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Review Article

Design and Construction of a Novel Recirculating Aquaculture System for the Initial Rearing of Hybrid Green Sunfish: A Case Study

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Abstract

Recirculating Aquaculture Systems (RAS) technology is being implemented across the world. This paper describes the creation of a unique RAS system used initially for rearing hybrid sunfish [green sunfish (*Lepomis cyanellus*) x bluegill (*Lepomis macrochirus*)]. They system consisted of four, 2.44-m diameter tanks, radial flow separators, a bead filter, a heater/chiller, three pumps, three ultraviolet lamps, an oxygen generator, oxygen concentrator, and a custom-built degassing tower. Modifications during use included adoption of dual horizontal/vertical spraybars to facilitate tank hydraulic self-cleaning, elevated center tank drains to prevent plugging, additional oxygen generation, installation of outlet screens to prevent fish jumping, and elimination of electronic controls on the biofilter. The heater/chiller was unable to adjust water temperatures during the summer months and its use was discontinued during periods of high ambient temperatures. Initial use of the system was hampered by putting it into service too soon, prior to complete colonization of the biofilter. Addition of sodium bicarbonate at 20 to 25% of the daily ration, monitoring and adjusting water chemistry, and proper feed management were essential to maintain fish health and growth. Based on the results of this case study, temperatures above 23° C are recommended for hybrid sunfish, along with slow-sinking diets. Hybrid sunfish grew best on Optimal feeds.

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Interdiction

Recirculating Aquaculture Systems (RAS) continually re-use water for fish production, with the water treated by a series of processes [1]. RAS units generally include components to remove fish waste and other solids [2,3], biofilters to detoxify ammonia [4,5], strippers to remove carbon dioxide [6], devices to add oxygen [7], heaters/chillers for temperature control [8], and ultraviolet radiation for microbial control [9,10].

Governmental fisheries management agencies have recently become more interested in using RAS to produce fish for recreational and conservation needs [11,12]. In early 2020, the natural resource agency for the state of South Dakota, USA (Department of Game, Fish and Parks) began designing and constructing its first RAS system, with the intent of producing catchable-sized (approximately 200 g) hybrid green sunfish (*Lepomis cyanellus*) x bluegill (*Lepomis macrochirus*) for stocking into recreational fishing waters in the spring of 2021. This paper describes the rapid development and employment of this system, along with initial observations on the rearing of hybrid green sunfish in RAS.

System Components

The RAS system consisted of the following:

1. Four, 2.44-m diameter circular fiberglass tanks with radial flow separators.
2. One bead filter (BubbleBead XS20000, Aquaculture Systems Technologies, LLC, Baton Rouge, Louisiana, USA).
3. One heater/chiller (Aquacal SQ166R, St. Petersburg, Florida, USA).
4. Two 0.75 hp water circulation pumps (Artesian2, Performance Pro Pumps, Hillsboro, Oregon, USA).
5. One pump for the heater/chiller loop (WLS150 sprinkler pump, Wayne Pumps, Harrison, Ohio, USA.
6. Three 150-watt high output ultraviolet lamps (Pentair, London, United Kingdom).
7. Oxygen generator (UFB 200, Gaia Water, Victoria, British Columbia, Canada).
8. Oxygen concentrator (Max 10, Pro O2, Birmingham, Alabama, USA).
9. 1.02 m^3 degassing media (CF1200, L.S. Enterprises, Gainesville, Florida, USA).

System Construction

Tank setup

Each, approximately 45-L, culture tank was a four-piece bolt together design comprised of two sides, a sump, and a Radial Flow Settler (RFS). The tanks were designed to use the Cornell Dual Drain System and had both a main cleaner water effluent and small concentrated waste stream [13]. The central tank sump was a recessed 61 cm x 61 cm square with a 5 cm hole in the middle for an exit (Figure 1). The sump drain exited the tank into the RFS on the side of the culture tank and was responsible for approximately 10-to-30% of the total tank effluent (Figure 2). The other 70-to-90% of the effluent exited the culture tank via the side drain, bypassing the RFS. The RFS captured and contained a large amount of the settleable solids in the system (Figures 3 & 4).

Figure 1: Tank sump.

Figure 2: Interior drain structure.

Figure 3: Side drain structure in operation.

Figure 4: Exterior view of the drain structure.

