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In-Pond Raceways

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There are four basic types of fish culture systems: open-ponds, cages, raceways, and recirculating systems. Each system has advantages and disadvantages in culture performance, water quality, ease of management, and economic returns.

In fish culture, traditional raceways are enclosed channel systems with relatively high rates of moving or flowing water. This high rate of water movement gives raceway systems distinct advantages over the other culture systems. Advantages of raceways can include:

- higher stocking densities
- improved water quality
- reduced manpower
- ease of feeding
- ease of grading
- ease of harvest
- precise disease treatments
- collection of fish wastes
- less off-flavor

Most raceway operators believe they have more control over their fish production, and they see this as the major benefit of raceway culture. This control is achieved only if flow rate and water quality are relatively stable over time.

Stocking densities for raceways are usually higher than for other culture systems. Densities of 10 to 15 fish per cubic foot are not unusual for raceway systems. These high densities have distinct disadvantages including: more rapid disease spread, less reaction time when problems occur, and large volumes of effluent with dilute fish wastes.

In general, water cannot be economically pumped through raceways; it must flow through them by gravity. The need for large volumes of good quality water is the principal reason raceways have been limited to sites with large springs. Most raceway culture in the U.S. is with coldwater species such as trout and is based around locations with high volume, cold springs, or creeks. A few raceway systems for warmwater species have been located at sites with warm geothermal springs.

Problems involving lack of water movement through cages in watershed ponds led to the development of air-lift pumps to move water through them (see SRAC Publication No. 162, *Cage Culture – Cage Construction, Placement, and Aeration*). This in turn led to research on developing raceways that would float in a pond (or any body of water) and have a constant flow of water, supplied by air-lift pumps. The idea was to develop a raceway system powered by air-lift pumps that could float in existing ponds and have some of the advantages of traditional raceways such as: 1) higher fish densities, 2) better water quality, 3) waste collection, 4) precise disease treatment, and 5) better control over feeding, grading, harvest, etc. In a pond, this system would also have the advantage of not discharging wastes into the public domain since the pond would act as reservoir and treatment system.

The development of an air-lift driven In-Pond Raceway (IPR) began at Auburn University in 1991. However, literature searches have revealed that systems of somewhat similar design or concept had been developed, and even patented, since the turn of the century.

Raceway construction

In-Pond Raceways consist of rectangular boxes that can be constructed in various sizes and from several types of materials depending on the intended use. IPRs have been used in research and

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*Auburn University; University of Florida commercial production at several locations in the South and Midwest since 1992. The smallest IPRs have been used for production of fish fry and were only about 84 cubic feet in volume (6x4x3.5 feet). The largest to date have been used for commercial production of catfish and were approximately 670 cubic feet in total volume (24x8x3.5 feet).

IPRs have been constructed from marine and treated plywood, plastic sheets, and plastic liners. Each of these materials has advantages and disadvantages. Plywood becomes saturated with water and extremely heavy unless coated with non-toxic water-resistant marine paint. Plastic sheets (usually 1/4 inch thick) expand and contract with heat, making their shape irregular. Plastic liners (80 mil) cannot be walked in (during harvest or grading) and may collapse due to wave action.

A frame around the outside of the IPR is used for attachment of the plywood or plastic. Both treated lumber and metal frames have been constructed. All IPR materials, including screws and nails, need to be water-resistant and non-toxic. Although treated lumber contains some toxic compounds, these have not been a problem in the IPRs because of the high water exchange rates. However, it may be advisable to coat the wood with non-toxic marine paint.

The IPR is designed to float in any body of water; therefore, a recommended component is a dock or pier for ease of management (e.g., feeding, water testing, etc.). It is possible to anchor the IPR to a stationary pier or to the pond bottom if water levels do not fluctuate. However, if anchored to the pond bottom without a dock, then daily activities must be conducted from a boat. The IPR pier should be constructed of walkways (3 to 4 feet wide) to allow access to all sides of the IPR and provide space for attaching equipment (see Figure 1). For ease of management the pier must be constructed so that the IPRs are positioned close to the walkways. Security should also be considered in construction. Theft and vandalism can be a problem in any type of high density fish culture system.

Figure 1. IPR with dock–note that blower housing and air-manifold are at the forward end of the raceway.

