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Advances in fish harvest technologies for circular tanks

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ABSTRACT

Improved equipment and husbandry practices are required to effectively grade and harvest fish in large land-based culture tanks. The objective of our work was to develop and evaluate several types of relatively inexpensive, portable, and efficient fish handling equipment to reduce the labor requirement for grading and harvesting fish from large circular culture tanks. This equipment and husbandry practices also had to provide for worker safety and minimize the stress or damage to the fish. Two techniques were developed and evaluated to remove the entire population from a large and deep circular tank, i.e. (a) purse seine and (b) carbon dioxide avoidance response. Two other techniques were developed and evaluated to remove the fish from a large (150 m^3) and deep (2.44 m) circular culture tank after they had been top-graded *in situ* using a 3-panel clam-shell grader: (c) an airlift fish pump and hand sorting/dewatering box and (d) a sidewall drain box for hand sorting/dewatering. Some of these technologies are new, while others (such as the purse seine) have been used in other applications. Our commercial-scale evaluation of these technologies provided insight into the advantages and disadvantages of each option. With use of the clam-shell grader, the majority of the fish in the culture tank were never lifted from the water during the self-sorting process, which minimized stress, perhaps enhancing final product quality. In contrast, harvesting the tank using the purse seine and hand brailing was much more labor intensive and increased the stress on the fish, as indicated by a nearly 10-fold increase in fish mortality compared to the mortality observed when the clam-shell type crowder/grader system and an airlift fish pump or sidewall drain box were used during fish harvest. The combination of the clam-shell crowder/grader with the sidewall drain harvest box was our preferred harvest method, because of its low labor requirement, relatively low fish mortality, and rapid harvest rate. We also think that the carbon dioxide avoidance harvest technique can be used effectively, with little labor input and practically zero mortality when the entire fish population must be removed from a fish culture tank, but not during a selective harvest using *in situ* grading. Ultimately, the more effective technologies and practices should help fish farmers overcome scale-up issues and improve land-based fish farm profitability.

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1. Introduction

Increasing the scale of intensive fish culture systems can significantly improve their economics by reducing both fixed and variable costs per unit of production. However, an increase in system scale requires working with much larger tanks and water flows. For example, as much as 75–150 ton of annual production can be supported in a 1000-m^3 culture tank, depending on the species and the flow through the culture tank. Providing this volume in large and deep circular tanks can improve floor space utilization sufficiently to reduce building costs by as much as 40% when compared with tanks only 15–20% as large (Freshwater Institute, unpublished data). Large tanks will also reduce the cumulative fixed cost of tank flow and level control structures, fish feeders, dissolved oxygen probes, and float switches. The time spent analyzing water quality, distributing feed, performing cleaning chores, and harvesting fish will also be reduced. A reduction in labor per unit of production is probably the largest savings in variable costs realized by moving to larger tanks (Wade et al., 1996).

When large and deep circular tanks are used, both equipment and husbandry practices require better management. In addition, the ability to effectively grade and harvest fish in a large culture tank allows the producer to use continuous stocking and harvesting strategies that can double production efficiency relative to batch stocking and harvesting (Hankins et al., 1995). Even when an 'all in—all out' fish stocking and harvesting approach is used to maximize biosecurity, large tank-based production systems could reduce production costs if relatively inexpensive, efficient, and portable fish handling equipment were available to reduce the

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labor requirement for grading and harvesting fish from large circular culture tanks. Unfortunately, there are few, if any, publications that describe harvest methods for fish stocks in large and deep circular tanks (Timmons et al., 1998). Therefore, researchers at the Conservation Fund Freshwater Institute have worked to develop and evaluate such equipment and practices. In addition to being cost effective, this equipment must also minimize the stress on fish and provide for worker safety. Two techniques were developed and evaluated to remove the entire population from a large and deep circular tank, i.e. (a) purse seine and (b) carbon dioxide avoidance response. Two other techniques were developed and evaluated to remove the fish from a culture tank after they had been top-graded *in situ* using a 3-panel clam-shell grader: an airlift fish pump and hand sorting/dewatering box (c) and (d) a sidewall drain box for hand sorting/dewatering. We hope that these technologies will help overcome scale-up issues and improve land-based fish farm production per unit investment. These technologies, as well as their advantages and disadvantages, are described below.

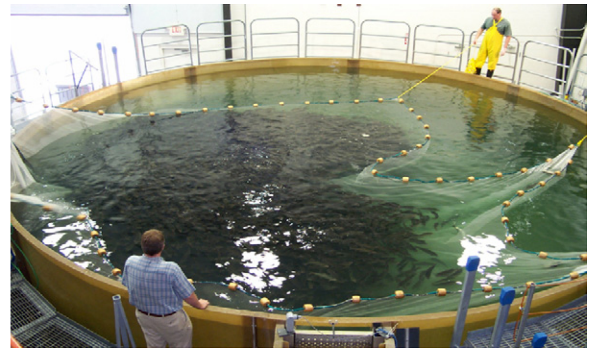

Fig. 1. The modified purse seine used to crowd fish in the growout tank is 3.66 m (12 ft) deep by 30.5 m (100 ft) long to stretch around the perimeter of the tank. Extra weights were added to the bottom lead line and ropes were secured to the float line at the top of the seine to keep it ballooned out and in a stable position, otherwise the water current created by the rotating flow and the pull of the pursing ropes at the bottom of the net tended to pull the seine out of shape or position.

2. Techniques to remove the entire population from the circular tank

A major challenge has been to find the best way to effectively harvest fish from large circular culture tanks, i.e., tanks that are too wide and deep to enter without swimming. Harvest of rainbow trout (*Oncorhynchus mykiss*) and Arctic char (*Salvelinus alpinus*) was studied in a 150-m^3 tank (9.1 m diameter by 2.4 m deep) and in several 10 m^3 tanks (3.7 m diameter by 1.1 m deep) at the Conservation Fund Freshwater Institute. During this research, staff never entered any of the tanks while they were filled with water and fish.

2.1. Purse seine

The combination of a purse seine (Fig. 1) and a hand sorting box (Fig. 2) was the first techniques developed and evaluated for selective harvest of Arctic char from the growout tank.

