese hatcheries to early U.S. fish cultural practices.

Seines are used where it is impossible to rack and trap the river economically. On the Tokachi River, a stream of similar size to Washington's Cowlitz River, a ten-foot-high barrier dam 20 miles above the tidal area stops all migrations (Plate 3). River seines and dip nets as large as 4' x 4' are used to catch adults. Once caught they are sorted and held in live boxes for immediate spawning, transferring to holding areas, and harvesting of excess males.

All females are used for spawning while approximately 3/4 of the males are sold in the round at approximately 300 yen per kilogram, or about \$0.73 per pound. Spawmed salmon bring around \$0.25 per pound and are handled and boxed with care for shipment.

Attempts are being made to spread the egg-taking throughout the timewise duration of the run. In fact, transplants are being made amongst river systems in attempts to spread the timing out even more so than naturally occurs. The apparent logic is to better utilize existing hatchery space--i.e., to produce more fry from a given hatchery.

TABLE 3. Number of Adults Trapped and Spawmed, Number of Eggs Taken and Number of Fry Released in Hokkaido Chum Salmon Hatchery Program, 1945-65

Year	Number of Adults (thousands)	Number of Eggs (millions)	Number of Fry (millions)
1945	633	194	165
1946	414	171	142
1947	361	178	137
1948	408	189	157
1949	482	236	182
1950	489	283	222
1951	294	238	189
1952	312	221	160
1953	212	211	170
1954	386	334	269
1955	294	298	248
1956	182	168	140
1957	448	461	362
1958	489	566	417
1959	353	410	314
1960	305	269	203
1961	428	455	359
1962	371	355	281
1963	360	362	272
1964	592	413	334
1965	806	772	549

Source: Japanese Fishery Resource Conservation Agency, 1966.

In Washington

In the state of Washington most salmon are diverted by river or creek barriers into fishways leading to holding areas. Several hatcheries rely totally on the effluent waters to attract chinook and coho to these areas. It is believed this would also be successful for chums. Beach seines at river sites away from the hatcheries have been used for chums, with the captured fish trucked to holding areas. On occasion, fish have been purchased from Indian tribes once captured in river gill nets. Purse seines have recently been used to capture chum in marine areas. Once captured, they are transferred, often with difficulty, to fresh water holding areas.

Discussion

The adult holding facilities as now used by the Washington Department of Fisheries and sister fishery agencies in the U.S. are more than adequate in design. The trapping of smaller streams to obtain eggs for an accelerated chum program appears quite feasible.

SPAWNING AND EGG SHIPMENT

In Hokkaido

The spawning technique probably varies slightly from site to site, but seemed to be fairly standard.

Seining of holding areas is conducted using conventional equipment (Plate 4). However, the fish are not crowded to the shore; i.e., all fish are held by bagging the seine with each end attached to the live box or rack. This procedure seemed to produce a minimum amount of thrashing by the fish, probably minimizing broken eggs and increasing the chance of survival of unripe fish that must be held an additional time. The ripe fish are sorted into the live boxes, killed and spawned once the box is full. Both males and females are killed with a single blow from a heavy stick. They are then placed in wooden boxes, separated by sex with about 7 females to a box (Plate 5). These are usually transferred by truck within an hour to the spawning shed close by. The Japanese do not bleed females, as they found it to be of no value and often harmful to egg survival.

At the spawning shed, the females are placed on tables and opened with spawning knives. The eggs are collected in circular pans 20" wide and 6" deep (Plate 6). Sperm is added after the eggs of from three to six females have been collected. To this point almost no water or slime gets into the pan. Once the pan is approximately 1/2 full of eggs and sperm, water is added. Mixing is then done and the eggs are placed into an 8' x 2' x 2' tank with running water. There they are left for approximately 60 minutes to harden, after which they are removed for shipment in 40" x 16" x 16" wooden boxes with lids. No water is used during shipment, and the boxes are filled to capacity so that when the lid is in position the eggs are held pressure tight.

Once at the hatchery they are placed in incubators.

In Washington

There are far more individual variances in spawning and egg-handling techniques in Washington hatcheries. Often sperm is placed in the container before collecting the eggs. To collect the eggs, five-gallon pails are more commonly used, but so are the older shallow spawning pans. The amount of sperm and mixing varies. Some managers club fish on the head while others use cleavers. Bleeding the females is universally conducted.

Our egg-shipping procedures are also more variable. Fertilized eggs may be shipped partially water-hardened and dry; they may be water-hardened but transferred in water; or some managers may transport sperm and unfertilized eggs. Heavy losses of eggs have occurred during shipment of green eggs, so a standard procedure--perhaps the Hokkaido one--needs to be developed in anticipation of a large-scale chum program.

