Floating Horizontal and Vertical Raceways Used in Freshwater and Estuarine Culture of Juvenile Salmon, *Oncorhynchus* spp.

WILLIAM R. HEARD and ROY M. MARTIN

Introduction

Salmonid culturists commonly use a wide variety of containers including raceways and ponds of various types (Burrows and Chenoweth, 1955, 1970), circular tanks (Larmoyeux, et al., 1973), and vertical drums and silos (Buss, et al., 1970). Frequently new modifications are developed in response to specific requirements associated with a particular fish culturing activity.

In 1973 we began experimentation with the use of raceways floating in the estuary of Little Port Walter Bay, Baranof Island, southeastern Alaska, where the Northwest and Alaska Fisheries Center Auke Bay Laboratory maintains a year-round field station to conduct a variety of salmonid research programs (Fig. 1). We developed the floating raceways as a tool in our efforts to determine the practicality of rearing coho salmon, *Oncorhynchus kisutch*, fry to smolts in estuarine net pens (Heard and Crone, 1976; Heard et al.[1]). In this paper we describe the construction and operation of the horizontal and vertical floating raceways we are using at Little Port Walter.

The culture of newly emerged salmon fry (0.2-0.4 g depending on species) in net pens requires openings no larger than ⅛ inch square mesh to retain the fish. Most other pen culture of salmonids begins with fish larger than fry and larger openings (mesh sizes) can be used. In the Puget Sound area salmon are raised to smolt size (usually 10-15 g) before they are put into pens in the estuary for raising to pan size (Novotny, 1975). Salmon of this size range generally can be cultured in pens made with square mesh openings of ¼-⅜ inch.

When salmon fry are cultured in net pens the required small meshes must be cleaned frequently or they become

William R. Heard and Roy M. Martin are with the Auke Bay Laboratory, Northwest and Alaska Fisheries Center, National Marine Fisheries Service, NOAA, P.O. Box 155, Auke Bay, AK 99821.

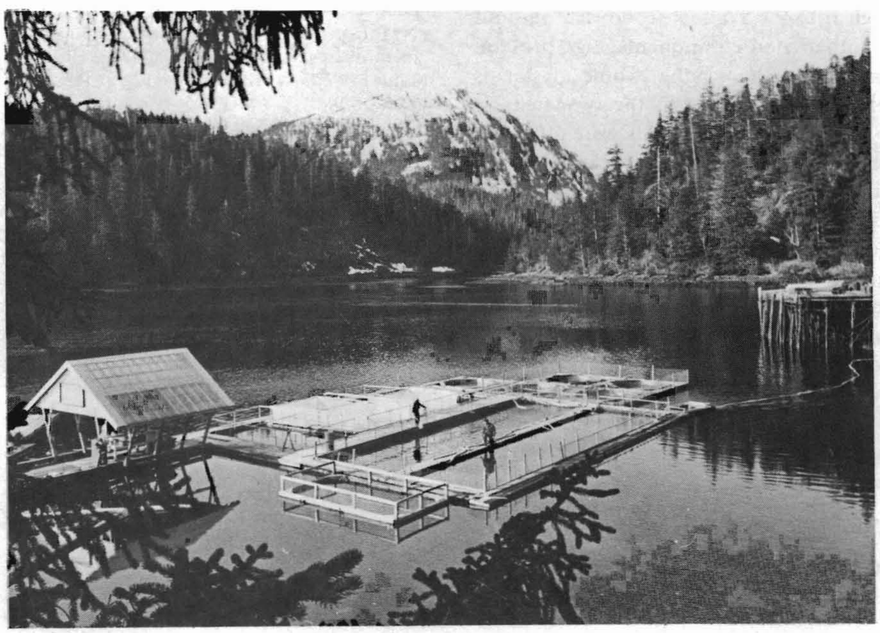

Figure 1.—Floating salmon culture facility at Little Port Walter Bay, south Baranof Island, Alaska, showing general array of horizontal and vertical raceways and net pens. Floating hose on surface is used to transport fry from shore-based incubation station (out of view) to the floating culture unit.