One of the most common IPRs has been built of treated plywood, framed with treated 2x4 lumber or steel, and coated with epoxy paint. Sizes have been either 16 or 24 feet long, 4 feet wide, by 4 feet deep (only 3 feet underwater). Figure 2 shows the basic design of this raceway. The air-lift pump is attached to the front or "intake" end of the IPR, and the waste collection system (if needed) is attached to the "discharge" end. The intake end wall of the raceway is constructed so its upper edge is approximately 9 inches below the sides of the raceway. This space allows the air-lift pump to be adjusted for flow control (see air-lift pump section). The rear discharge wall of the raceways is constructed so that its lower edge ends about 4 inches above the raceway bottom. This allows discharged wastes to be drawn off the bottom of the raceway for removal.

An "eddy board," usually 2x6 or 2x8, is placed across the width of the raceway about 4 to 6 feet from the water discharge of the air-lifts. This board should be attached with about 1 inch extending above the water surface when the pumps are running. The eddy zone behind this board is the feeding area of the raceway. Feed dropped in this area is held against the board, keeping it from being washed out of the raceway. Cage-type mesh material (usually 1/2-inch mesh) is used to keep cultured fish inside the IPR and exclude wild fish from entering, without restricting water flow. Mesh is placed in front of the air-lifts and at the discharge end of the raceway. The mesh in front of the air-lifts should be in an "L"-shape, forming a trough across the raceway about 6 to 8 inches in front and 4 to 6 inches below the air-lift's water discharge. This trough traps debris and wild fish that enter through the air-lifts, without restricting water flow. A second mesh screen is placed about 1 foot from the rear of the raceway and extends completely across the width and height of the raceway. The rear screen keeps the cultured fish from leaving the raceway and wild fish from entering through the water discharge opening.

Hinged lids or doors should cover the top of the IPR to discourage predators and stop fish from escaping by jumping out. Usually several small lids are preferable to one or two large ones because of weight and the need to access only certain sections of the raceway at a time. Mesh material (similar to that described above) should be used in the section over

Figure 2. IPR (out of the water) showing position of air-lift system and eddy board.

the feeding area so feed can be dropped into the raceway without opening the lid. The remaining lids can be constructed of a solid material or can be covered with a material such as shade cloth to reduce light and its associated stress on the fish. A 16x4x4 foot IPR has an effective culture volume of 210 cubic feet (15x4x3.5 feet) or 1,571 gallons. A 24-foot-long IPR would have an effective

Figure 3a. IPR (out of the water) built from treated plywood showing external frame and attachment of tube settler.

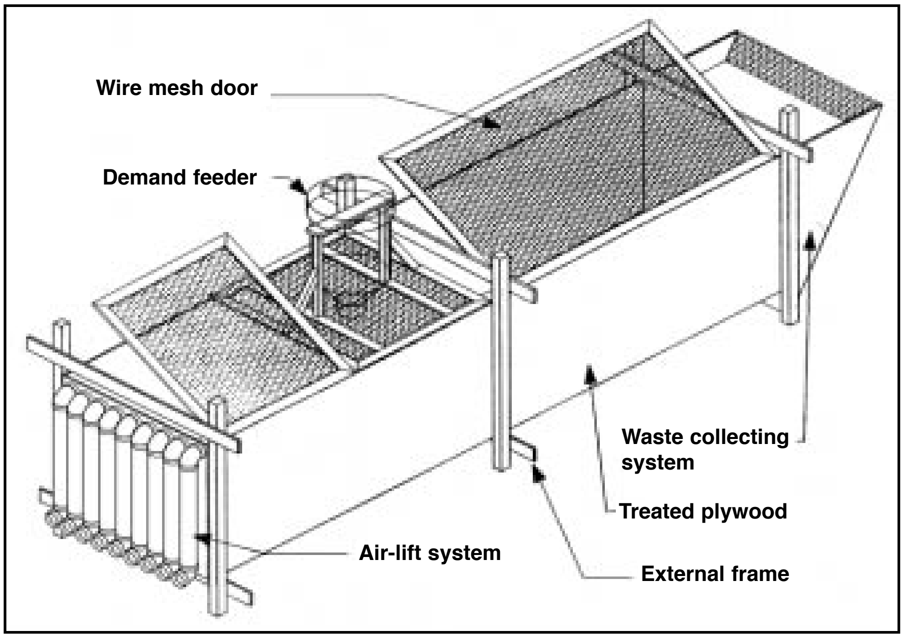

Figure 3b. Drawing of IPR showing attachment of air-lifts, tube settler, lids, and demand feeder.