INCUBATION

In Hokkaido

Once a shipment of fertilized eggs arrives at the incubation facilities, they are carefully transferred to each incubation unit. The most common incubation unit observed was a deep trough, in principle identical to that used in Washington and Oregon. Drip incubators and the Montana or California box type unit (Jochimsen & Bedell, 1968) were observed, but apparently have very limited use. Successful eying of eggs was observed using the 4' x 4' x 4' California boxes.

Their new deep trough units are being made of plastics and were originally copied after the Atkinson version developed in New England during the late 19th century (Plate 7). They are normally set in tandem with the first pair flowing to a second pair and sometimes into a third. Each unit is approximately 7' long, 1' wide and 1' deep, holding 4 stacks of trays set in frames (Plate 8). Ten or eleven trays can be set in each stack with 2,500 eggs per tray. Thus, each 7-foot unit holds approximately 100,000 eggs.

Water used for incubation is always spring water and most often around 8°C (46°F); however, 10°C (50°F) water is used at one station. The volume of water to each trough or the amount of water flowing through one square foot of tray is 20 liters per minute (lpm), or 5.3 gallons per minute (gpm). As in our deep troughs, water upwells through each stack of eggs. Malachite green is used to control fungus, and if nitrogen gas in the water exceeds saturation, the splash method is used to reduce the levels.

Approximately 5 percent of the eggs die or are not viable at the eyed stage. At this point all eggs are shocked, then transferred to heated working areas where temporary employees hand pick and remove the dead eggs prior to returning the viable ones to the trays (Plate 9). Salt dipping is used very rarely, and only when excessive losses occur.

Once all eggs in a given unit hatch, they are removed immediately, placed in an empty tank, then pumped into the gravel-lined incubation channels for final yolk absorption.

The gravel incubation channels are 2 m wide, 0.2 m deep, and variable in length, with perhaps 30 m being standard. These are built in parallel, usually with common walls (Plate 10). The channel bottoms are level, as measured from head end to tail end. Water from one channel flows into another with a drop of a third to a half a meter to provide aeration (Plate 11). The walls are normally of concrete material and the bottom either concrete or earthen material, depending upon the permeability of the soil.

The most desirable gravel for covering the channel's bottom was stated by the Japanese experts to be 15 mm to 50 mm (1/2 to 2 inches) in diameter. The amount used can be described as 1 rock deep with open concrete in about 10 percent of the area. The stated purposes of the rock were to provide resting areas and to maintain even fry distribution. Cleaning of the gravel is an annual practice.

At the Chitose hatchery the gravel incubation channels had an upwelling system using two parallel perforated pipes beneath the gravel and running the length of the channel. This was not seen in new construction. Also, it is interesting to note this system was designed to hatch on trays almost identical to the Netart system (Lannon, 1974) where fry hatch on trays and fall through to the gravel below. The latter is no longer used in Hokkaido.

In all cases light is kept from the yolk-sac fry either by covering the individual channels with boards, or covering all channel units with a steel-frame building. The latter system is apparently preferred, as it is being incorporated at a new hatchery still under construction.

In all cases spring water, again about 8°C, is the sole source used in the incubation channels. Each 2 m-wide channel maintains a water level of about 12 cm (5 in.). The volume varied at different hatcheries between 200 and 350 lpm (53 to 79 gpm).

Newly hatched yolk-sac fry are transferred and spread evenly over the gravel at a maximum concentration of 15,000 fry per m. (12,540 yd²). This would be equivalent to a layer about 1 fry deep.

Eyed eggs are apparently not usually distributed over the gravel prior to hatching, for reasons we did not ascertain.

Once the fry absorb the yolk, the screens are removed from the ends of the channels and fry migrate on their own to the rearing areas. Feeding in the incubation ponds is an exception and conducted only when the walls are constructed high enough to provide sufficient depth.

Generally speaking, the incubation channels have no other functions than a holding space for the yolk-sac fry.

In Washington

Deep troughs, the Atkinson type, and drip incubators (Burrows & Palmer, 1955) are the more common methods of egg incubation in the state of Washington, although shallow troughs and the recently introduced pond trays (Senn, Pattie, & Clayton, 1973) incubate and hatch nearly 30 percent of all eggs (chinook, coho, and chum).

Gravel incubation is being used on test lots and at one channel 1.0 million chum salmon have been thus incubated (Kral, 1967). Also, Zimmer boxes (Zimmer, 1964) are being used on an experimental basis.