A customized purse seine (Fig. 1) was purchased from Memphis Net and Twine (Memphis, Tennessee) in 2000 for approximately $ 1000. The purse seine could be used in the 150 m^3 tank because the tank's center drain was located flush with the tank bottom. The net was 3.66 m (12 ft) deep by 30.5 m (100 ft) long and designed to stretch around the perimeter of the tank. By design, the seine was fabricated deeper than the tank to provide some extra stretch when crowding fish. The seine was made of a knotless, non-coated, nylon netting with 1.3 cm (1/2 in.) diamond shaped openings. Use of a soft net material was extremely important given the sensitive skin of Arctic char. Floats were positioned on the top of the net every 18 in. to keep the top of the net afloat and to prevent fish from swimming or jumping over the top of the net (Fig. 1). Plastic rings were sewn into the bottom of the net every 15 cm (0.5 ft) and a 36.6-m (120 ft) pulley string ran through the plastic rings to purse the seine. The string can be pulled from either ends of the net to tighten up the bottom lead line and to crowd the fish closer to the side of the tank (Fig. 1). The lead line at the bottom of the net is intended to keep the net on the bottom of the tank, which prevents fish from escaping under the net.

We used the seine for the first time to crowd the fish close enough to the side of the tank to obtain an accurate sample. The net was dropped into the tank around the perimeter and was tied off at each end. The water's strong rotational velocity forced the seine out of position and prevented the seine from enclosing all of the fish in the tank. However, the net still engulfed a large percentage of the fish and we were able to take an accurate sample of crowded fish using a dip net. Some mortality (about 20 dead fish) occurred during and after the use of the seine.

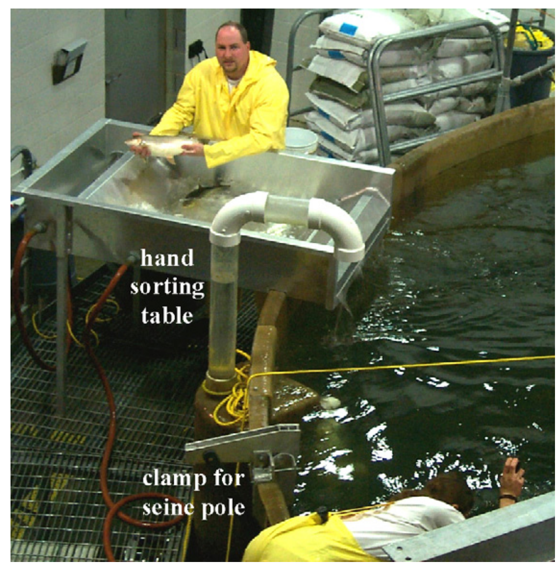

Fig. 2. 1–2 people hand-sorted the Arctic char for size and condition nearly as fast as another 1–2 people could hand brail the fish from the culture tank and onto the custom fabricated sorting table. Note the clamp to hold a seine pole in the picture (seine pole not shown). Trough end.

To improve the design, during the next effort we attached seine poles to each end of the net and more weight was added to the bottom lead line. The top of the net was secured using ropes to keep it ballooned out and in a stable position (Fig. 1). When employed, only one end of the pulley string was able to tighten the bottom of the net, while the other end most likely became entangled. Nonetheless, the seine worked well. Approximately 80–90% of the fish were captured in the net and were crowded close enough to the side of the tank to initiate a small harvest and collect a random sample. This process required 5–7 people at various times, including two people to hold the seine poles. Minimal mortality occurred afterwards.

In its third use, the seine was used to crowd the fish and to hand-sort and cull out runts and deformities from the population. Procedures were similar to the previous seine event. This time the pulley ropes worked perfectly and we estimated about 90% capture inside of the net. It took about 3.5 h to hand-sort close to 10,000 fish when using a specialized sorting table that we designed and

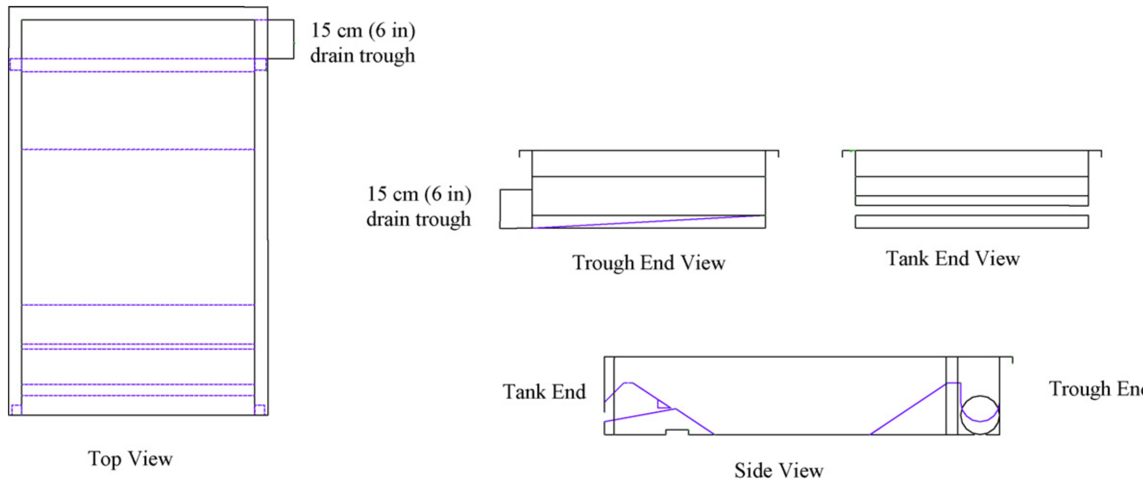

Fig. 3. The custom fabricated sorting table is compact (width × length × depth, 103 cm × 161 cm × 31 cm) and lightweight (23.7 kg) for portability. It provides a 10-cm (4 in.) deep sorting pool that is connected to a garden hose for continuous freshwater flushing and with a discharge trough to carry the harvest size fish to a holding tank.

fabricated for this application (Figs. 2 and 3). Fish were hand brailed from the tank and onto the sorting table, where 1–2 people hand-sorted the fish for size and condition as fast as the fish could be brailed from the culture tank. Using the sorting table was much faster than trying to sort fish in the brail nets. However, the total process still required 4–5 people, because at least 1 person was still responsible for holding a seine pole, while 1–2 people hand-sorted and brailed the fish from the culture tank and another person counted, weighed, and recorded fish removed from the tank. Total mortality as a result of this fish handling event was estimated to be 0.5–0.6% (50–60 fish), although mortality was slightly lower in later harvest events using the same technique.