[1]Heard, W. R., R. M. Martin, and A. C. Wertheimer, 1973. Report of progress on the feasibility of salmon smolt production in estuarine husbandry pens at Little Port Walter, January 1-June 1973. Unpubl. manuscr., 13 p. Northwest and Alaska Fisheries Center Auke Bay Laboratory, Auke Bay, AK 99821.

clogged with biofouling growths, uneaten food, and fecal matter. An alternative to frequent cleaning of the pens while they are holding fry is to regularly transfer the fry to clean net pens. However, frequent in situ cleaning of fouled meshes, transferring or handling of fry, or inadequate sanitation all stress the fish which can encourage disease or reduced growth (Wedemeyer and Wood, 1974; Wood, 1974).

The use of floating raceways at Little Port Walter grew, in part, from the need to find alternatives to mesh pens for culture of fry. Experimentation with these units has led to year-round culture from fry to smolt in fresh water and in controlled intermediate saline water—operations not possible in estuarine net pens. Other advantages of the floating raceways over their shore-based counterparts include lower cost and simplified construction.

Design, Construction and Use

Basically, the floating raceways are containers of lightweight, relatively inexpensive, nylon-reinforced plastic fabric with a one-way flow of water. A floating log or styrofoam framework, from which the liners are suspended, provides rigidity. Floating raceway shapes are determined by design and by maintaining a slight hydraulic head normally 0.5-1.0 inch over the surrounding water. Flow of water through the units is determined by location of inlet water and an outlet "drain." The drain is usually made from nylon netting sewn into the plastic fabric. The raceway is formed by attaching the upper edge of the plastic fabric to the float frame with wood battens, generally allowing 4-8 inches between the water surface and the top of the liner.

We designed and tested five shapes of floating raceways at Little Port Walter between 1973 and 1976 (Fig. 2). The design and extent of testing of each shape depended on available material, available waterflow, and the specific requirements for particular test lots of fish. The raceways were designated as horizontal (Fig. 2A) or vertical (Fig. 2B-E), based in part on shape and on the direction of waterflow.

Three weights or thicknesses, light-, medium-, and heavy-weight, of

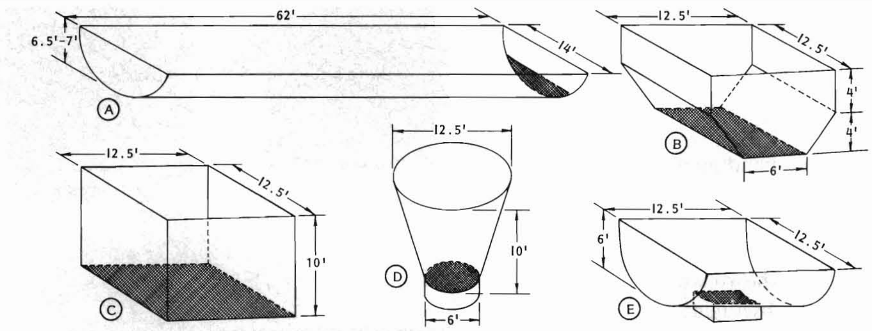

Figure 2.—Schematic diagrams of floating raceways designed and tested at Little Port Walter between 1973 and 1976. A, horizontal raceway; B-E, vertical raceways.

impervious plastic material were used in constructing the raceways. Light- and medium-weight materials were used in prototypes and intended to last for a few weeks or months. The heavy-weight material was used in working units intended to last for several years. The plastic fabrics had nylon or polyester lamination that made them resistant to tears although sharp objects could puncture the material. The light material weighed 0.25 pound/square yard and was made of polyethylene with approximately two nylon fiber meshes per inch. The medium-weight material weighed 0.50 pound/square yard and was made of vinyl with approximately four polyester fiber meshes per inch. The heavy material weighed 1.25 pound/square yard and was made from vinyl with approximately 14 nylon fiber meshes per inch. The heavy material is called C-Lite vinyl-coated nylon fabric.[2]

All of the floating raceways were constructed from mill-run widths of the plastic materials. The appropriate pieces were double-stitched and sewn together with a heavy-duty sewing machine using dacron or nylon threads.

The flow of controlled intermediate salinity water through the floating raceways is accomplished with a simple venturi device that injects seawater into the freshwater delivery system. Salinity and flow can be regulated by using interchangeable component parts of the venturi and stable salinities of up to 20‰ can be maintained for several months (Heard and Salter, 1978).