Other than gravel incubation, the other types of incubation handle the eggs from fertilization through yolk absorption. All require the dead eggs to be removed. Shocking is conducted after the eggs have been subjected to 500 temperature units. Hand picking or salt dipping follows. Egg losses on all species that are not being shipped are usually less than 5 percent, although on chinook and coho eggs shipped green or unfertilized, the loss has often been considerably more than this.

The upwelling, sectioned, deep trough used in Washington is in principle like the Atkinson type as used in Japan. The exceptions are that the trays in Washington are deeper, handling approximately 3 times as many eggs per tray. About the same number of eggs are present per given area of trough. However, nearly twice as much water is passed through a tray per unit area with the Washington deep trough compared to the Hokkaido incubator, about 10 to 15 gpm. This high velocity could be a cause of incubation problems of coho eggs and fry in our hatcheries that become evident in the early stages of feeding. The lesser velocity used in Hokkaido should probably be used for chum.

Drip incubators pass about the same amount of water through a given area of screen trays for incubating the eggs and fry as the Hokkaido deep trough system, 5 gallons per minute per square foot of screen. An incubator 16 trays high will hatch and incubate approximately 120,000 fry. This method is quite successful for chinook and coho and appears satisfactory with the limited experience on chum. The cost of each unit is high, however.

The shallow trough incubation uses the upwelling system with eggs in six 11" x 25" x 5" wire baskets, all placed in troughs 15' x 1' x 0.5'. Approximately 25,000 eggs per basket can be eyed while only 12,000 can be hatched per trough. Approximately 7 gpm is used in shallow trough incubation, passing through each basket. The flow rate is very similar to that of the drip incubator. This system takes lots of space, but produces fairly good quality fry, provided they are kept darkened. The troughs can also be used as an area for picking dead eggs or handling fish for marking or study purposes.

The pond incubation method uses 3' x 5' screen trays stacked one upon another within a hatchery rearing pond. A space between each tray is provided to allow a horizontal flow of water over the eggs, but not through them as in deep trough, shallow trough, or drip incubators. Eggs are placed in trays at a maximum density per unit volume of 1/3 that in the deep trough trays or nearly identical to the Hokkaido trays. Fry are free to swim from the trays as the yolk is absorbed. Up to 11 million eggs have been eyed on trays placed on one 40' x 10' x 2' raceway using 400 gpm. This relatively new system has worked well for chinook and coho, but has not been fully tested for chum. When clear water is available (a must) this is a very economical technique and has provided excellent quality coho fry. The studies in progress on chum look encouraging.

Gravel incubation has been used on a very limited scale, but has produced a high quality fry. The gravel used is usually 1 to 3 inches in diameter and will handle around 6,000-9,000 eggs and fry per yd². The Netart or the Hokkaido principle is

used by the Quinault Indian Tribe and others. Gravel incubation boxes of a number of sorts, such as Zimmer and Bams type (Bams, 1973), have been used in small streams in Washington, Oregon and British Columbia.

Discussion

While the egg incubation methods used in the hatchery systems on the Pacific Coast appear very adequate for chinook and coho, the incubation of the yolk-sac chum fry is an area that likely needs improvement. In Hokkaido a compromise situation exists where gravel is sparingly used in combination with standard hatchery incubation. This system of handling chum eggs and fry appears to work well and is recommended for our use, at least initially. Astro-turf, yolk-sac fry incubator substrate being tested in Alaska (Bailey and Taylor, 1974), may have an eventual use in our system also.

Gravel incubation ponds, if built in Washington, would not need to be covered with a building, since our mild climate would present no problem, provided spring water is used. The use of concrete to line the channels is probably unnecessary and should be avoided, if possible, to save construction costs. Plastic sheeting covered with sand and rock to line the channel could suffice.

Spring water, avoidance of light, and proper incubation velocities appear to be the main factors which produce high quality fry in Hokkaido. Thus, every effort should be made to incorporate these features for Washington chum, egg and fry incubation.

Where feeding is not programmed, gravel incubation is probably the most intelligent approach. Gravel channels, ponds with gravel, or gravel boxes all should be considered. Even if feeding is programmed, gravel incubation like that of the Hokkaido system should be strongly considered on new developments.

FRY REARING

In Hokkaido

Once yolk-sac absorption has been completed, fry move (usually on their own) from the incubating channel to one or more rearing areas. The maximum density for initial feeding is 20,000 fry per m³ (about 700 per ft³).

The standard rearing areas are earthen ponds of variable dimensions. Plate 12 shows one about 100 m. long by 20 m. wide by 1 m. deep. One station had 8 concrete ponds, 25 m. long by 6 m. wide by 1 m. deep. Regardless of construction material, they all connect directly to the incubation channels upstream and are screened on the downstream end with flat plate screens. The water for rearing may be 100% spring water (8°C), if suitable quantity is available, or a combination of spring water and 4-12°C river water may be used.