The hand sorting box (Figs. 2 and 3) was custom fabricated from aluminum. It was relatively lightweight (23.7 kg), compact (103 cm wide × 161 cm long × 31 cm deep), and inexpensive ($ 1000 in 2001). The sorting table was easy to set-up and move into position overhanging the top lip of the culture tank (Fig. 2).

To further reduce the labor requirement for harvesting the growout tank, all later seining events used two custom fabricated support clamps (pictured in Fig. 2) that were bolted near the top lip of each culture tank to hold the two seine poles in place against the side of the tank. The seine support clamps eliminated the need for 1–2 people to hold the seine poles. Therefore, only 3 people were now required to brail, hand-sort, count, and weigh fish removed from the growout tank. However, hand netting the fish out of the tank still required heavy lifting, which is hard on staff and potentially damaging to the fish as they thrash about within the net when packed tightly together and unsupported by water.

These harvest experiences indicated that use of a fish pump at the side of the culture tank could reduce labor to only 2 people to pump, hand-sort, count, and weigh fish harvested from the growout tank, or 3 people could be used to increase the rate of harvest. These changes significantly improved the rate of harvest and reduced labor requirements.

2.2. Carbon dioxide avoidance response

Rainbow trout swim away from dissolved CO_2 as the concentration approaches 60 mg/L. Thus, a passive and non-invasive approach can be used to 'herd' fish to a distinct location in a fish tank (Fig. 4) by creating this natural response (Clingerman et al., 2007). In replicated experiments, we determined that rainbow trout that are seeking to avoid water containing 60–110 mg/L of dissolved CO_2 will swim to an area containing a relatively low concentration (<10–20 mg/L) of CO_2, such as the inlet of a fish pump, a pipe leading to another culture tank, or a harvest/depuration tank. We found that nearly all (i.e., 99% fish movement) harvest size rainbow trout would voluntarily move out of a circular culture tank through a 41-cm (16 in.) diameter fish transfer tunnel (Fig. 5) when CO_2 concentrations reached 60–110 mg/L and the flow of low CO_2 water entering the growout tank was restricted at the end of the fish transfer process. Alternatively, this technique can be used to passively herd fish to a distinct location in the tank (where low dissolved CO_2 enters the culture tank) from which they can be readily harvested using a fish pump or brail net. Specific details on this novel fish transfer system are reported elsewhere (Clingerman et al., 2007). Fortunately, there are currently no withdrawal requirements for fish that have been exposed to dissolved CO_2. Therefore, CO_2 may be used as long as U.S. Food and Drug Administration (FDA) guidelines for low regulatory priority drugs are followed. Furthermore, CO_2 is an extremely soluble gas that is relatively easy to dissolve in water. As such, CO_2 gas can be transferred into water within the same unit processes used to dissolve pure oxygen (O_2) gas, as in the fish herding application (Fig. 5) reported by Clingerman et al. (2007). Stripping excess dissolved carbon dioxide can be relatively straight forward using conventional gas transfer equipment, as long as relatively high volumetric flows of air:water are maintained. We conclude that the CO_2 avoidance technique can provide a

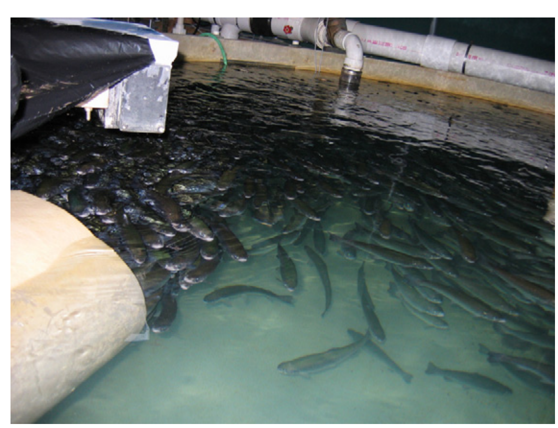

Fig. 4. Rainbow trout are shown to crowd to an area where water containing relatively low levels of CO_2 enters the circular tank (this is where a fish pump would be located) when CO_2 concentrations throughout the rest of the tank approached or exceeded 60 mg/L (from Clingerman et al., 2007).