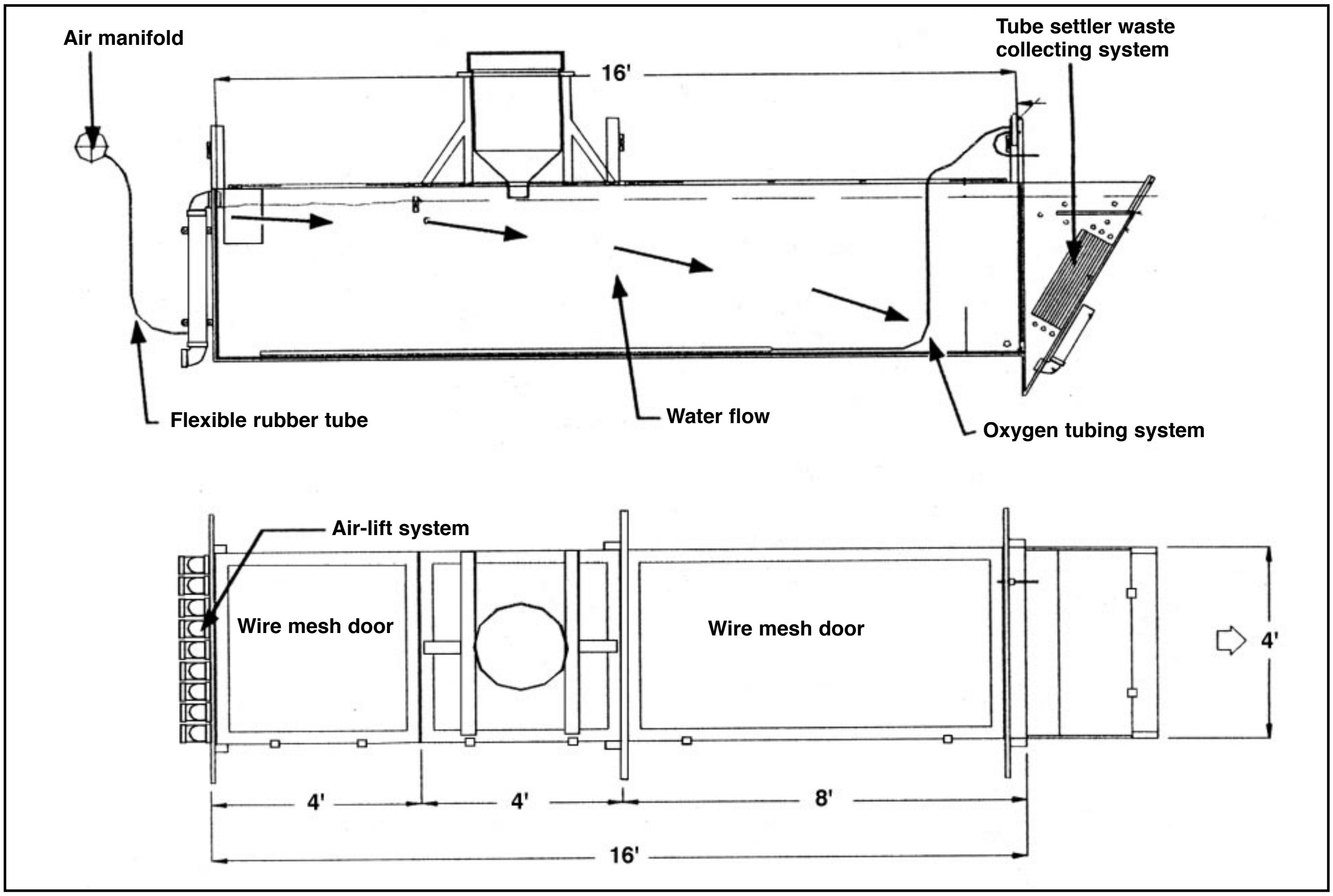

Figure 3c. Drawing of IPR in cross section and top view showing attachment of air-lifts, tube settler, demand feeder, and emergency oxygen tubing system.

culture volume of 322 cubic feet (23x4x3.5 feet) or 2,409 gallons. An IPR with dimensions of 24x8x4 has an effective culture volume of 644 cubic feet (23x8x3.5 feet) or 4,817 gallons.

IPRs have also been constructed using plastic liners. There are several synthetic compositions (i.e., chemically different) of plastic liners. These are commercially available in 19 to 80 mil thickness, with 40 mil being adequate for use in most IPR situations. Liners are ultraviolet light-resistant and have a lifetime of at least 10 years. Liner manufacturers can fashion liners in many shapes and sizes, so it is possible to have a liner custom-made for a specific IPR design. The flexible nature of a liner allows the raceway to be moved to the pond bank or pier and collapsed for easy harvesting of the fish.