The Japanese appear to push the holding capacity of their available water supplies to the limit, closely monitoring the dissolved oxygen of inflowing and outflowing water and the water temperature.

The following formula and table of factors were offered as their criteria for determining the weight of fish to be held per unit of inflowing water:

$$W = \frac{C_2 - C_1}{K} V$$

where: W = total weight of fish held (kg)

C₂ = D.O. of the inflowing water (cc/l)

C₁ = 4.0 cc/l (This is the minimum allowable D.O. concentration for outflowing water.)

V = water flow (l/hr)

K = a factor varying with water temperature and individual fish size (cc/kg-hr)

For chum salmon of one gram average weight, the maximum normally achieved during rearing, the following K values were given to us:

Temp C	5	6	7	8	9	10	11	12	13	14	15
K	113	132	151	170	188	206	223	240	258	275	293

We converted this relationship into our most commonly used measure of pond loading, pounds of fish per gallon of water per minute, interpolating from the Japanese data for temperatures of 4 and 16 degrees C. This schedule is as follows:

Temperature C	4	6	8	10	12	14	16
Temperature F	39	43	46	50	54	57	61
Lbs/gal/min	21.9	18.0	12.7	9.5	7.4	6.0	5.4

The fry are allowed to enter the rearing ponds voluntarily after absorbing their yolk sacs in the incubation channels. Feeding therein begins immediately. No particular feeding rates are predetermined. The fish are simply fed until it is subjectively determined that they have had enough to eat. They are fed 8 times daily.

The formula for the Hokkaido dry diet is in TABLE 4. The initial pellet used is quite comparable in size to our 1/32" pellet. Mash is not used as a starter diet. A total of 100 to 150 metric tons of dry diet is used annually in all Hokkaido hatcheries (about 220,000 to 330,000 lbs). Their food to fish conversion rate was estimated by their staff to be about 1.5 lbs. of food to produce 1 lb. of fish. Feeding generally terminates at the proper release time, which on the average provides 30 to 40 days of rearing. They attempt to reach an average release weight of 0.8 gms., but based upon the figures given us on numbers of fed fry released (TABLE 4), total food fed, and a food conversion rate of 1.5:1, the actual average attained may not be this high.

TABLE 4. Numbers of Chum Salmon Fry Liberated and Total Adult Returns Attributed to Hokkaido Salmon Hatcheries

Brood year	Fry liberated (millions)	% of fry fed	Return by age in millions (high seas and coastal catch, and spawning escapement)				Total return brood year (millions)	Estimated hatchery return (90% of total)	Hatchery returns as % of fry liberated	
			.2	.3	.4	.5				.6
1950	222	0	-	0.77	2.14	0.27	0.01	3.190	2.871	1.29%
1951	189	0	0.03	1.09	1.63	0.46	0.02	3.230	2.907	1.54
1952	160	0	0.04	0.63	1.12	0.21	-	2.000	1.800	1.12
1953	171	0	0.03	0.69	1.20	0.19	-	2.110	1.899	1.11
1954	269	0	0.05	1.25	2.11	0.14	-	3.550	3.195	1.19
1955	248	0	0.03	1.01	1.23	0.18	-	2.450	2.205	0.89
1956	140	0	0.05	0.59	1.26	0.32	0.01	2.230	2.007	1.43
1957	362	0	0.03	0.66	1.88	0.56	0.02	3.150	2.835	0.78
1958	417	0	0.02	0.77	1.31	0.17	-	2.270	2.043	0.49
1959	314	0	0.06	0.91	2.04	0.40	-	3.410	3.069	0.97
1960	203	0	0.02	1.64	1.81	0.20	-	3.670	3.303	1.63
1961	359	0	0.14	1.99	3.71	0.61	-	6.450	5.845	1.62
1962	281	10.1	0.01	1.01	1.69	0.43	-	3.140	2.826	1.01
1962	272	26.5	0.04	1.70	3.34	0.31	-	5.390	4.851	1.78
1964	334	31.0	0.10	0.99	1.30	0.09	-	2.480	2.232	0.67
1965	549	22.1	0.02	0.98	2.05	0.15	-	3.200	2.880	0.52
1966	272	57.9	0.18	2.64	3.90	0.28	-	7.000	6.800	2.31
1967	435	48.6	0.08	2.11	6.20	0.97	-	9.360	8.424	1.94
1968	207	92.6	0.07	1.80	3.40	(0.32)*	-	5.650	5.085	2.46
1969	362	76.5	0.17	3.94	(4.59)*	-	-	8.70**	7.830	2.16
1970	442	72.6	0.08	(3.16)*	-	-	-	-	-	-
1971	576	75.6	(0.10)*	-	-	-	-	-	-	-
1972	475	79.2	-	-	-	-	-	-	-	-
1973	446	77.3	-	-	-	-	-	-	-	-

*Includes only the inshore catch plus escapement. High seas catch would add 10-12% to these values.