Horizontal Raceways

The horizontal raceways are semicylindrical in cross section and the water flows in one end and out the other (Fig. 2A). Two prototype horizontal units were used for 13 weeks in 1973 to culture 1972 brood coho salmon, *O. kisutch*, in fresh water and at intermediate salinities of 7 ‰ (Heard et al.[3]). These two units, approximately 40 feet long, 6 feet wide, and 2 feet deep, were constructed from the light polyethylene-nylon material. Three parallel logs with heavy timbers across their ends provided the floating frame. The drain consisted of a 4-inch diameter outlet at the downstream end screened with nylon webbing containing ⅛-inch square mesh openings.

Two larger horizontal units were used to culture 1974 brood coho salmon over a 1-year interval during 1975 and 1976 (Heard et al.[4]). These larger units,

[2]The plastic material used to build the floating raceways and ponds was sold under C-Mesh and C-Lite trade names by Canton Containers Division of Northern Petrochemical Company, Canton, Ohio. Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

[3]Heard, W. R., R. M. Martin, and A. C. Wertheimer. 1974. Progress report on 1972 brood year coho salmon fry-to-smolt rearing in estuarine pens at Little Port Walter, July 1-December 31, 1973. Unpubl. manuscr., 21 p. Northwest and Alaska Fisheries Center Auke Bay Laboratory, Auke Bay, AK 99821.

[4]Heard, W. R., R. M. Martin, and A. C. Wertheimer. 1977. Estuarine and freshwater culture of 1974 brood coho salmon in net pens and floating raceways at Little Port Walter. Unpubl. manuscr., 55 p. Northwest and Alaska Fisheries Center Auke Bay Laboratory, Auke Bay, AK 99821.

approximately 62 feet long, 14 feet wide, and 7 feet deep, were constructed in 1975 from the nylon-reinforced heavy vinyl material. These units were designed to fit into part of the general float structure used for suspending net pens in the Little Port Walter estuary (Fig. 1, 3). Initially the outlet was a 4-foot² piece of ¼-inch square mesh webbing sewn into the bottom of the downstream end of the raceway. Subsequent trials indicated that a 2-foot² drain was adequate for the low flows (exchange rates) we were using. To retain small fish capable of escaping through ¼-inch square mesh openings, a temporary overlay panel of ⅛-inch square mesh webbing was attached with Velcro[5] fastening tape over the permanent panel. The overlay of smaller mesh webbing was easily removed when fish had grown enough to be retained by the larger mesh openings.

Figure 3.—Horizontal floating raceways at Little Port Walter

Figure 4—Conical-shaped vertical floating raceways at Little Port Walter.

Vertical Raceways

In the vertical raceways (Fig. 2B-E) the water flows in at the top and out at the bottom. These units were all built to fit the flotation frames we had on hand which were initially designed and built by the Alaska Department of Fish and Game for suspending net pens. These frames had a 12.5-foot² opening, a 2.2-foot-wide walkway around the opening, and were approximately 17 feet² overall.

Two 8-foot-deep vertical raceways. (Fig. 2B) were used to culture approximately 22,000 1973 brood sockeye salmon, *O. nerka* for 9 weeks in 1974; half of the salmon were maintained in fresh water and half were maintained at 15‰ salinity (Heard et al.[6]). These two raceways were made of the medium vinyl-polyester material. They measured approximately 12.5 feet by 12.5 feet at the top and at the upper 4-foot depth, and tapered to an 8-foot by 8-foot outlet drain opening in the lower 4-foot depth. The bottom was 3/16-inch square mesh nylon webbing.

Vertical raceways rectangular in shape with a cross section of about 12.5 feet by 12.5 feet and a depth of 10 feet (Fig. 2C) were constructed in May 1975 of the nylon-reinforced heavy vinyl material. Initial testing revealed difficulties in maintaining the designed shape of these units due to the greater density of the seawater (28-32‰) surrounding the units relative to the density of the fresh or intermediate salinity water inside the units—the whole unit tended to float. The lower portion of the units hung unevenly, even with 250-300 pounds of weights added along the bottom edge. Salinity intrusions were evident by the presence of sharp haloclines inside the unit above the mesh bottom.