A disadvantage of plastic liner construction is that the walls can collapse inward from wave action, reducing the raceway volume unless a frame is used to maintain its shape. Also, the attachment of solid waste collection systems and air-lifts is more difficult since it is hard to glue materials to the liner. Cost of plastic liners is also a consideration. Depending on thickness, the type of liner, and custom shaping, they can range in price from $0.50 to several dollars per square foot. This cost is only for the liner and does not include frame, blower, air-lifts, etc.

A small IPR (8x3x3 feet) of 23 mil plastic liner has been tested for use as a fry rearing unit. For this purpose an IPR offers advantages as mentioned before and also provides a steady supply of planktonic food organisms essential for good growth and survival of fry. A saran mesh sock of 250 microns was placed over the air-lift discharge or outflow to prevent any predaceous insects or fish from entering the raceway. The saran sock will not screen out plankton in the water. Problems were encountered with fouling of the rear mesh screen because of its small mesh size and removing solids from the bottom of the raceway. Results of this study on fry production were promising, however.

Air-lift pumps

Air-lifts provide a simple and efficient means of moving large volumes of water. Rising air bubbles inside an air-lift's tube act like a piston pushing water above it. However, this is efficient only if the water is lifted a small height above the surface. In fact, most air-lifts will not lift water over 3 or 4 inches above the water's surface. Air-lifts work most efficiently when they are releasing water at or very near the surface. A single 3-inch air-lift discharging at the surface will move between 50 and 60 gallons per minute if built as described below.

Air-lifts have the added benefit of aerating incoming water when dissolved oxygen (DO) concentrations are much below saturation. In research trials, when pond DO fell below 2 mg/L the DO in the IPRs has been maintained at 3 mg/L even with high biomass. Because of the mixing action of water and air in the air-lifts, supersaturation is virtually eliminated in the water entering the IPR.

Air-lift pumps consist of a battery of single air-lifts. Individual air-lifts are constructed from a 36-inch long section of 3- or 4-inch PVC pipe. A 4-foot-wide raceway has room for the attachment of 9 3-inch diameter air-lifts. A PVC 90º elbow or "L" is glued to the top of each air-lift. Each air-lift is designed so that air from the blower enters the pipe at approximately 32 inches below the center of the PVC "L". Regenerative blowers are most efficient at powering air-lifts if the air is injected between 30 and 34 inches below the surface of the water. Optimally the air-lifts are submerged to the halfway point of the "L" or to the top of the "L". Each air-lift is attached to a plywood or plastic panel. A circular cut-out is made so that each "L" protrudes through the panel and into the raceway area. Silicon sealer can be used around the cut-outs to seal the "L's" to the panel.

Figure 4a. Air-lifts attached to a sheet of plywood at the front of raceway, showing garden hose attachment at a water depth of 32 inches.

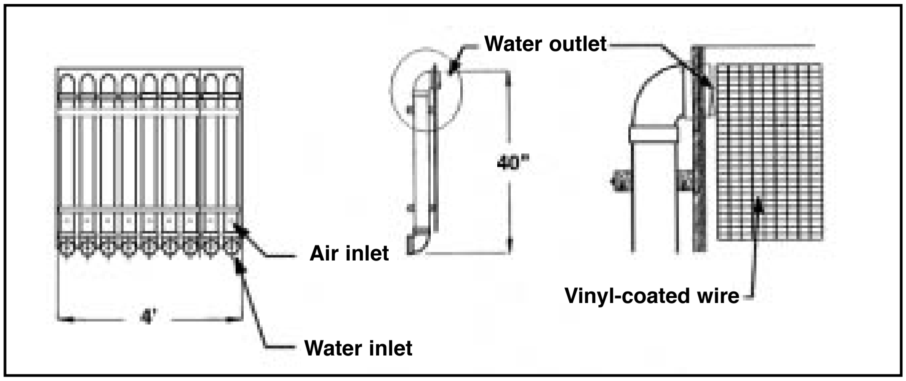

Figure 4b. Drawing of air-lift pump design showing attachment of individual air-lifts to plywood or plastic sheet.

This keeps water from escaping the raceway around the “L’s”. Air-lifts are attached to the panel with screws or by pressure straps. Bolts or screws should not extend into the pipe more than 1/2 inch, as debris can become caught on this obstruction and reduce water flow through the air-lift. **Each air-lift in an IPR system must be built identically to all others and attached to the same air-manifold and blower in order to work properly.**

The panel to which the air-lifts are attached fits into tracks along each side at the front of the raceway. These tracks allow the air-lift pump to be raised or lowered to adjust the height and therefore the water flow through the air-lifts.