Water Inlet and Drain Structures

Initially, water was directed into each tank with single vertical spray bar constructed of 5 cm Poly Vinyl Chloride (PVC) pipe submerged approximately 46 cm beneath the water surface. Despite providing adequate tank spin, tank self-cleaning properties proved to be lackluster with little draw exiting the central drain. The spraybar was subsequently redesigned and refabricated to include both a vertical and horizontal section [14,15] (Figure 5). Both sections were connected by a threaded tee, allowing each to be individually adjusted. Replacing vertical spraybars with this two-piece design provided much more control of in-tank water velocities and greatly enhanced the self-cleaning properties of the circular tanks [16,17]. Just as with the spraybar changes from the initial design, the central tank drain screen was also modified after its initial use. For the first 70 days, simple aluminum screens with 0.635 cm holes were used to cover the tank sumps, similar to a typical single-pass culture tank [18]. However, as feeding rates increased, the metal screens created quiescent zones in the tank sumps, interfering with waste movement to the RFS units. To solve this problem, the metal screens were removed and replaced with 5 cm PVC drainpipes [16] (Figure 6). Each new drainpipe was press-fit into a 90-degree PVC elbow that was molded into each tank sump. By removing the metal screen, waste had an unobstructed path to the central drain, and by modifying the inlet/outlet structures daily cleaning was dramatically reduced.

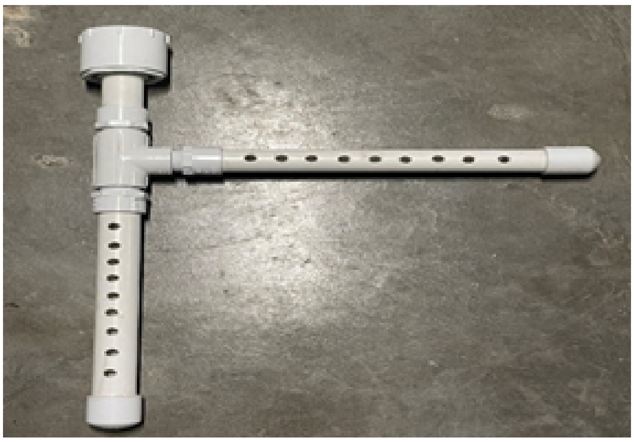

Figure 5: Tank spraybar.

Figure 6: Tank central drainpipe.

Carbon Dioxide Degassing Unit

To remove carbon dioxide, a stripping device based on a cascade design where large air volumes contact process water was used [6]. Initial calculations indicated that at approximately 0.028 m^3 of bio-media would be required to maintain appropriate carbon dioxide levels at maximum carrying capacity and feeding rates of one percent bodyweight per day [19,20] (Figure 7). In addition to degassing, the media also acted as trickling bioreactor. Aluminum framing and 1.2 x 2.4 m sheets of black HDPE panels were used to construct the counter-flow packed tower [21]. The tower was large enough to accommodate four layers of bio-media, each 91.4 cm x 91.4 cm x 30.5 cm, and was semi-modular to accommodate possible future expansion (Figure 8). The top of the tower had a manifold leading to four spray nozzles that evenly distributed the water across the media (Figure 9). The skirt on the bottom of the structure was submerged in a 1,250 L Intermediate Bulk Container (IBC) tote that served as a collection basin for the water that was pumped through the tower. a 6.4 m^3/min CFM blower distributed the air underneath the media for maximum gas transfer (Figure 10). The exhausted air was vented out the top of the tower, with a connection to an existing sewer vent for expulsion from the building.

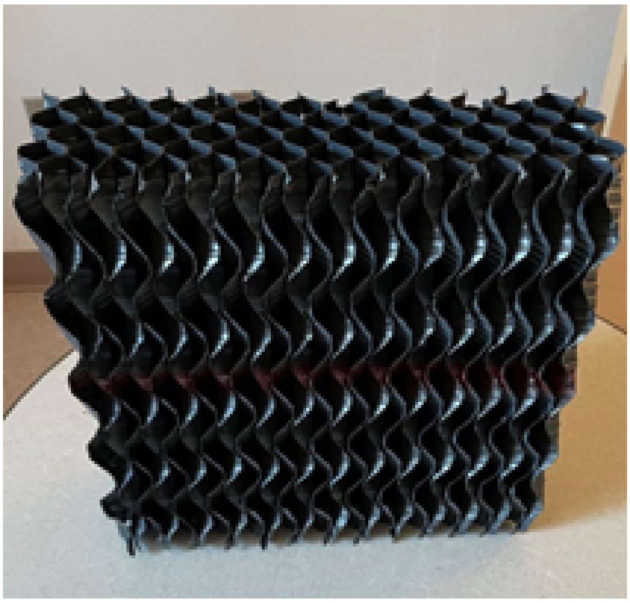

Figure 7: CF1200 Media for carbon dioxide degassing tower.

Figure 8: Sideview of the carbon dioxide degassing tower.

