

A Water-Recycling System for Hatchery Rearing of Chum Salmon Fry

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Abstract: We developed a closed water-recycling system for rearing chum salmon alevins and fry at hatcheries with insufficient water supplies. The system included a bio-filter and an intermittent water-flow system. The experiment was carried out in two fish-rearing tanks (1,200 L each) with a common water recycling system. The water recycling system contained bio-filters made of crushed coral, a glass-ring filter, and a nylon string filter set in 100-L and 200-L plastic boxes. The maximum water flow was 126 L/min. A total of 22,600 alevins (initial mean body weight = 0.2 g) was held in each of the two rearing tanks. Ammonia nitrogen, nitrite nitrogen, and nitrate nitrogen concentrations were controlled in the water-circulation system, and the average water temperature was maintained at 9°C. The alevins stayed healthy, and fry could be fed without water exchange in the rearing tanks. The mean body weight of fish reached 1 g after 98 days of rearing. No diseases occurred among the test fish, all of which tolerated a seawater challenge test. These results suggest that our closed water-recycling system is effective in producing healthy salmon fry at hatcheries where water shortages and diseases frequently occur.

Keywords: chum salmon fry, intermittent water-flow system, water-recycling system

INTRODUCTION

Salmon hatcheries are often built in areas with abundant groundwater and river water supplies. However, at some of these locations water supplies are becoming limited. Such conditions are often related to land development (Shimizu 2013) and have forced hatchery managers into high-density culture methods. These conditions can trigger a number of problems including bacterial and parasitic diseases.

Parasitic diseases occur frequently in hatchery-reared chum salmon (*Oncorhynchus keta*) fry in northern Japan. The causative organisms include the parasitic flagellate *Ichthyobodo salmonis* and the ciliates *Trichodina truttae* and *Chilodonella piscicola* (Urawa 1996, 2013). In particular, *Ichthyobodo* infection occurs in approximately 40% of salmon hatcheries in Japan (Urawa 1992). It can live in both salt water and fresh water (Urawa and Kusakari 1990). Heavy infections disturb osmoregulation in juvenile salmon due to skin destruction that subsequently reduces marine survival of anadromous fish (Urawa 1993). In addition, inadequate rearing conditions such as a shortage of rearing water or high

rearing densities cause high mortality of *Ichthyobodo*-infected fish (Urawa 1995). A bath in a dilute formalin solution is the most effective way to treat infected fish (Urawa 2013). In Japan, however, the use of formalin in hatchery fish has been restricted since the revision of the Pharmaceutical Affairs Law in 2003. Alternative effective treatment methods are currently not available for hatchery-reared salmon. Further, some hatchery managers believe that the recent decrease in chum salmon returns in Japan might be caused in part by parasitic infections (Urawa 2013).

The use of closed water-recycling systems can keep water free of disease agents, thus making it easy to control fish diseases (Yoshino 1999). Such systems also reduce the disposal of organic wastes into the environment and increase the efficiency of fish culture. For all these reasons there has been an increase in the design and use of these water-recycling systems in modern aquaculture (Maruyama and Suzuki 1998). Wolters et al. (2009) reported that the culture of Atlantic salmon (*Salmo salar*) using a recycled-water aquaculture system can be operated with 98% water reuse.