The intake of the air lift should be approximately 36 inches underwater. The intake can be moved upward or downward to utilize different water temperatures or conditions. For example, if warmer and more oxygen-rich surface water is desired, the intake could be turned upward (starting at the bottom of the 36-inch vertical section) using elbows and pipe to place the intake closer to the water’s surface. A longer vertical extension could be used if cooler water was desirable. This would depend upon the quality of the deeper water.

Air is supplied to the air-lift pumps by a regenerative blower. Regenerative blowers are high-volume, low-pressure units. The blower is attached to an air-manifold that holds a large volume of air under constant pressure. Without the proper volume in the air-manifold the air-lifts will not function effectively, and the regenerative blower will be damaged due to overheating. Typically a 1-horsepower blower requires a minimum of 20 feet of 4-inch PVC or 12 feet of 6-inch PVC air-manifold (approximately 2,500 cubic inches). One-half-inch PVC tubing connectors are tapped into the air-manifold and into the air-lifts (at 32 inches as described previously). A section of garden hose (5/8 inch), polypropylene, or plastic tubing (1/2-inch ID) can be used as air-line between the air-manifold and the individual air-lifts. The air-line attaches over the tubing connectors from the air-manifold to each air-lift.

The key to making all the air-lifts work properly is that they all must be constructed exactly alike, and each requires a constriction orifice at the attachment of the air-line to the air-manifold. The constriction orifice should have a 3/16- to 1/4-inch hole in its center. This orifice can be made from PVC or Plexiglas sheeting (1/8 to 1/4 inch thick) and hot-glued to the PVC tubing connector. If constructed in this fashion, a 1-horsepower blower can efficiently power 27 individual air-lifts or enough for 3 separate 4-foot-wide raceways with 9 air-lifts each.

Figure 5a. PVC tubing connectors with restriction orifice(s).

Water flow through the IPR(s) with this air-lift pump design can be regulated by raising or lowering the air-lift pump, or by stopping the air flow to individual air-lifts. With all 9 air-lifts functioning properly the flow rate averages about 450 gallons per minute. At this flow rate a 16x4x3.5-foot raceway completely flushes in less than 4 minutes. At this flushing rate the carrying capacity of the 9 air-lift IPR appears to be approximately 3,000 pounds with warmwater species (e.g., catfish), a stocking rate of 13.4 pounds per cubic foot.

Air-lift pumps have also been constructed in a box or square design. In this type of pump a box is made from plywood or plastic panels 3 inches wide with vertical partitions every 3 inches, resulting in a unit with each individual air-lift a 3-inch square tube, 3 feet long. Air injection, water discharge, screening, and vertical slide adjustments are similar to those described for the PVC air-lifts above. This design allows as many as 13 air-lifts in a 4-foot-wide area.

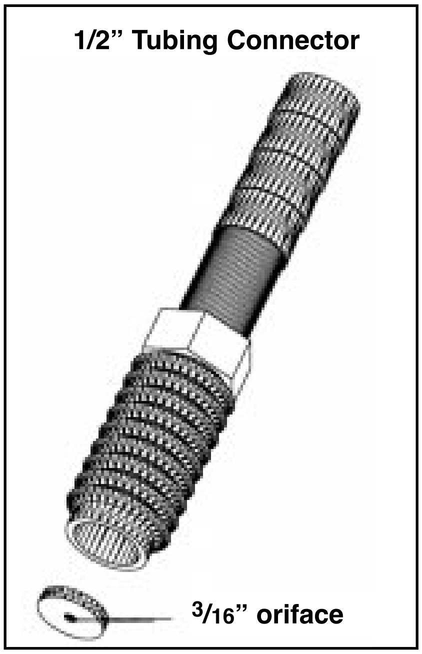

Figure 5b. Drawing of PVC tubing connector with restriction orifice.

Emergency systems

The IPR needs emergency back-up systems in case of electrical disruptions or mechanical failures. A backup blower is recommended in case of blower failure. In addition, the two blowers can be equipped with a pressure sensor that will turn on the backup blower in the event of a failure. Sensors can be purchased that will sense not only power failures but air-pressure loss (in the case of a cracked air-manifold). These sensors can be attached to phone dialers which will call managers and alert them to problems and can automatically trigger emergency generators or oxygen supply systems.