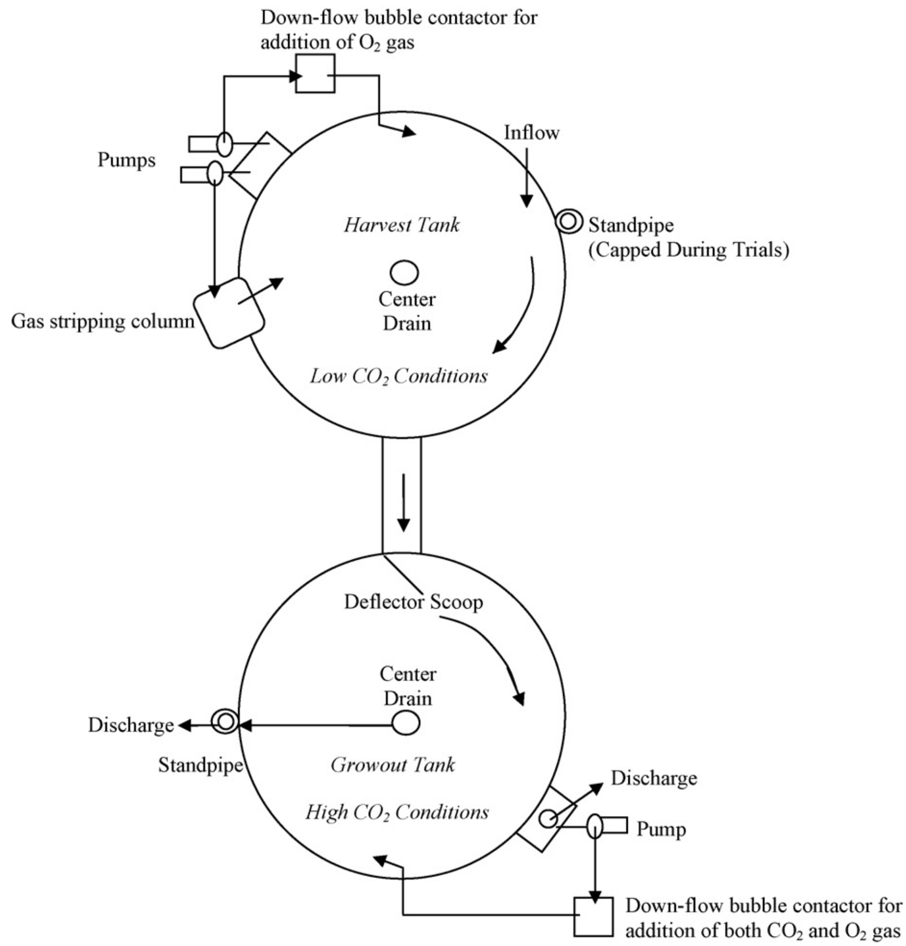

Fig. 5. Schematic drawing of the experimental system used to herd rainbow trout from a 10-m^3 'growout tank' to a 10-m^3 'harvest tank' (from Clingerman et al., 2007). Arrows indicate the direction of water flow and rotation. Fish moved counter-current to the water flow that passed through the fish transport channel.

convenient, efficient, relatively low cost, and reduced labor approach for fish transfer, especially in applications that use large and deep circular culture tanks.

3. Techniques to selectively top grade fish during harvest

3.1. Clam-shell crowder/grader

Clam-shell crowder/grader gates have been used for many years in tank-based aquaculture systems (Larmoyeux et al., 1973; Piper et al., 1982). We evaluated the use of a clam-shell crowder/grader (Fig. 6) in three nursery tanks, as described elsewhere (Summerfelt et al., 2004a), to separate advanced fingerlings into large and small size classes by splitting the fish at roughly 100 g. The 3-panel Grade-Right™ clam-shell crowder/grader (Lance Industries, Bayboro, NC) was designed to conform to the geometry of the 3.7 m diameter by 1.1 m deep nursery tanks. One of the side panels of the clam-shell crowder/grader contained slot holders for two removable racks of clear acrylic bars (Fig. 6). Two pairs of removable racks were purchased to provide uniform 1.59 cm (5/8 in.) or 1.91 cm (3/4 in.) gaps between adjacent bars. Use of the racks containing 1.59 cm or 1.91 cm gaps between adjacent bars roughly split the rainbow trout at 57 g or 114 g, respectively. Slots were also provided to insert a solid aluminum sheet to close off the side of the grader, which prevents fish from moving through the bars. The solid aluminum sheets are inserted after we had achieved a complete grade to prevent small fish from swimming back into the grader. The clam-shell crowder/grader with one pair of removable racks cost approximately $ 2400 (in 2001). Its frame was fabricated from aluminum and the entire unit weighed 53 kg, which made it possible for two people to lift the clam-shell into and out of a culture tank. One person can lift the individual components of the clam-shell into the tank if it is first disassembled and then reassembled in the culture tank.

The clam-shell crowder/grader was used to size separate each cohort of Arctic char or rainbow trout advanced fingerlings. To operate, the clam-shell crowder/grader was placed in a culture tank and all fish were moved to the portion of the culture tank outside of the area enclosed by the clam-shell, i.e., moved out of the relatively small area enclosed by the three hinged panels. Approximately every 10–15 min over the next 30–60 min, one end of the clam-shell was pulled about the tank's circumference to slowly crowd the fish and provide the opportunity for the smaller fish to swim past the grader bars (Fig. 6). Roughly 85–95% of the small fish were able to self-sort by swimming past the grader bar during this procedure. At this point, the small fish were hand netted out of the tank, counted, weighed, and then culled while the large fish were hand netted out of the tank, counted, sized and then moved to the growout tank. The clam-shell crowder/grader was lifted out of the tank when not in use. None of the Arctic char or rainbow trout jumped out of the tank or over the clam-shell grader gates during the grading and netting activities. Fish mortality was zero or minimal (1–2 fish) during each use of the clam-shell grader.

We also evaluated a larger clam-shell crowder/grader (Figs. 7 and 8) that was fabricated from PVC pipe and fittings by on-site staff for the 9.1 m diameter × 2.4 m deep growout tank within a

Fig. 6. A 3-panel clam-shell crowder/grader (Grade-Right™, Lance Industries, Bayboro, NC) has been used for over 8 years to crowd Arctic char or rainbow trout in the 3.7 m diameter by 1.1 m deep nursery tanks at the Conservation Fund Freshwater Institute. The fish crowded within the clam-shell grader were given up to 1 h to self-size sort as the smaller (less than 110 g) fish swam through the 1.91-cm (3/4 in.) gaps between the clear acrylic bars and into the open part of the culture tank.

commercial scale recycle system (Davidson and Summerfelt, 2004). A side panel of the clam-shell crowder/grader contained PVC bars that provided uniform 3.8 cm (1.5 in.) gaps for fish smaller than approximately 800 g to swim between adjacent bars (Figs. 7 and 8). The PVC clam-shell crowder/grader weighed close to 75 kg when dry, so the unit was lifted into and out of the tank using an electric wench and pulley attached to a steel beam above the tank. To begin harvesting, the clam-shell grader was lowered into the water so that the majority of fish were excluded from the

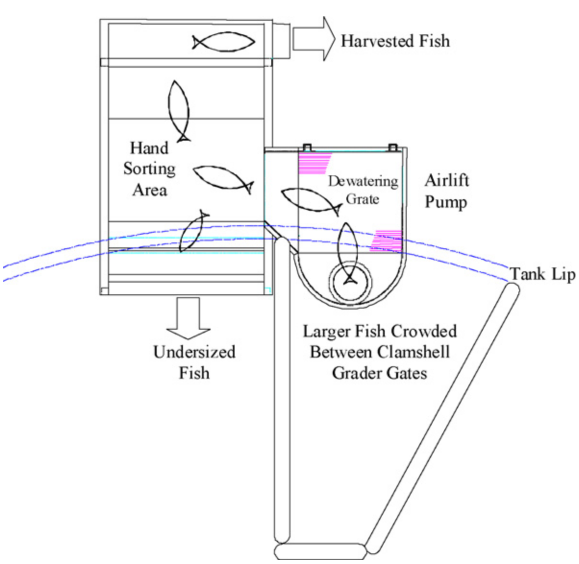

Fig. 7. Illustration of a portable and relatively low cost airlift fish pump and clam-shell crowder/grader that were used to remove fish from the circular tank to a sorting box, where they were hand-sorted according to size during fish harvest events (drawing by Fabritek Inc., Winchester, VA; from Summerfelt et al., 2004b).