**Minimal in that no 5-year-olds included.

Source: personal communication Hokkaido Salmon Hatchery staff.

In Washington

Without exceptions chum fry go directly from the incubation units to concrete or asphalt-lined ponds for their initial feeding. The receiving waters are generally very cold, 4°C - 5°C. Initial ponding levels average 200 fry per ft³ of water; however, maximum levels of 300-450 have been used successfully on a short-term basis. Feeding by "eye" is used initially, starting with fine mash.

After a week or two mash is replaced by a 1/32" pellet. Feeding levels are generally determined by feeding all the fish will eat, 8 times each day initially, but less often as the fish grow. Up to five percent or more of body weight is commonly fed per day when water temperatures are 48°F or above.

A pond receiving 450 gpm will adequately hold, by our standards, 1/2 lb. per ft³ or about 2,000 lbs. of chum fry at 1.5 gms each. This is 4-5 lbs. per gallon per minute, considerably less than the Hokkaido levels of pond rearing. The rearing period at Washington hatcheries is about twice as long as in Hokkaido with emphasis placed on growing the fish to about a size of 300 fish per lb. at the time of release (1.5 gms each), or about double the size of the Hokkaido fry.

Discussion

The rearing program, as conducted in Hokkaido, differs from that in Washington a number of ways. The advantages of a large earthen pond compared to a series of smaller concrete ones are cheaper construction costs, less time needed in feeding a given quantity of fish, and better breakdown of waste products. On the other hand, if a disease outbreak occurs, all fish are in one pond, and there is the risk of heavy loss. The Japanese expressed no concern on the latter, however.

The dry diets in Hokkaido work well in their spring water. However, the Oregon moist pellets have proven superior to any diet, dry or wet, tested by the Washington Department of Fisheries. Any variations from the OMP diet should be on a test basis only. Mash as a starter diet might not be required if we start feeding chums in warmer water. This would be desirable, since mash often produces a gill irritation.

The feeding techniques do not appear to differ greatly; however, the Japanese probably assign far greater man days to this end. One interesting comment was that they worry little about the dead and care for the live ones. In their type of pond the dead fish drift to the downstream end and collect on the screen areas.

The average pond loading of fish, as related to water inflow, is similar to ours at the beginning of rearing, but far exceeds ours at the end point. One of their guides to determine when maximum load is approached is when oxygen level falls to about 5.0 ppm. We have never approached such heavy loading with our chum, although normally we do so with coho. Their heavy pond loading is probably allowed by the use of clear, disease free, straight flow-through, and constant temperature spring water. Our use of river water with fluctuating water temperatures and native fish populations above the intakes for possible disease sources undoubtedly reduces our capabilities.

It is not recommended we necessarily project our new production using their pond loading standards, but recognize their apparent differences in hatchery design and incorporate these in new construction so as to perhaps reach their level of pond loading in the future.

TABLE 5. Composition of Hokkaido Dry Diet

Type	Dried mixed feed			
Pellet size	First-half rearing	0.5 mm~1.0 mm	(0.3 g~0.5 g)	
	Last-half rearing	1.0 mm~1.5 mm	(0.5 g~1.0 g)	
Composition	Crude Protein	48.0~54.0%		
	Crude Lipid	4.0~7.0%		
	Crude Fiber	0.2~1.5%		
	Crude Ash	10.0~13.0%		
	Moisture	7.0~10.0%		
Material	White fish meal, liver powder, blood powder, yeast, defatted milk (powder), wheat flour, starch, mixed mineral, mixed vitamin Trace elements (Fe, P, Ca)			
Vitamin content (per Kg)	A	4,400 IU	Niacin	450 mg
	B1	30 mg	Pantothenic acid	200 mg
	B2	90 mg	Para-amine benzoic acid	200 mg
	E	180 mg	Choline	4,000 mg
	B6	30 mg	Inositol	600 mg
	B12	0.05 mg	Bitotin	2.5 mg
	K3	20 mg	Folic acid	10 mg
	D	1,000 IU		
	C	1,000 mg		

Source: personal communication, Hokkaido Salmon Hatchery staff

RELEASE TIMING

The Japanese closely monitor the stream and estuarial environment to attempt to release the fry at an optimal time for survival. The factors mentioned were stream and estuarial temperatures, and plankton abundance. They strive for a release time that apparently coincides with ice-out in the rivers and spring plankton bloom. If the release time is too late in the spring, survival is apparently decreased. The indicator factor for this is ocean temperature. It was reported that if this exceeds 15°C at release time, poor survival results.