A simple oxygen supply system can be constructed using cylinders of bottled oxygen connected to a normally-closed electric solenoid valve that opens if electrical power is interrupted. High-pressure tubing leads from the cylinders to each raceway and is delivered through milli-pore tubing in the bottom of each raceway, similar to a hauling tank system. Flow regulators control the volume of oxygen delivered and must be adjusted depending on the biomass of fish in the raceways. Typically a single cylinder of oxygen will maintain a raceway for several hours. This system is also used to maintain adequate oxygen supplies during therapeutic bath treatments for disease (see disease section which follows).

Species and stocking rates

To date, species that have been successfully cultured in IPRs include: channel, blue, and hybrid catfish; trout, striped bass and its hybrids, yellow perch, bluegill, and tilapia. Probably any species that tolerates flowing water can be cultured in an IPR.

Channel catfish and Nile tilapia have been successfully polycultured in the IPR. In one experiment tilapia were mixed in the IPR at a 1:10 ratio with catfish. In other experiments tilapia were isolated in a separate section of the IPR behind the catfish and were not fed, under the assumption that they would eat any uneaten catfish feed, catfish wastes, and plankton. The tilapia grew well in both these experiments.

Blue catfish and channel X blue hybrid catfish did not perform as well in the IPR as channel catfish in experiments at Auburn University. However, producers in more northern climates have reported success in culturing these in raceways. These observations may indicate more about the temperature preference of the blue catfish than about the culture system.

Stocking rates for most of these species have varied between 9 and 15 fish per cubic foot of effective culture volume. At least in the case of catfish, no difference in growth or food conversion has been found between stocking at 9 or 14 fish per cubic foot. From an economic standpoint, the high stocking rates of the IPR are probably necessary to offset the cost of construction and operation.

Finally, it is important to remember that stocking densities must be balanced with pond size. In open-pond catfish production it is common to stock 6,000 or more fish per surface acre but expect to harvest only 3,500 to 4,000 pounds of catfish per year. In cages, catfish are normally stocked at only 1,500 to 2,000 fish per surface acre (unless aeration is supplied), and all the fish are harvested in a given year. In the case of the IPR, it is recommended to stock no more than 6,000 fish per acre and expect to harvest all of the fish (see economics section) in a given year.

As a note of interest, several species of freshwater mussels have also been cultured behind catfish in the IPR in an attempt to reduce effluent wastes. The mussels were somewhat effective at reducing solid wastes in the effluent, and some species of mussels showed significant growth under these conditions. This research may have implications for the culture of freshwater mussels (the shells of these species are used as nuclei for cultured pearls) or in the culture of other shellfish species in brackish or marine environments.

Feeding

Feeding rates (percent body weight per day) and times depend more on species cultured than on the culture system. For information on feeding rates and time of feeding, check other SRAC literature on specific species. Floating feed is recommended for the IPR, because the manager can see fish eat and determine if any feed is being wasted or uneaten. The IPR does allow the use of sinking feeds, including medicated feed if necessary. For information on how to calculate feed rates see SRAC Publication No. 164, *Cage Culture – Handling and Feeding of Caged Fish.*

Traditional raceway culture has often utilized demand or automatic feeders. Research on catfish in the IPR has shown that demand feeders work well. In fact, with catfish and tilapia there were no differences in growth or feed conversion using demand feeders as compared with twice-a-day hand feeding.

Fish cultured in raceways have better feed conversions than fish grown in open ponds with the possible exception of tilapia. This is also true of the IPR. In 5 years of research on catfish and tilapia, the average feed conversion ratio (FCR) was 1.45:1 (pounds feed fed to pounds of fish produced).

Finally, because of the high density and lack of any natural foods, raceway culture depends on high quality complete diets. In IPR research on catfish and tilapia at Auburn University, a 36 percent protein commercially available diet was fed in most experiments, rather than the 32 percent protein diet that is commonly used in pond culture. Most cage producers also use a 36 percent protein complete diet.

Disease treatments

Disease treatments in raceways are usually drip treatments. The therapeutant is dripped into the incoming water, and a specific concentration is maintained for a certain period of time, usually 1 hour. Problems with this method are that the concentration is difficult to maintain, a large amount of therapeutant is used, and therapeutant is released into the environment with the discharge.