Fig. 8. Picture showing the stationary grader gate of the clam-shell crowder/grader (in bottom photo; note, gates used to pivot about the tank are not shown) and the airlift pump and dewatering box that is placed above and to one side of the culture tank, resting on the tank's lip. The clam-shell crowder/grader and the airlift pump and hand sorting/dewatering box were used in combination to selectively harvest Arctic char and rainbow trout (shown) from the 150 m^3 growout tank.

relatively small area enclosed by the closed clamshell's three hinged panels. The end of the first clam-shell panel was clamped to the culture tank wall. Then, approximately once every 10–15 min over the next 30–60 min, the third clam-shell panel was pulled about the tank's circumference to slowly crowd the fish, which provided the opportunity for the smaller fish to swim past the grader bars (Figs. 7 and 8). Typically, approximately 70–90% of the smaller fish were able to self-sort by swimming past the grader bar during this procedure. Thus, the majority of the fish that remained in the growout tank following a harvest were never airlifted or handled and did not have to endure the stress of an *ex situ* size sorting process. Following the crowding and grading process, fish were airlifted from the bottom of the culture tank in the area enclosed by the clam-shell grader into a hand sorting and dewatering box (Figs. 7 and 8).

3.2. Airlift fish pump and hand sorting/dewatering box

Commercially available fish pumping and grading equipment is effective, but can also be expensive, heavy, and large, which could make it difficult to position and move in the limited space available around circular fish culture tanks. Airlift fish pumps have been used for more than 5 years at the Freshwater Institute to reduce labor required to remove fish from large circular culture tanks and to minimize fish stress during harvest. Figs. 6 and 7 depict how the clam-shell crowder/grader was used to crowd fish to the combination airlift fish pump and dewatering and sorting basin.

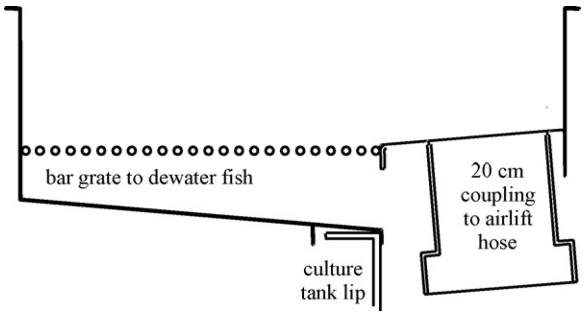

Fig. 9. Profile drawing of the airlift pump (incorporating a 20-cm diameter riser-pipe) and dewatering box that is placed above and to one side of the culture tank, resting on the tank's lip (drawing by Fabritek Inc., Winchester, VA). The device airlifts fish from the bottom of the culture tank, dewaters the fish (but holds them in a pool of water 10 cm deep), and returns the pumped flow back to the culture tank.

The 20 cm diameter (riser-pipe) airlift pump and dewatering box is placed above and to one side of the culture tank and rests on the tank's lip (Figs. 7–9). Air is injected into a custom fabricated manifold fitting (Fig. 10) that is supported 15 cm above the floor of the tank. A 5-hp positive displacement blower package supplies approximately 170 m^3/h (100 scfm) of air at 4 psig using. The 'AIRLIFT' software developed by D.J. Reinemann and M.B. Timmons (available in Timmons et al., 2002) estimates that this air flow will produce a water flow rate of $\geq$2300 L/min (i.e., $\geq$1.4 m/s pipe velocity) against a 25-cm lift. The unit airlifts fish from the bottom of the 2.29 m deep (2.43 m sidewall height) culture tank, dewaters the fish, and returns the pumped flow back to the culture tank. In its primary application, airlift-pumped fish enter a flooded basin where the flow was allowed to return to the culture tank and the fish were manually sorted within the integral hand-sorting box (Figs. 7–9). Harvest-size fish were hand-swept to one end of the box, where they slid down a chute into a palletized fish hauling tote containing oxygenated water. Fish too small to harvest were swept to the other end of the box, where they fell back into the culture tank on the 'less crowded side' of the crowder/grader clam-shell. The clam-shell grader gates were closed further as fish density within the clam-shell grader declined. The clam-shell grader was hoisted from the tank at the end of each harvest. This harvest strategy was used to selectively harvest rainbow trout larger than 900 g and Arctic char larger than 1.3 kg from the growout system once every 2–3 weeks over a period of several years. Each harvest would remove approximately 1000–7000 kg of fish within approximately 1.5–6 h, i.e., approximately 1000–1500 kg per hour, with a crew of 1–2 workers, but not including staff required to count, weigh, and move harvested fish.

The airlift fish pump/dewatering/sorting box that rests on top of the tank lip was fabricated from aluminum and cost approximately $ 5000 in 2002. It was lightweight (47 kg) and compact (approximate 200 cm wide × 160 cm long × 41 cm deep), which makes it easy for two people to set-up and move into position. The 5-hp positive displacement blower package used to drive the airlift cost approximately $ 3000 in 2002.

A second airlift fish pump/dewatering/sorting box was built slightly different from the first unit (i.e., the unit that rested on the tank's lip), so that it would channel the outlet water through the wall of the culture tank (Fig. 11). The elevation of the connecting channel was set to flood the sorting chamber with 10–15 cm of water when it was installed through the culture tank wall at the same elevation as the normal water surface in the culture tank. Thus, water was airlift-pumped into the top of the sorting tank but would flow out at the same elevation as the water level at the top of the culture tank (Fig. 11). We had hoped that the rainbow trout would also swim into this strong current, since we have previously observed these fish attempting to jump or swim into cascades and strong currents that entered the culture tank. However, fish in the culture tank did not swim into the current exiting the sorting box. Rather, fish pumped through the airlift into the sorting box were able to rapidly swim out and return to the tank, which was unacceptable. To correct this problem, we placed a screen across the channel connecting the sorting box to the culture tank and then proceeded to use this airlift fish pump/dewatering/sorting box with good results. Its single advantage was that it lowered the elevation of this sorting pool about 30 cm. Therefore, workers that were hand sorting fish could stand on the work platform and not on a short step-stool, which was a little more comfortable. However, the design had two disadvantages: (1) it was no longer easily portable because it was bolted to the wall of the culture tank and (2) it was not built to allow staff to readily sweep small fish up over a ramp and back into the fish culture tank. Fish had to be picked up out of the sorting box and then dropped back into the culture tank, which was more time consuming.