Figure 9: Carbon dioxide degassing tower sprayer manifold and air exhaust vent.

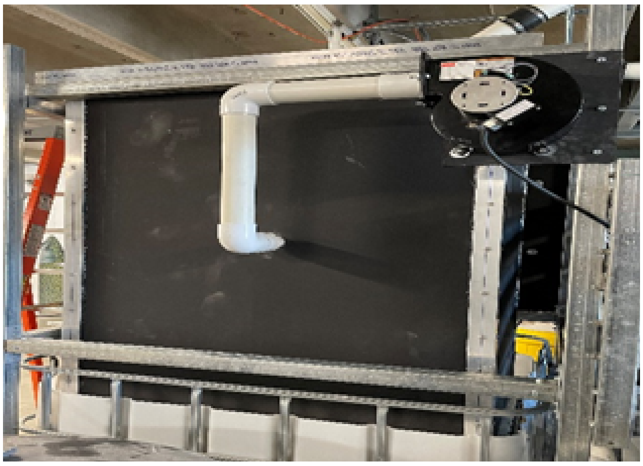

Figure 10: Carbon dioxide degassing tower air inlet with blower.

Oxygenation

The nano bubbler with the capacity of 18 kg of oxygen per day at approximately 85 percent efficiency, was incorporated into the main system pump line to deliver oxygen to the system [22] (Figure 11). This eliminated the need for a side loop and additional pumps. While this component was reliable, there were concerns that the head pressure required would affect tank hydraulic retention times. This problem can be mitigated by incorporating the nano bubbler on the pump of another water treatment process or upsizing to a larger unit. Upon reflection, using the larger UFB 300 may have been a better choice because it would have likely dramatically-reduced head pressure. To provide up to an additional 10 L/min of oxygen at approximately 95% purity, the oxygen concentrator was also used (Figure 12).

Figure 11: The GAIA UFB 300 oxygen generator (top) the smaller UFB 200 generator (bottom).

Figure 12: The Max 10 oxygen generator.

Temperature Control

For temperature control [8], water was pumped on a side loop from the carbon dioxide tower collection tank to the chiller/heater and returned to the collection tank (Figure 13). Air flow exchange problems were encountered during the summer months, when the unit exhausted heat into an already hot room. To prevent excessive operation of the unit, water temperatures were allowed to rise above optimal levels during the summer. Design considerations moving forward are to construct a fume hood over each unit to exhaust at least 99 m^3/min of air. Aside from the peak summer months, the chiller/heater worked well.

Figure 13: The AquaCal heater/chiller.

Bio-Filtration and Sterilization

A bead filter was used as the primary biofiltration [23,24] (Figure 14). It contained approximately 0.28 m^3 of media and acted as both a biofilter and solids filter [25]. At feed rations of 5 kg/day, ammonia levels remained within acceptable limits [8]. Bead filter backwash frequency was primarily determined by efficacy of radial flow settlers, total feed ration, and prudent feeding practices [24,26,27]. The integrated automatic timer to independently initiate bead filter backwashes failed several months into service, which required manual backwashes there-after. The bead filter was eventually replaced with the T Polygeyser HPPG 25 (Aquaculture Systems Technologies, LLC, Baton Rouge, Louisiana, USA) which operates solely with air; no electronics are used (Figure 15). Three 150-watt ultraviolet sterilizers were used for disinfection [28,29] (Figure 16).

Figure 14: BubbleBead XS20000 biofilter.

Figure 15: Polygeyser HPPG 25 biofilter.

Figure 16: 150-watt UV lamps.

Water Flow

Two pumps were used to move the water. The first pump moved the water through the BubbleBead filter, the UV lamps, and up to the top of the carbon dioxide degassing tower. The second pump moved the eater from the degassing tower through the nano bubbler to a head tank. A master valve after the second pump allowed for synchronization between the two pumps. While it worked effectively, this two-pump system was temperamental and difficult to balance. A schematic of the entire RAS system is show in (Figure 17).

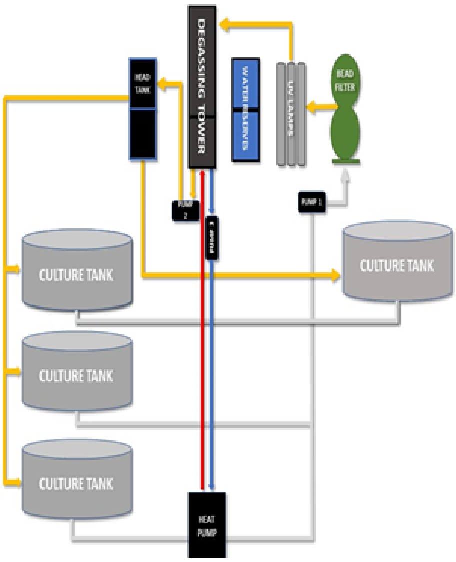

Figure 17: A schematic of the recirculating aquaculture system used for rearing hybrid green sunfish, with arrows indicating water flow.