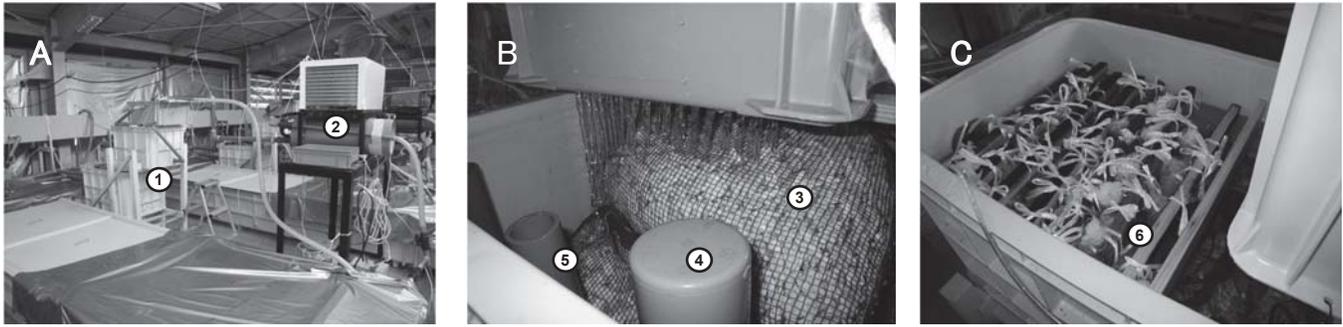


Fig. 1. Overview of the closed water-recycling system (A), bacterial filter tank 1 (B), and bacterial filter tank 2 (C). Components of the system include: (1) bio-filter unit; (2) water temperature control unit; (3) crushed corals and glass rings; (4) drain pipe (with siphoning); (5) drain pipe (normal pipe); and (6) bio-cord.

The purpose of this experiment was to develop a closed water-recycling system for rearing chum salmon alevins and fry with minimal water exchange at low water temperatures. In developing this system we kept in mind the need for easy purchase of materials and equipment, simple operation, and low maintenance.

MATERIALS AND METHODS

Water Recycling System

The experiment was carried out in two fish rearing tank (tanks 1 and 2, 1200 L each) with a common water recycling system.

Rearing water is taken out of the rearing tanks using a water pump (Fig. 1A). The water then enters the water temperature control unit, after which it flows into the bio-filter unit. The bio-filter unit has a wet-and-dry intermittent siphoning system (Fig. 2). The water is then returned to the rearing tank.

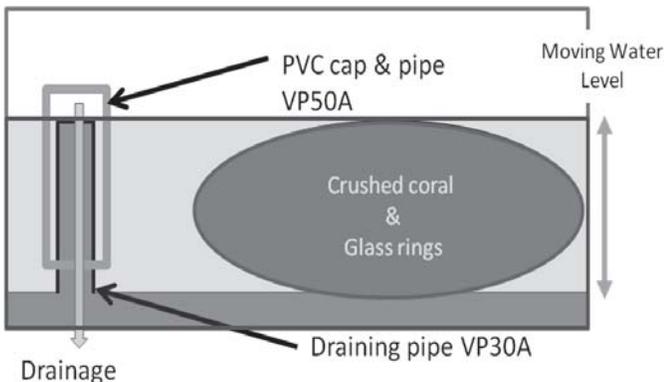


Fig. 2. Siphoning system in bacterial filter tank 1.

Bio-filter Unit

The bio-filter unit is contained in 100-L and 200-L plastic tanks (Sanbox, Sanko Co., Ltd., Tokyo, Japan). These boxes were stacked on top of each other near the rearing tank (Fig. 1A). Recycled water flowed from the end of the fish-rearing tanks through a drainpipe to a water chamber that contained a magnetic-drive pump (PMD-2531A2F, Sanso Electric Co., Ltd., Himeji, Japan) and a submersible pump (FP-15S, Tsurumi Pump, Osaka, Japan). From this chamber, water was drawn into the temperature control unit, which was a heater tank with a 1-kW heater (Nittokizai Corporation, Kawaguchi, Japan). The water then entered the bio-filter tanks. First, particulate matter was removed in a 40-L plastic tank that was placed on top of the 100-L tank and contained a nylon fiber mat. Five VP25A PVC pipes and one VP30A PVC pipe were fixed to the wall of the 40-L tank and connected to the 100-L tank. Crushed coral (40 kg) and glass rings (30 kg) were placed in a mesh bag set inside the 100-L tank (Fig. 1B). Three drainpipes (one VP30A and two VP50A diameter, all 33 cm long) connected the 100-L

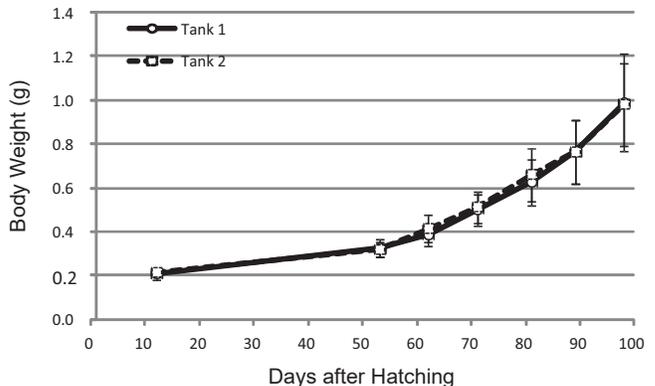


Fig. 3. Changes in the mean body weight of chum salmon fry in rearing tanks 1 and 2 of the closed water-recycling system. Bars indicate SD.