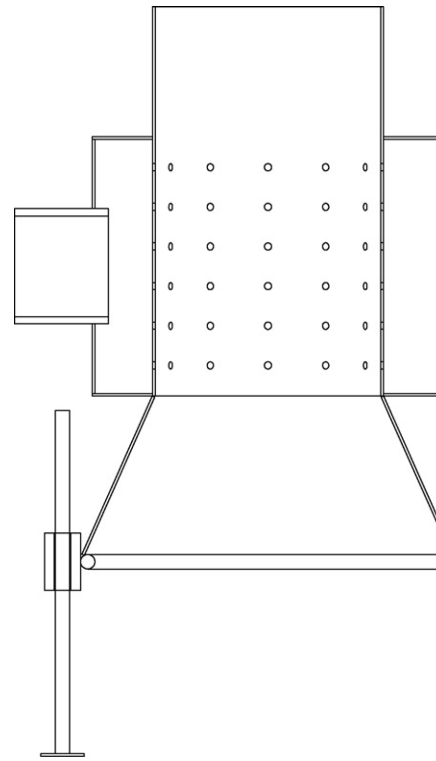

Fig. 10. Profile drawing of a custom fabricated manifold fitting that is supported approximately 15 cm above the floor of the tank and serves as the location where the air and fish enter the airlift (drawing by Fabritek Inc., Winchester, VA).

Harvested fish were slid from both sorting boxes by gravity through a 20-cm diameter neoprene rubber hose to an insulated PVC hauling tote. Fish were then counted and weighed in bulk before being moved in a second hauling tote, with a forklift, to one of two 10 m^3 depuration tanks. In the depuration tanks, the harvested fish were held off-feed for an average of 7 days for rainbow trout and 7–14 days for Arctic char, respectively, to purge off-flavor. Another airlift pump was used to remove fish from these 1.14 m deep (1.22 m sidewall) depuration tanks (Fig. 12). However, the airlift pump did not work quite as effectively in the shallow tank as in the deeper tank. In this shallower application, fish are airlift-pumped into a dewatering box, where all fish slide into a percussive stunning device (Fig. 12) that humanely kills the fish before they are packed with

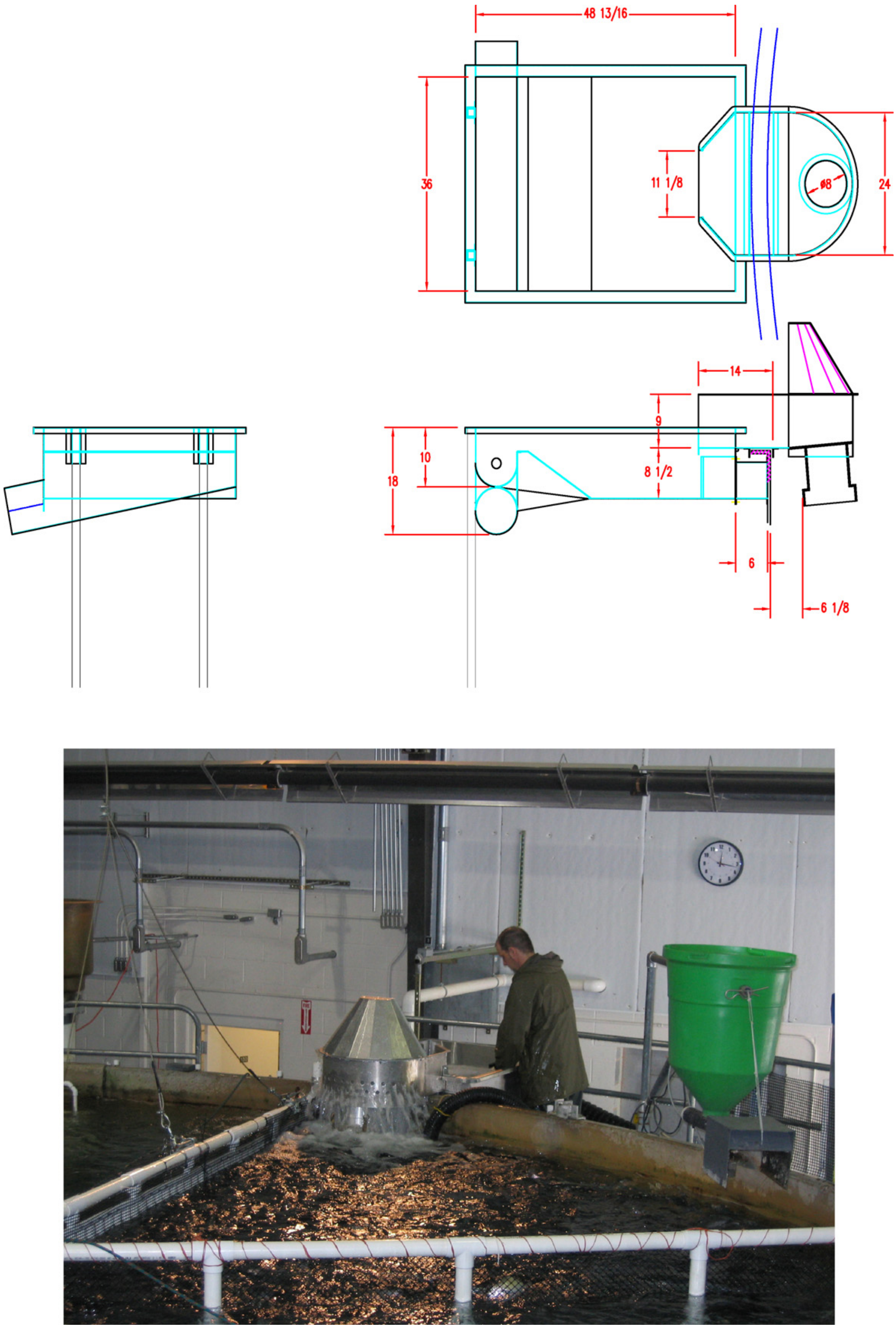

Fig. 11. Drawings (above) and photo (below) of a second airlift fish pump/dewatering/sorting box that was bolted to the wall of the culture tank and channeled the outlet water through the wall of the culture tank (drawings by Fabritek Inc., Winchester, VA).