Modification of the rectangular-shaped vertical raceways led to the inverted frustrum (conical) design (Fig. 2D, 4). Under most conditions the

[5]Reference to trade names or commercial products does not imply endorsement by the National Marine Fisheries Service, NOAA.
[6]Heard, W. R., R. M. Martin, and A.C. Wertheimer. 1975. Progress report on estuarine husbandry research of 1972 and 1973 brood salmonids at Little Port Water, Alaska, January 1-December 31, 1974. Unpubl. manuscr., 39 p. Northwest and Alaska Fisheries Center Auke Bay Laboratory, Auke Bay, AK 99821.

conical-shaped vertical raceways keep their design shape in the water. An 18-inch velum-like extension below the bottom mesh prevents unwanted seawater intrusions. Weights can be added along the lower edge of the velum to help maintain the intended shape and orientation of the conical units.

The first two conical units were used to culture 20,000 1974 brood coho salmon at 7-9 ‰ salinities from July 1975 until they were released in spring 1976 (Heard et al., footnote 4). These units were 13 feet in diameter at the top opening, 6 feet in diameter at the bottom opening, and 10 feet in depth along the mid-line. The bottom outlet was a permanent ¼-inch square mesh panel attached with Velcro tape.

Four additional conical units, identical in shape and dimension to the first two but with a permanent drain panel of ⅛-inch square mesh for the bottom outlet, were used in spring and early summer 1976 for 30- to 90-day culture of 1975 brood pink salmon, *O. gorbuscha*, fry at intermediate salinities. Similar conical units were also used in a variety of applications involving culture of 1975 brood coho salmon fry, fingerlings, and smolts in fresh water and intermediate salinities.

The floating raceway illustrated in Figure 2E is a shortened version of the horizontal raceway, modified so the outlflow is through a drain in the bottom. This produces a vertical rather than a horizontal flow. We used one unit of this design for 5 weeks in 1976 for the initial feeding of 1975 brood coho salmon. The unit was 12.5 feet by 12.5 feet at the top and about 6 feet deep and was constructed from the heavy vinyl material. The drain was 1 foot^2 of ⅛-inch square mesh nylon webbing and had a 1-foot velum extending below the webbing.

Operation of Floating Raceways

Floating raceway operation involved several factors including water delivery, snow and ice accumulation in winter, raceway cleaning, fish sampling, and predator control. A major distinction between culturing juvenile salmon in net pens and in floating raceways is that while net pen culture depends on movements of tidal currents through the meshes to maintain a suitable environment, floating raceways require a system of controlled, directed water delivery to provide suitable water exchanges. The water delivery system for the floating raceways at Little Port Walter is described below.

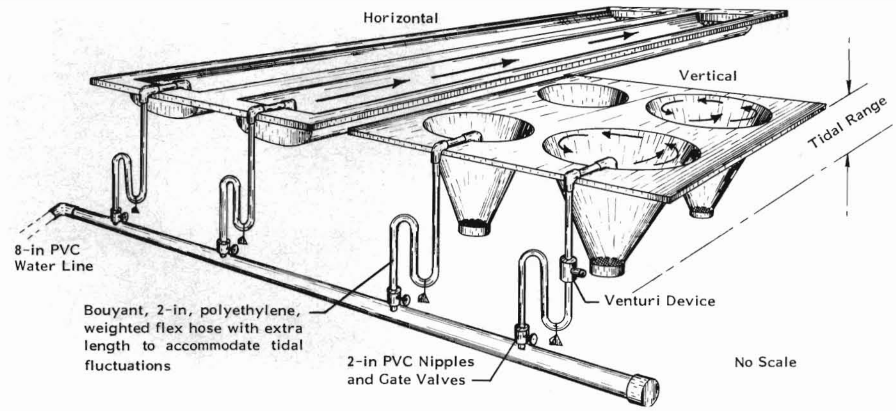

Figure 5.—Schematic diagram of plumbing system used to deliver waterflow to the floating raceways at Little Port Walter

Water Delivery

Fresh water is gravity fed from Sashin Creek across the bottom of the estuary via a 6-inch line (1973 and 1974, 8-inch after 1974). Water is passed from the main line through a manifold into 2-inch diameter flexible polyethylene hoses which lead up to the floating raceways. The flexible hoses were needed to compensate for fluctuations in tidal height (Fig. 5).