Fish Rearing

Two days after construction of the system, approximately 11,000 hybrid green sunfish (ranging from 0.83 to 4.1 grams) were placed in the tanks. Feed was withheld for seven days to acclimate the fish and to allow for at least some bacterial growth in the biofilter. On the eighth day, the fish were fed at a rate of 100 grams/tank for the next 13 days. At day 21, feed was increased to 0.4 kg/tank for the next 7 days. There-after, at approximately two-week intervals, feeding rates were set at 90% of the amount consumed (apparent satiation) at 15 minutes.

Lessons Learned

1. *Do not rush the system!* Supply chain issues caused system construction to require more time than anticipated. As a result of the delay, this initial RAS unit was only allowed to run for two days before the insertion of fish into the system. This timing did not allow the biofilter to be fully-functioning. At rearing day 28, ammonia spiked to unreadable levels [30-32] and caused catastrophic mortality. If the biofilter had been allowed the time to be fully-functioning, and if a water quality testing routine had been established, this mortality would likely not have occurred.

2. *Add sodium bicarbonate at 20-to-25% of daily feed ration.* No sodium bicarbonate was added to the system, with total alkalinity only 5 mg/L when the 28-day mortality event occurred. Alkalinity is extremely important for nitrifying bacteria, with low levels resulting in biofilter malfunction [33,34]. Because of the premature start of rearing in the system, practically all alkalinity had been consumed by bacteria [34,35].

3. *Fish do not always stay in tanks.* While the tops of the tanks were partially-covered, fish still jumped from tanks [36]. In some cases, these escapee fish blocked return lines, caused every tank to overflow, and led to minor mortality. Placing a screen over every side drain outlet eliminated this problem (Figure 18).

Figure 18: Side outlet screen.

4. *Know water quality parameters and test for the proper ranges.* During the ammonia spike, a water quality testing routine had not been established. In addition, reagent kits for "optimal water parameter readings" were the only kits on site. When the situation reached acute severity, accurate information could not be obtained because the ranges were too high to register on the spectrophotometer.

5. *Proper feed management is key to system health.* Initially, the fish were grossly overfed. This led to constant system imbalances, as well as inconsistent and unpredictable cleaning cycles. Using an adaptive feeding strategy based on near-satiation was extremely important, reducing daily tank cleaning to zero. In addition, BubbleBead filter flushing was reduced to only 2-to-3 times per week.

Observations Regarding Bluegill X Green Sunfish Hybrids

Temperature - The sunfish appear to feed quite well at any temperature above 23° C, with smaller fish feeding voraciously at even lower temperatures. As fish grew, it became necessary to increase temperature to 27° C to maintain an acceptable feeding response [37].

Density - The maximum density reached in a culture tank was approximately 30 kg/m^3, although higher densities can likely be achieved.

Diets Used and Feeding Behavior- A variety of feeds were used during this initial rearing trial, with the nutrient profile of the Optimal Fish Food Junior floating diet most closely matching the requirements for sunfish [38]. These diets and the response of the sunfish is described in (Table 1). The sunfish much prefer a slow sinking diet compared to a floating diet. Larger fish appeared to feed aggressively on the floating diet for a short period of time, but then slowly lose interest throughout the day.

Diet	Manufacturer	Observations
CleanAssist	Skretting[a]	Aggressive feeding behavior
Classic Trout	Skretting	Not eaten, rapid pellet disintegration
Europa	Skretting	Mixed feeding behavior, fish rejected sizes > 3.0 mm
Starter	Optimal[b]	Readily accepted up to 3.0 mm
Junior	Optimal	Very aggressive feeding
EP2	Otohime[c]	Feeding after it sinks

Table 1: Diets used, feed manufacturers, and feeding observations of hybrid green sunfish in an initial recirculating aquaculture system.

[a]Skretting = Tooele, Utah, USA

[b]Optimal = Omaha, Nebraska, USA

[c]Otohime = Pacific Trading Company, Fukuoka, Japan

Conclusion

This initial attempt of rearing hybrid green sunfish in a uniquely designed and quickly fabricated RAS system was moderately successful. Fish were reared to the desired size. Most importantly, the lessons learned from this initial effort will lead to changes in subsequent system design and rearing procedures. Abundant further research and development opportunities exist.

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