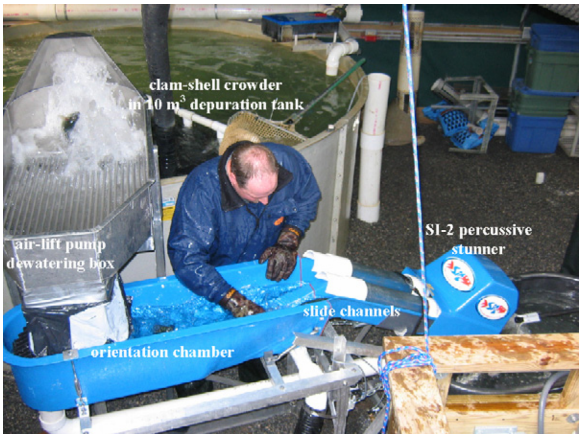

Fig. 12. An airlift fish pump delivers rainbow trout from a 1.2-m deep fish depuration tank to the fish orientation chamber of a percussive stunning device. Fish swim automatically or manually slid into the slide channels that feed into the Model SI-2 (Seafood Innovations, Brisbane, Australia) percussive stunning chamber and then into a basin of water to collect the stunned fish (from Summerfelt et al., 2005).

ice in a hauling tote (Summerfelt et al., 2005). The percussive stunning device, i.e., Model SI-2 from Seafood Innovations (Brisbane, Australia), was used to humanely slaughter the food-size rainbow trout. The percussive stunner was highly effective, rapid, and a more humane and safe slaughter technique (Summerfelt et al., 2005) than other slaughter methods, e.g., CO_2 asphyxiation.

The clam-shell grader and airlift pump system were used at the Freshwater Institute to harvest approximately 34 mton of Arctic char in 2003 and almost 130 mton of rainbow trout from 2004 to early 2008.

Fig. 13. Rainbow trout were crowded to the sidewall drain box using a purse seine, but this was not as effectively as crowding with the clam-shell grader.

3.3. Sidewall drain box for dewatering and harvesting fish

Many of the large circular culture tanks that have been installed in North America during the last several years include a sidewall drain box to create a dual-drain tank (Davidson and Summerfelt,

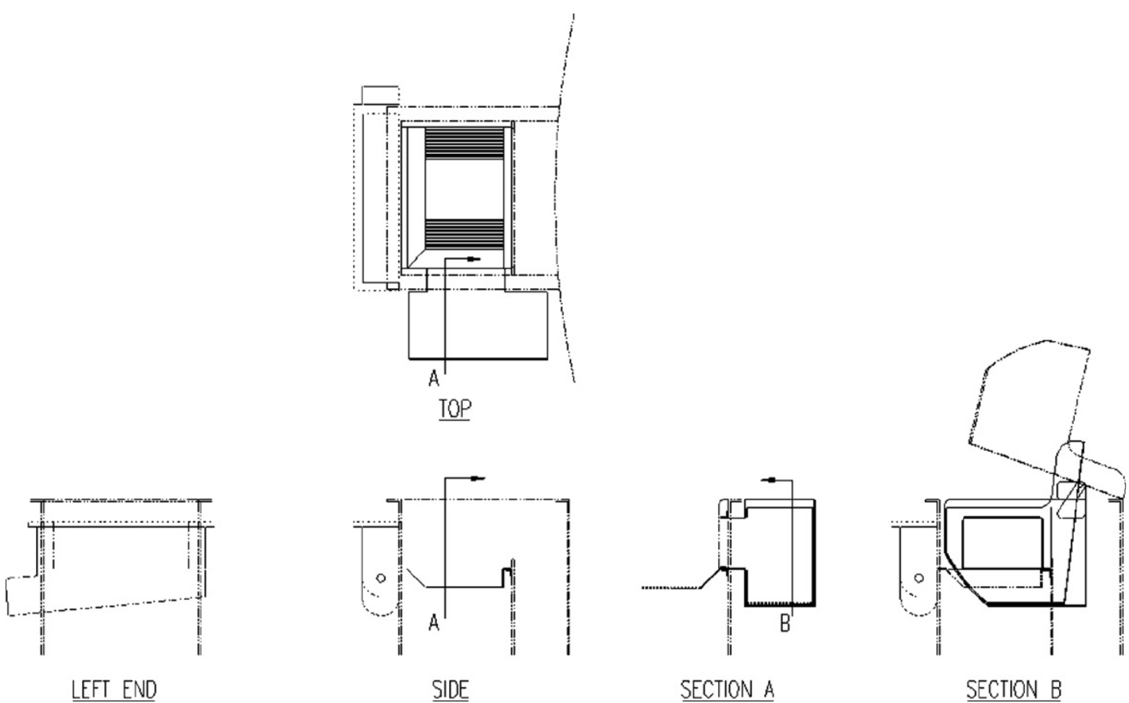

Fig. 14. When a normally vertical and perforated door through the sidewall drain is opened, fish that are crowded to this location rapidly flow into the sidewall drain box, where the majority of water flow passes down through a dewatering rack. The fish collecting on this dewatering rack then slide or are directed into one of two outlet locations. The primary outlet accepts the fish and slides them via gravity into a drain pipe and onward to a transport tote. The second outlet box is to one side of the dewatering chamber and is used to accept smaller fish that are hand-sorted out of the dewatering chamber. The secondary outlet box contains a screened basket that is hinged to allow fish placed in the box to slide back into the culture tank when the basket is lifted up, i.e., pivoting its lower lip over the culture tank, just to the outside of the clam-shell crowder (shown tilted up in drawing Section B; drawings by Fabritek Inc., Winchester, VA).