When water of intermediate salinity was needed, a venturi device was plumbed into the flexible hose below the low salinity surface water of the estuary (>3 feet). Seawater (28-31 ‰) injected into the freshwater flow through the venturi device provided a fairly stable intermediate salinity (from 1 to 20 ‰) flow. The blend of fresh water and seawater—hence the specific salinity—was determined by variable features of the venturi (Heard and Salter, 1978).

Because of continuous and concomitant changes in hydraulic head caused by tidal fluctuations, precise flow rates to the units could not be maintained. Daily changes in elevation ranged from 4 to 15 feet. In 1973 and 1974, waterflows in the floating raceways varied roughly fourfold (0.1-0.4 exchanges per hour) between the lowest and highest tides. The 6-inch line used in these years had only 2 feet of hydraulic head above the highest tides; consequently, flows were lowest at high tide. In 1975 and 1976, waterflows only fluctuated 10-20 percent between high and low tides because the 8-inch line delivered water from a hydraulic head of 120 feet above the high tide level. Loading densities of fish in the floating culture units generally were maintained between 0.2 and 0.6 pounds of fish per cubic foot of rearing volume and were based on the minimum flows that occurred at high tide.

Snow and Ice Problems

During the winter we have had to remove heavy snowfalls from the walkways around the floating raceways (Fig. 6) and adjust the inflowing water to reduce ice formation in the units, especially in the horizontal raceways with the larger surface areas and fresh water. To reduce ice formation on these raceways, surface agitation was increased by augmenting the waterflows and adding extra inflow points throughout the unit. If the horizontal raceways had been using intermediate salinity water, surface ice formation would have been reduced due to its greater warmth and lower freezing point. Intermittently, ice up to 8-10 inches thick forms over most of the Little Port Walter estuary, but this ice causes no disruptions in the flow of water to the raceways.

Cleaning Raceways

In the horizontal raceways, depending on flow rates and water velocities, some uneaten food, fecal material, and other loose debris was moved along the bottom and flushed through the mesh drain at the outlet end. Material that did not flush out was removed with an underwater vacuum device connected by flexible hose to either the suction intake of a centrifugal pump or venturi. The gently curving sides and bottom permitted easy, efficient operation of the vacuum head. The raceways shown in Figure 2 could be completely cleaned by vacuum in 15-20 minutes. Depending on densities of fish, feeding rates, and water temperatures, these units were cleaned at 1- to 7-day intervals.

The vertical raceways had important self-cleaning characteristics because of the downward spiraling flow of water and high density of most debris. The conical units were almost totally self-cleaning (especially with ¼-inch square mesh webbing in the bottom)—two of these units were used for 9 months with no accumulation of food or feces. During this period the only items to accumulate on the bottom of the conical units were an occasional dead or distressed salmon and a few dead marine organisms that entered the inflow water through the unscreened suction intake of the venturi and subsequently died from reduced salinity.

Hunter and Joyner (1975), in testing a scale Plexiglas model of a floating cylindrical tank with the drain located at the apex of a conical-shaped bottom, found no accumulated wastes during 3 weeks of observation.

Growths of algae on the inside walls of both the horizontal and vertical units were removed at infrequent intervals with long-handled brushes and squeegees. Occasionally a neoprene-suited diver entered the vertical units to clean algae from the lower portion of the unit. During the initial testing in 1973 and 1974, there was a rapid buildup of marine growth on the outside of the floating raceways, primarily barnacles, mussels, and tunicates, so the outside surfaces of all subsequent units were coated with copper-based marine antifouling paint.