Table 1. The apparent growth in body length and weight (mean \pm SD) and survival rate of chum salmon fry in rearing tanks 1 and 2 of the closed water-recycling system.

Tank	Initial			Final			Survival rate (%)	Seawater challenge test ^{*1} (%)
	Estimated number of fry	Total length (mm)	Body weight (g)	Estimated number of fry	Fork length (mm)	Body weight (g)		
1	22,631	22.2 \pm 0.74	0.21 \pm 0.02	22,480	48.6 \pm 3.38 ^{*2}	0.99 \pm 0.22 ^{*3}	99.3	100
2	22,667	23.0 \pm 0.68	0.21 \pm 0.02	22,400	48.3 \pm 2.84 ^{*2}	0.98 \pm 0.19 ^{*3}	98.8	100

^{*1}Survival rate after 48 h.

^{*2}No significant difference in fork length between fish reared in tanks 1 and 2 at the end of the experiment (Student t-test, $p > 0.05$).

^{*3}No significant difference in body weight between fish reared in tanks 1 and 2 at the end of the experiment (Student t-test, $p > 0.05$).

tank to the 20-L tank. A VP30A pipe covered by a VP50A pipe formed a siphon for the intermittent water-flow system (Fig. 2). This intermittent system controlled the water flow by siphoning and by a pump drive with an electrical timer (program timer KS-1500, Asone, Osaka, Japan). The water pump drive was programmed to produce 5 min of pumping followed by a 2-min shut-off. This timing allowed the bio-filter unit in the 100-L tank to dry out. Bio-cord (Bio-cord MK-N50, TBR Corporation, Toyokawa, Japan) nylon strings were hung in the 200-L tank (Fig. 1C). Each 80-cm-long cord was folded in half and then submerged in the tank. A total of 35.2 m of Bio-cord was placed in the tank. Three drainpipes (VP50A) were fixed to the wall 20 or 30 cm from the bottom of the 200-L tank. Water was then returned to the fish-rearing tank through these pipes.

Experimental Fish

Eggs were taken from mature chum salmon on 16 November 2013. Fertilized eggs were stocked in an incubation box filled with spring water until they reached the eyed-egg stage. A total of 23,000 eggs was stocked in each of the two experimental fish-rearing tanks; eggs were distributed on hatching trays in the tanks. The total weight of eggs was measured to estimate the total number of eggs. The number of hatching alevins was estimated from the number of

remaining unhatched eggs. The experiment was performed from 19 December 2013 to 28 March 2014.

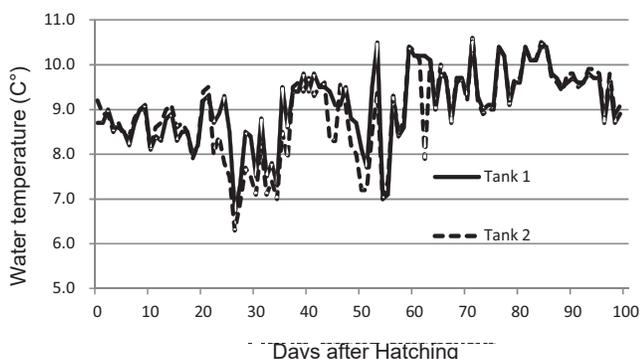
Fish Rearing Tanks

Each of two fish-rearing tanks (4.0 \times 1.0 \times 0.6 m) was constructed of fiberglass-reinforced plastic and contained 1,200 L of water. A barrier was set at the end of the tank to prevent fish from escaping. Sixty plastic mesh pipes (Netlon pipe P-N1, Dainippon Plastics Co., Ltd., Osaka, Japan) were placed on the bottom of the tank to provide shelter for the alevins. The plastic pipes were bound into bundles of 10 and spaced at 30-cm intervals. The shelters were fastened with a PVC pipe (VP40A) to stop them from floating. The shelters were removed when the fry began swimming. The water level was controlled by the height of three drain pipes, which kept the water depth at 10 cm during the larval period and at 30 cm during the fry period.