2004; Summerfelt et al., 2004b). At the Freshwater Institute, the sidewall drain box on the 150 m^3 culture tank removes approximately 93% of the 4700 L/min total recirculating exiting the culture tank. Fish can be crowded to this sidewall drain box using a purse seine (Fig. 13) or a clam-shell grader (Fig. 14). Then, when a normally vertical and perforated door through the sidewall drain is opened (Fig. 15), fish crowded to this location could rapidly flow into the sidewall drain box. A dewatering rack and two fish outlet channel boxes (Figs. 14–16) were installed in and about the existing sidewall drain box to enable rapid fish harvest through this box. The primary outlet channel box is located opposite the entry gate (Figs. 14–16); this outlet chamber slopes more than 5% to its lower end, where it connects to a 20-cm diameter transfer hose; the transfer hose is used to slide harvested fish to another location, e.g., a palletized transfer tote in this application or a central depuration and slaughter facility at a commercial facility. The second outlet box is to one side of the dewatering chamber and is used to accept smaller fish that are hand-sorted out of the dewatering chamber. The second outlet box contains a screened basket that is hinged to allow fish placed in the box to slide back into the culture tank when the basket is lifted up, i.e., pivoting its lower lip over the culture tank, just to the outside of the clam-shell crowder (Fig. 14).

Fish were harvested through the sidewall drain box assembly three times: (1) during its first use approximately 1300 kg were harvested in 70 min when crowding/grading with the clam-shell panels, which included some hand sorting to remove relatively smaller fish passing the sidewall drain box; (2) during the first of two harvest events that would ultimately empty the 150 m^3 culture tank, approximately 3800 kg were harvested in 3.0 h when fish were crowded to the sidewall drain box using the clam-shell panels, but with no hand sorting in the sidewall drain box; and (3) during the final harvest event that removed the approximately 3600 kg of fish remaining in the culture tank using either crowding with the purse seine (Fig. 13) or the clam-shell crowder (Figs. 15 and 16). The rate that fish could be removed through the sidewall drain box was much faster and simpler to facilitate when the clam-shell crowder was used, compared to crowding with the purse seine. In addition, the combination of the clam-shell crowder and sidewall drain box was always much faster than the rate that the harvested fish could be counted and moved or stunned and placed in totes on flake ice. Thus, the sidewall drain box, when operated in conjunction with a clam-shell crowder, could readily harvest approximately 1500 kg of fish per hour, with little or minimal labor. And, if desired, harvest rates could be increased even further by more frequently reducing the space available within the crowder in front of the sidewall drain box.

The combination of the clam-shell crowder with the sidewall drain harvest box was our preferred harvest method, primarily due to its low labor requirement, low fish mortality, and rapid harvest rate, which could readily exceed 1500 kg fish per hour.

Fig. 16. The normally vertical and perforated door through the sidewall drain has been lowered and fish crowded to this location are rapidly flowing onto a dewatering rack. The fish pass over the dewatering rack and into the primary outlet channel box, which is located opposite the entry gate. Smaller fish can be hand-sorted while above the dewatering rack and slid into a secondary outlet box (pictured on the right hand side), which contains a screened basket that is hinged to allow fish placed in the box to slide back into the culture tank when the basket is lifted up, i.e., pivoting its lower lip over the culture tank, just to the outside of the clam-shell crowder. The primary outlet chamber slopes more than 5% to its lower end, where it connects to a 20-cm diameter transfer hose (not shown); the transfer hose is used to slide harvested fish to another location.

Fig. 15. Fish were crowded to the sidewall drain box using a clam-shell crowder/grader. The stationary grader gate of the clam-shell crowder/grader is pictured. Note that the normally vertical and perforated door through the sidewall drain has yet to be opened. When this door is in the vertical position, it prevents fish from sliding with the flow into the dewatering area of the sidewall drain box.

4. Conclusions

Fish transfer and grading technologies for large circular tanks were evaluated for their labor-saving potential and fish survival, as well as to demonstrate the technology required to enable dramatic increases in domestic commercial fish production. A clam-shell type crowder/grader system used with an airlift fish pump or with a culture tank sidewall drain box (both including a dewatering/sorting chamber) were found to reduce labor when grading and harvesting large circular culture tanks (Table 1). Only 1 worker was required at the sorting box (plus another located to count and weigh the harvested fish) to selectively grade and harvest a 150-m^3 circular culture tank. With these selective harvest technologies, the majority of the fish in the culture tank were never lifted from the water during the self-sorting process, which minimized stress, perhaps enhancing final product quality. In contrast, harvesting the tank using the purse seine and hand brailing was much more

Table 1
Comparison of estimated equipment costs (in 2008 US$), supply costs, labor in person-hours, and mortalities incurred by each harvest technology, under conditions tested.

	Equipment costs ($)	Supply costs ($)	Estimated person-hours[a]	Estimated mortalities/event
Purse seine, pole clamps, & hand-sorting box	3,000	0	12[a]	<0.6%
Clam-shell crowder/grader & airlift pump	15,000	0	5–7[a]	<0.1%
Clam-shell crowder/grader & sidewall harvest box	10,000	0	2–4[b]	<0.1%
CO_2 avoidance	4,000	10/ton	1[c]	<0.2%

[a] To move, hand-sort, count, and manually weigh 1–2 ton of fish that were top-graded from a 150 m^3 growout tank. Note that most fish were passively size sorted within the tank by the clam-shell grader.
[b] Harvest rates could have been increased dramatically if manually weighing the harvested fish and then transporting them to a depuration tank did not hold-up and delay the process.
[c] To move <1 ton of fish harvested from a 10-m^3 growout tank. Transfer rates would likely increase dramatically in a larger scale application, particularly if the CO_2 avoidance technique were used to induce fish to move to the intake of a fish pump.

labor intensive (Table 1) and increased the stress on the fish, as indicated by a nearly 10-fold increase in fish mortality compared to the mortality observed when the clam-shell type crowder/grader system and an airlift fish pump or sidewall drain box were used during fish harvest.

In addition, a non-invasive technique that takes advantage of the fish's carbon dioxide avoidance response was developed to passively encourage fish to congregate in a distinct location where they could be readily pumped to another location, or to voluntarily swim into a separate tank.

Application of these new processes can provide a more efficient, inexpensive, safe, and reduced stress process for transferring fish from large and deep circular culture tanks. This work, together with technologies being developed by industry, could significantly improve production efficiency in land-based fish farms, and pave the way for major expansions in overall production.

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