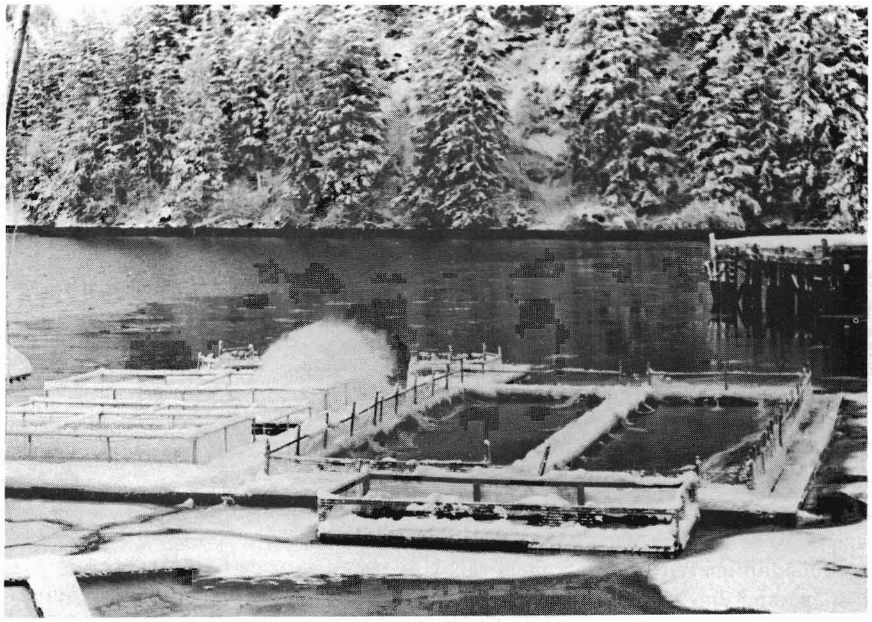

Figure 6.—Winter scene at floating salmon culture facility at Little Port Walter showing snowblower removing snow from walkways around raceways and net pens.

Sampling and Removing Fish

Different techniques were used for collecting fish in floating horizontal and vertical raceways. In the horizontal raceways, conventional seines or dip nets were used to crowd fish toward one end where a lift net previously set along the bottom and sides of the unit was raised to capture the fish. Fish were then pursed into a small area and easily captured. In the vertical raceways, a 12-foot deep seine was lowered along the sides of one-half the periphery of the unit then slowly worked across the bottom and up the opposite sides. Aluminum poles and ropes were used to keep the seine webbing in close contact with the sides and bottom of the ponds. This technique is similar to one described by Buss et al. (1970) for removing fish from a 16.5-foot-deep silo and is quite effective. Usually over 99 percent of the fish were captured with two or three sets of the net. Sometimes, when we wanted to remove all the fish, a diver entered the raceway with a small seine with brails and a deep bag and captured the last few fish.

Predator Control

Because the floating raceways have a low profile, land otters, *Lutra canadensis*, and mink, *Mustela vison*, could readily enter them, so precautions were taken to keep the animals out. Initially, covers of small mesh nylon webbing were stretched over the units. Although the covers kept these predators out, they made it difficult to see the fish and accumulated snow during heavy snowfall Critical observation of fish in the raceways was necessary to evaluate feeding and other behavior which are important indicators of general fish health. A hardware-cloth fence, with 1-inch mesh and 18-30 inches high, kept most mustelids out and permitted easy viewing of the fish.

Birds that fed in the floating raceways included gulls, *Larus* spp; kingfishers, *Megaceryl alcyon;* and water ouzels, *Cinclus mexicanus*. A cover of large-mesh, fine-thread, gillnet webbing stretched over the hardware-cloth fence was effective against all birds except the water ouzel. This small bird was not considered a serious predator due to its size and its territorial defensiveness which resulted in only one individual feeding in the raceways.

The most effective protection from predation by both mammals and birds was a trained dog although one was not always available.

Discussion

Four years' experimentation with floating raceways at Little Port Walter have shown them to be a useful fish culture tool. They are effective alternatives to small-mesh net-pens for culture of small fry and are suitable year-round for fresh water or intermediate salinities.

Horizontal and vertical raceways each have special advantages. Vertical raceways, especially the conical design, have self-cleaning characteristics even at low exchange rates. Horizontal raceways are easy to clean with vacuum heads. They have more favorable volume-to-surface ratios than the vertical types (Buss et al., 1970) and would probably yield higher production for a given amount of flowing water. Fish are easier to observe in the horizontal raceways but the larger surface area did prove more troublesome because of ice during winter.

We made no evaluations of the hydraulic performance of the floating raceways at high exchange rates. Our exchange rates were generally less than 1 per hour, which, according to Westers (1970), is undesirable for production hatcheries. Based on our experience with the general concept and utility of floating raceways at relatively low stocking densities and low exchange rates, we believe these designs could be useful at higher production-level stocking densities and flows.

Acknowledgments

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