In Washington less attention has been given to release timing for chums, with more emphasis on size. It is obvious that experimental work with marked fish at various release times and sizes must be done in Washington prior to or along with the development of a production chum program.

FRY TO ADULT SURVIVAL

In Hokkaido

TABLE 5 shows the number of fry released and the total adult return by brood year, including high seas and inshore catches, and fish seined or trapped for spawning. From data presented (JFRCA, op. cit.) and confirmed by personal communication with Dr. Yonemuri, about 10% of the returns may be from natural spawning. Therefore, we assumed 90% of total production to be from hatcheries in an attempt to give an unbiased picture of hatchery success. Survival has ranged from 0.52% to 2.46%, averaging 1.39%. For the brood years prior to 1962 wherein no feeding was done, survival averaged 1.17%. Since 1962, survival has averaged 1.61%. There has been a recent sharp upward trend in survival, which seems to follow an increased amount of feeding of the fry.

In Washington

Survival data for three Washington hatcheries, two on Hood Canal (Hoodsport and Quillicene) and one on Willapa Harbor (Nemah) are given in TABLE 6. Except for recent experience at Hoodsport, survival has generally been less than in Hokkaido, averaging less than 1%. The recent high survival rates at Hoodsport were obtained with fry of about twice the average size at release as those in Hokkaido.

Discussion

The Hokkaido hatcheries are experiencing substantially higher survival rates than those in Washington, and with many more times the fish released. Perhaps ocean conditions are better for survival of chums on the Asian side of the Pacific Ocean than on the North American side. However, this is doubtful, since the respective stocks appear to have evolved the same growth rates, egg numbers, freshwater survival ability, and other life history characteristics. If there were different survival "pressures," one would expect quite different population parameters.

Thus, the Hokkaido survival rates present a target for U.S. hatchery chum production. It is quite probable that if we can duplicate Japan's three most apparent keys to success--constant temperature spring water, yolk-sac fry incubation channels, and releases closely timed to optimal stream and marine environmental conditions--we can have an equally successful hatchery chum program.

TABLE 6. Numbers of Chum Salmon Fry Liberated from Washington Hatcheries, and Total Adult Returns

NEMAH HATCHERY ¹ (Washington Department of Fisheries)						
Brood year	Fry liberated	Size of fry		Total brood year spawning escapement	Total brood year catch	% Adult return from fry plant
		gms/fish	fish/lb.			
1967	412,000	0.87	520	1,415	1,415	0.69%
1968	660,000	0.76	597	1,229	1,229	0.37
1969	667,000	1.06	430	1,982	1,982	0.30
1970	536,000	0.93	490	2,198	2,198	0.41
QUILICENE HATCHERY ² (U.S. Bureau of Sport Fisheries & Wildlife)						
1966	3,097,000	0.35	1,300	6,790	2,511	0.30%
1967	3,098,000	0.35	1,300	5,518	2,146	0.25
1968	2,100,000	0.35	1,300	5,092	4,149	0.44
1969	3,396,000	0.35	1,300	12,396	7,280	0.58
1970	6,840,000	0.35	1,300			
HOODSPORT HATCHERY ³ (Washington Department of Fisheries)						
1966	554,000	1.45	313	5,095	3,955	1.63%
1967	678,000	1.54	295	4,031	2,955	1.03
1968	1,658,000	1.20	379	6,728	9,140	.96
1969	795,080	1.39	327	5,868	8,802	1.85
1970	724,606	1.19	381	18,160	3,222	3.01

¹Assumptions are: (1) all fish returning to the hatchery were of hatchery origin; (2) all hatchery origin fish returned to the trap; (3) all fish matured and returned as 4-year-olds; and (4) 50% of the adult runs enter the fishery (personal communication, Mr. Sam Wright, WDF).

²Assumptions are that all hatchery fish are trapped and all return as 4-year-olds. Mr. Grant Fiscus, WDF, estimated the harvest rates and catches from his experience as manager of the commercial salmon fisheries of Puget Sound.

³Assumptions are that age composition in the run is the same as age composition in the Hood Canal commercial net fishery and that catch rates on the hatchery run are the same as on the entire Hood Canal run (personal communication, Mr. Robert Gerke, Washington Department of Fisheries).