Management of Fish Rearing

Temperature, dissolved oxygen, and pH were measured every morning and afternoon. Ammonia nitrogen, nitrite nitrogen, and nitrate nitrogen were measured weekly using a HACH DR850 portable colorimeter. Ammonia nitrogen was analyzed by using the salicylate method, nitrite nitrogen was analyzed by the diazo method, and nitrate nitrogen was analyzed by the cadmium reduction method. Water samples for counting bacteria were taken weekly from each rearing tank using a sterilized glass test tube. Numbers of bacterial colonies were counted on Trypticase soy agar plates (Trypticase Soy Agar, Becton, Dickinson and Co., Franklin Lakes, NJ, USA) incubated at 20°C for 120 hours in an incubator.

Chum salmon fry were fed extruded pellets (type A and B; Nippon Formula Feed Manufacturing, Yokohama, Japan). Fry were fed three times a day at about 2.5% body weight. Before the first feeding each day, particulate matter was swept away to the end of the tank. After the third feeding of the day, any remaining feed and particulates were sucked out from the bottom of the rearing tank by siphon. Dead fish were counted and removed from the tank every day. A water flow rate of 8 L/min and a water circulation of 42 L/min

**Fig. 4.** Changes in water temperature in rearing tanks 1 and 2 of the closed water-recycling system.

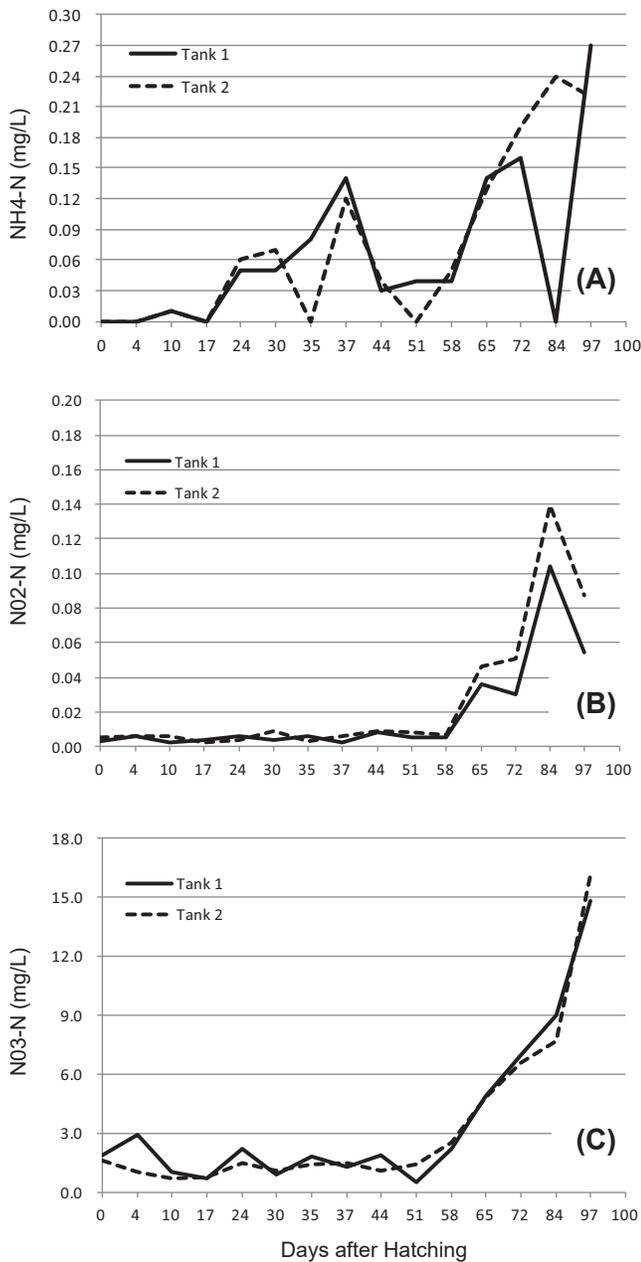


Fig. 5. Changes in ammonia nitrogen (A), nitrite nitrogen (B), and nitrate nitrogen (C) concentrations in rearing tanks 1 and 2 of the closed water-recycling system.