In the IPR, the emergency oxygen system can be used to conduct therapeutic bath treatments. In this case the air blower is turned off and the emergency oxygen supply system is used. With no water flow the raceway is treated as a tank of known volume. The therapeutant is mixed into the raceway at the prescribed concentration and maintained for the recommended time period. DO concentrations should be checked and the oxygen supply regulated during the treatment. After treatment the air blower is turned on, and the therapeutant is flushed out of the raceway within a few minutes. Obvious advantages of this system are that less therapeutant is used, a more precise concentration is achieved, and if problems occur the treatment can be terminated quickly.

Waste reduction

One of the anticipated benefits of the IPR was to capture or reduce wastes from the system. By doing this the IPR system would be more “environmentally friendly” and / or could produce more fish per acre, particularly when compared to cages in watershed ponds. However, it should be noted that fish wastes are mostly soluble, and solids are almost neutrally buoyant and therefore difficult to settle. If the pond utilized is large and the stocking density per acre low, it may not be necessary to practice waste reduction at all, since the pond should be able to absorb and decompose the waste effluent through natural cycles.

Several different low cost and low maintenance methods of trapping or reducing wastes from the IPR have been researched. These have included settling basins, tube settlers, sand and synthetic mesh filters, plant and gravel biofilters, artificial wetlands, and filter-feeding species in polyculture. The best methods appear to be polyculture with filter feeding species (see species and stocking rates section), and tube settlers (for the solids) coupled with some type of plant biofilter or artificial wetland outside of the raceway. Actual costs of these waste reduction systems and their total impact on the pond environment have not been adequately evaluated.

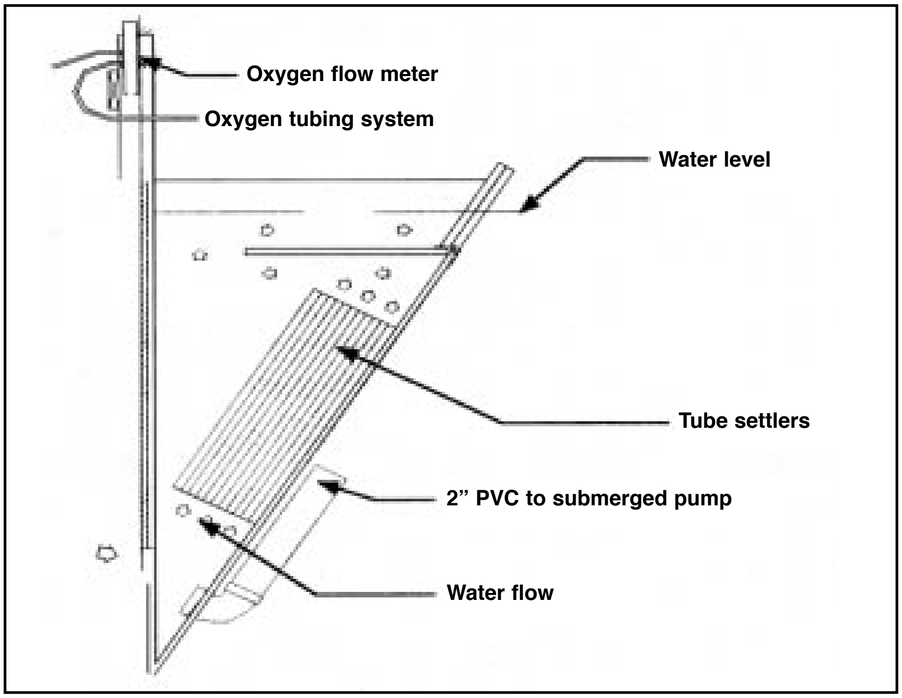

Figure 6b. Tube settler drawing showing construction with schedule 20 PVC and attachment of oxygen flow meter.

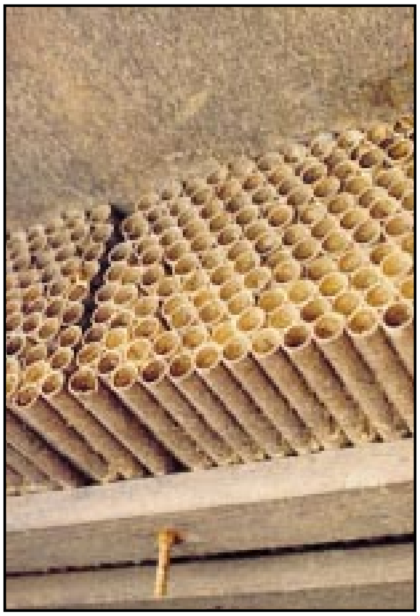

Figure 6a. Tube settler constructed of 3/4-inch schedule 20 PVC.