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PLATE 1. Bamboo river rack with "v" throated trap.

PLATE 2. Maine type
fish wheel on the
Chitose River.

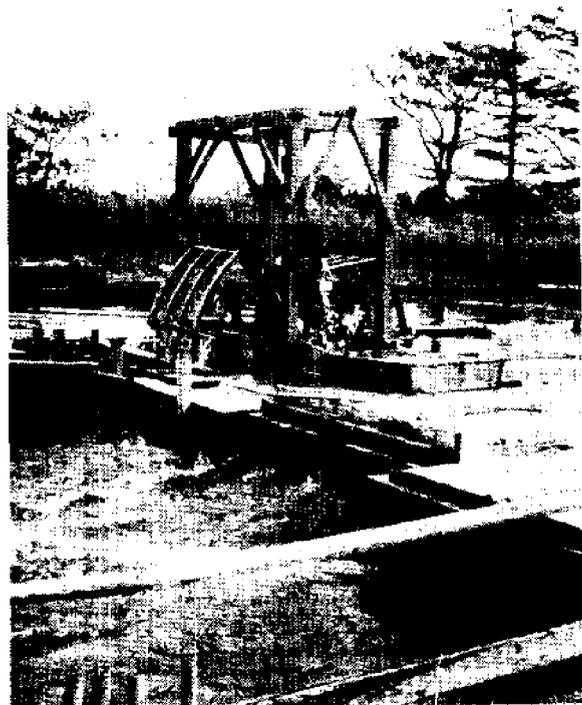


PLATE 3.
Barrier dam
seining site
on the Tokachi
River.

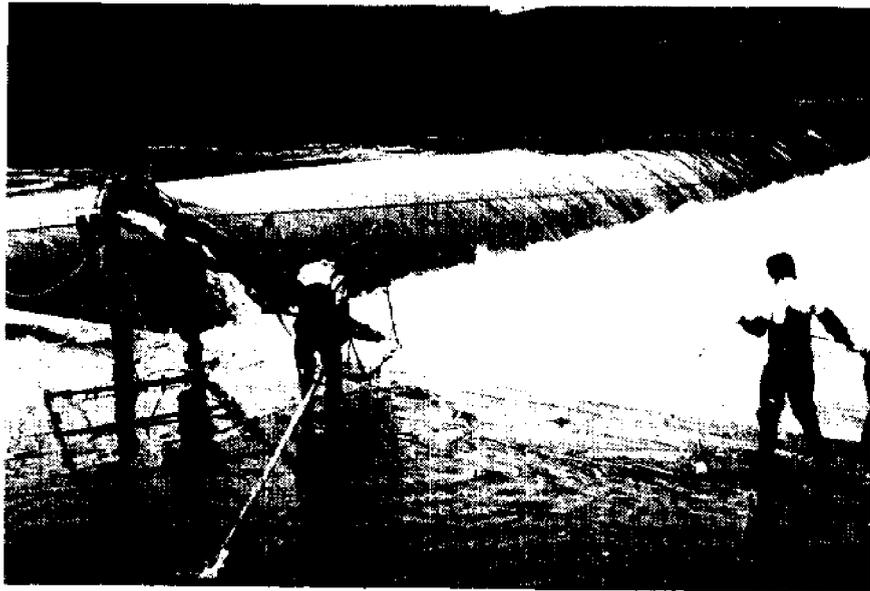


PLATE 4.
Sorting adult
fish from a
holding pond
for spawning.

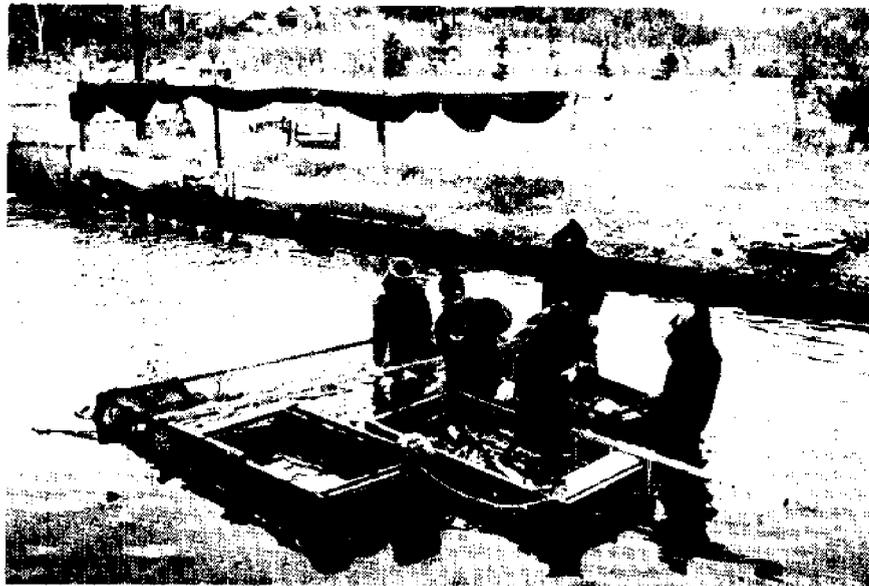




PLATE 5.
Transporting
ripe fish to
spawning shed.