were maintained until day 20; these water flows were used after hatching. Closed water circulation was started on day 21, with water flows of 42 L/min at the alevin stage and 126 L/min in the fry stage. The lowest temperature was set at 9°C by the heater. To confirm the ability of chum salmon fry to adapt to seawater, a seawater challenge test was performed before the fry were released (on day 93; Ban 2014). For seawater challenge tests, sixty fish were taken from each experimental tank and placed in a 100-L tank containing 60 L of artificial seawater (salinity 33 ppt; Tetra Marine Salt Pro, Tetra Japan Co., Tokyo, Japan).

RESULTS

There were no significant differences in body length and weight of chum salmon fry between experimental rearing tanks 1 and 2 at the end of the experiment (Student *t*-test, $P > 0.05$; Fig. 3), and the survival rate was 99.3% and 98.8% in tanks 1 and 2, respectively (Table 1). The average water temperature was 9.1°C (6.7–10.6°C) in tank 1 and 8.9°C (6.3–10.6°C) in tank 2 (Fig. 4), and the average dissolved oxygen concentration was 10.4 mg/L (9.1–11.7 mg/L) in tank 1 and 10.5 mg/L (9.3–11.7 mg/L) in tank 2. The average pH was 7.4 (6.9–7.7) in tank 1 and 7.4 (7.0–7.8) in tank 2. Ammonia nitrogen, nitrite nitrogen, and nitrate nitrogen concentrations increased when fry were fed two months after the start of the experiment in both tanks (Fig. 5). The average bacterial count in the rearing water was 1.3×10^4 CFU/mL in tank 1 and 0.9×10^4 CFU/mL in tank 2 (Fig. 6), and no diseases occurred throughout the experimental period. The 48-h seawater challenge test resulted in 100% survival of chum salmon fry in both tanks.

DISCUSSION

Chum salmon alevins stayed healthy, and fry could be fed without water exchange in a simple closed-rearing system. Fry reached 1 g in body weight and 5.0 cm in fork length 99 days after hatching, and the survival rate was 99% in both tanks. Each tank produced about 22,000 fry. The water temperature fluctuation was larger than expected because of the inadequate capacity of the heater unit. Therefore, the lowest water temperature (6.3°C) was recorded when the air temperature was lowest in the morning (–6°C), at which time the fish were not fed and excretion was kept at a minimum. During the rearing experiment, the concentrations of ammonia nitrogen and nitrite nitrogen remained lower than the harmful concentrations reported by Nogawa and Yagisawa (1994). Bacterial growth in rearing water was

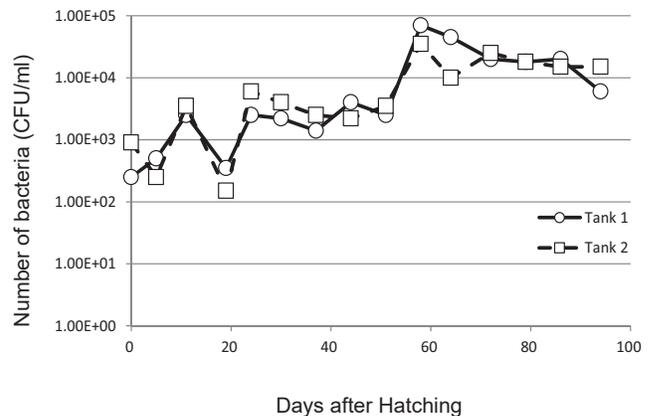


Fig. 6. Changes in bacterial abundance in rearing tanks 1 and 2 of the closed water-recycling system.

constantly around 10,000 CFU/mL. In this closed water-recycling system, however, the water temperature must be kept above 9.0°C to maintain bacterial activity for reducing ammonia concentrations.

The body and gill condition of chum salmon fry were normal, and bacterial and parasitic diseases were not observed throughout the experiment. In addition, the seawater challenge tests showed a 100% survival rate of chum salmon fry, suggesting the healthy condition of reared fish. This closed water-recycling system may be effective in producing healthy salmon fry at hatcheries, where water shortages and diseases frequently occur.

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