Problems

All culture systems have advantages and disadvantages. Like other high density raceway systems the IPR has problems related to disease, reaction time, and predators.

Diseases, particularly bacterial diseases, are common in all high density systems, especially raceways, cages, and recirculating systems. Bacterial diseases, particularly Enteric Septicemia of Catfish (ESC) and Columnaris, have been problematic with the IPR catfish research at Auburn University. Survival of catfish in IPR research has ranged from 65 to 98 percent, which is similar to cage research in the same pond. Tilapia survival has averaged around 97 percent; most of these losses have been due to escapement. Commercially operated IPRs have reported better overall survival.

Reaction time is another problem with the IPR as with other high density production systems. Backup systems, either generators or pure oxygen systems, are absolutely essential as power disruptions are inevitable. Since generators eventually run out of fuel and oxygen cylinders become depleted, electrical and / or pressure sensors with phone dialers are prudent components of these systems.

Predators, particularly birds, raccoons, and otters, are attracted to IPRs. The lids and mesh barriers around the inflows and outflows must be properly constructed and routinely maintained to exclude these persistent predators.

Economics

Cost of constructing an IPR system can vary greatly depending on the size and the materials used. The 16x4x4-foot IPR and dock system cost approximately $3,000 to build in 1994. This construction cost does not include the air-blower or the backup oxygen system (included in the budget, see Table 1). If constructed properly, an IPR system should have a viable life of 5 to 10 years (5 years in budget, Table 1).

Examining the economics of any new system is always difficult, and the reader should be aware that these are only examples for comparison. Assumptions have been made in Table 1 in order to compare the IPR system with traditional open-pond or cage production systems. In the example budgets presented, the data on production and labor costs are based on composites of actual data from research conducted on the IPR, cages, and open-ponds at Auburn University.

It should be noted that the IPR has been shown to have lower labor costs and better feed conversion when compared to the other two systems. However, the IPR has higher construction costs (not including pond construction), higher energy costs, and higher feed costs (if using a 36 percent protein feed for catfish).

In Table 1, the stocking rate is increased on a per acre basis for the IPR and decreased for cages (based on research and practical experience) as compared to open-pond production. The feed budgeted is a 36 percent protein diet for the IPR and cages and a 32 percent protein for the open-pond. Feed conversions are based on actual research data. In this comparison the IPR has the lowest breakeven costs and cages the highest. It should be noted that through evaluations of commercial catfish operations (SRAC - PESCAT Project) a 1-acre pond is too small, because of economies of scale, for economical catfish production. Therefore, the breakeven cost is high in all of these hypothetical situations.

TABLE 1. Economic comparisons between the IPR, cages and open-pond catfish culture (1-acre pond).[1]

	Open-pond[2]	Cage	IPR
Assumptions			
yield (lbs)	3,806	2,830	5,352
death loss (%)	6	10	10
feed conversion	1.8	1.6	1.45
% protein feed	32	36	36
Economic parameters (dollars)			
variable costs	3,135.63	2,391.27	4,160.25
fixed costs	787.72	850.16	1,111.26
total costs	3,923.35	3,241.43	5,271.51
breakeven price (cents per pound)			
to cover variable costs	82.39	84.50	77.73
to cover total costs	103.08	114.54	98.50

[1] Pond construction and management costs have not been included in the budgets.

[2] Open-pond production yields are based on actual average production values observed in the catfish industry in Alabama.

Remember, these are only estimated budgets based on research data and should be used as guidelines for evaluation purposes only.

Other uses

The IPR has also been utilized as an effective fish holding system. Several small processors of catfish have built and used IPRs to hold fish for later processing or live sales. They report that the fish adapt immediately to the IPR without any associated trauma, as usually occurs if large catfish are placed in cages. Feeding can also be started to continue weight gain or maintain the weight of the fish if they are to be held for a long time. The same processors have reported that catfish have been purged of off-flavor in the IPR within a few days to a week, as long as the pond in which the IPR was located did not have an off-flavor episode during the purging period.

Conclusions

The IPR has been shown to be a viable fish culture system for several fish species. The cost of production (considering capital costs) may be prohibitive for the culture of some species depending on their market value. Certainly, IPRs will not replace the open-pond culture system for catfish or most other species as presently practiced. However, it may have a viable place in watershed ponds, quarries, and possibly production in public waters where cage culture is not practical. IPRs may also be feasible where wastes must be collected or mitigated, or where high value niche markets can be exploited.

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