PLATE 6.
Spawning pan in
right foreground;
tank for water
hardening eggs
to the left.

PLATE 7.
Plastic deep
trough egg
incubator;
screen egg traps
stacked at left.



PLATE 8.
Egg incubator
screen tray.

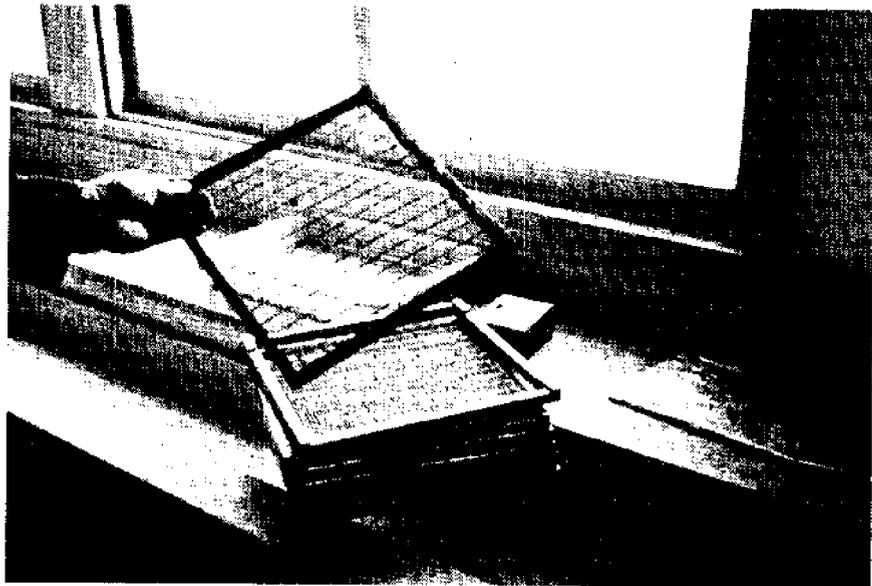




PLATE 9.
Hand picking
dead eggs.



PLATE 10.
Incubation
channels for
yolk sac fry.

PLATE 11.
Drop structure
between incuba-
tion channel
sections; large
rocks on right
used to break up
flow for
oxygenation
when channels
are in use.

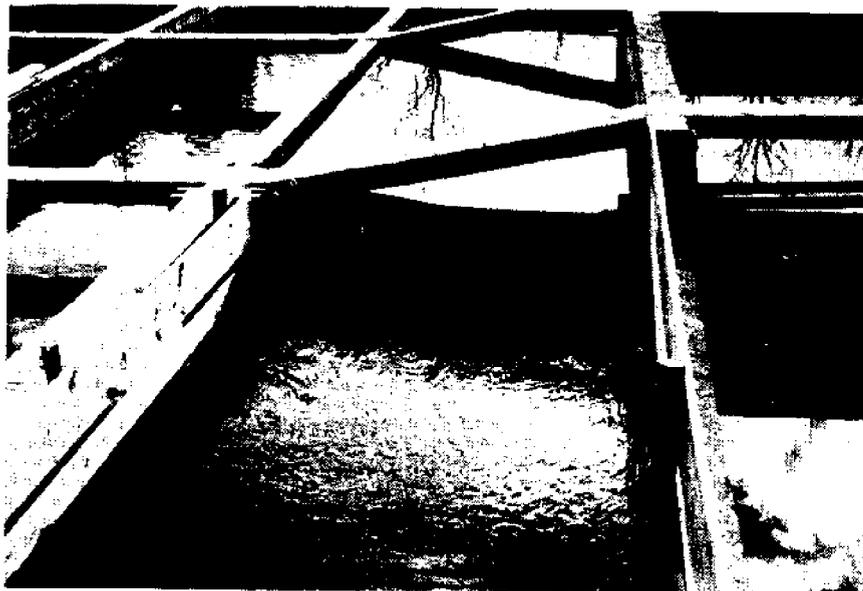


PLATE 12.
Earthen fry
rearing pond.



