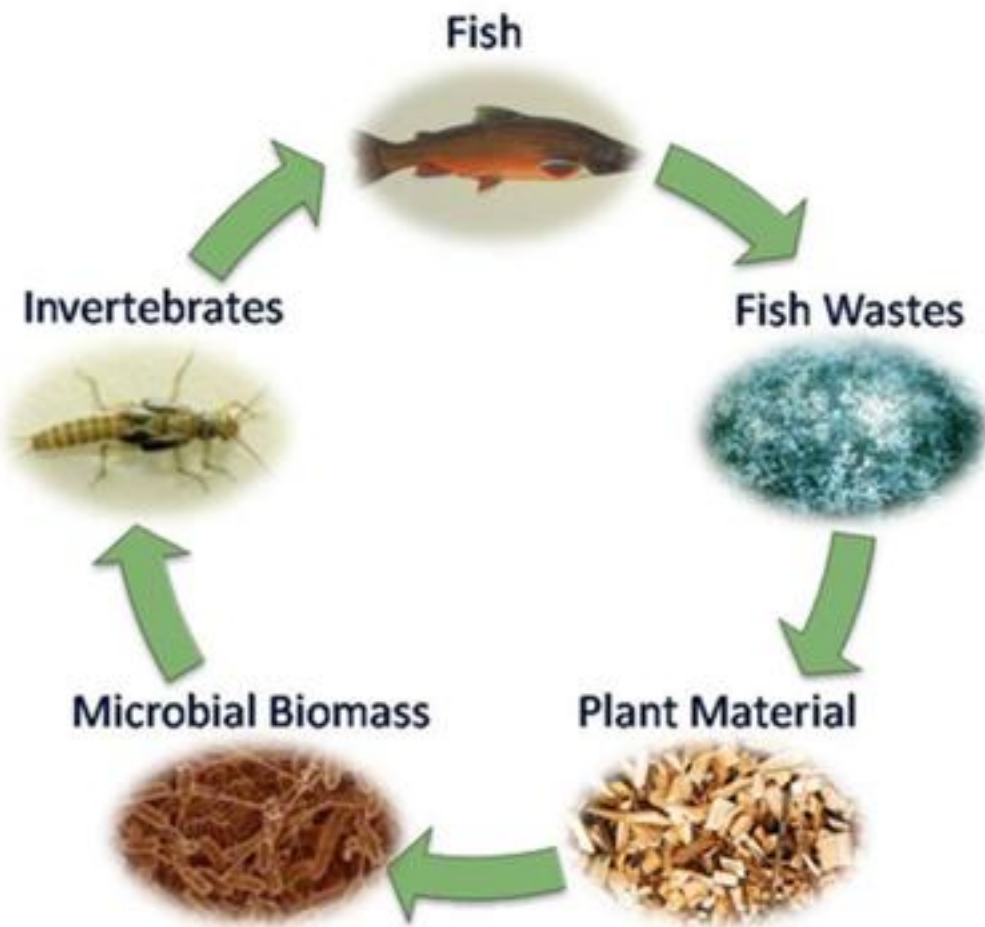




Rethinking Fish Farming with Ecologically Intelligent Aquaculture



This is an introductory document for those who are familiar with Recirculating Aquaculture Systems (RAS) but are not in general familiar with TimberFish Technologies and Ecological Intelligence and their co-evolutionary history.

When I was a boy my family spent our summers on a small lake with a relatively large island in the center, surrounded by forest, and with 6 small cottages and cabins in the south west corner. It was an experience that I continued for many years thereafter. We fished and canoed and I got to understand the lake and its ecology very well. One of the things that had a major impact on my thinking involved a beaver house on the north west corner of the lake.



Here the beaver would stockpile a lot of willow and alder cuttings in a mostly submerged pile right next to the beaver house. Some of these sticks would develop a sort of fuzzy appearance, like something was growing on their surfaces. There were always a lot of minnows around this pile and it was a good place to fish for bass that came to eat the minnows.

It became my first conscious recognition of an Ecologically Intelligent Aquaculture system. A pile of sticks in water with microbes living on them. Minnows eating the microbes, bass eating the minnows. The minnow and bass (and beaver) wastes provided the nutrients for the microbes so that they could eat more wood. Thus the water stayed very clean. Any waste nutrient would be immediately gobbled up by the microbes. There was no pollution. I (or perhaps an otter or heron or loon) would then remove the excess fish and the beaver would add more sticks. Brilliant!

When I grew up I went into science, microbiology, theoretical biology, but I continued to return to the lake in summers for many years. I have spent many years in various forms of environmental ecotechnology; 10 years in municipal wastewater treatment at the Town of Amherst, in New York State.



After this my brother and I founded Bion Technologies and built many systems in manure and nutrient management for large animal agriculture, and wastewater treatment for food and beverage production and processing facilities. Here is our first large system at a 1,000 dairy farm in New York.



Here is a 11,000 hog farm in North Carolina.



A wastewater treatment system for a citrus processor in Florida.



And a system for the Sugar Cane growers in Florida. This was important in that it could reduce phosphorus in the effluent to less than 20 ppb (rainfall would often exceed 50 ppb).

Bion Technologies Wetlands #11
Treatment system for runoff from sugar cane fields.



After Bion I co-founded TimberFish Technologies in 2008. Here is a treatment system for a distillery in New York that also raised fish.



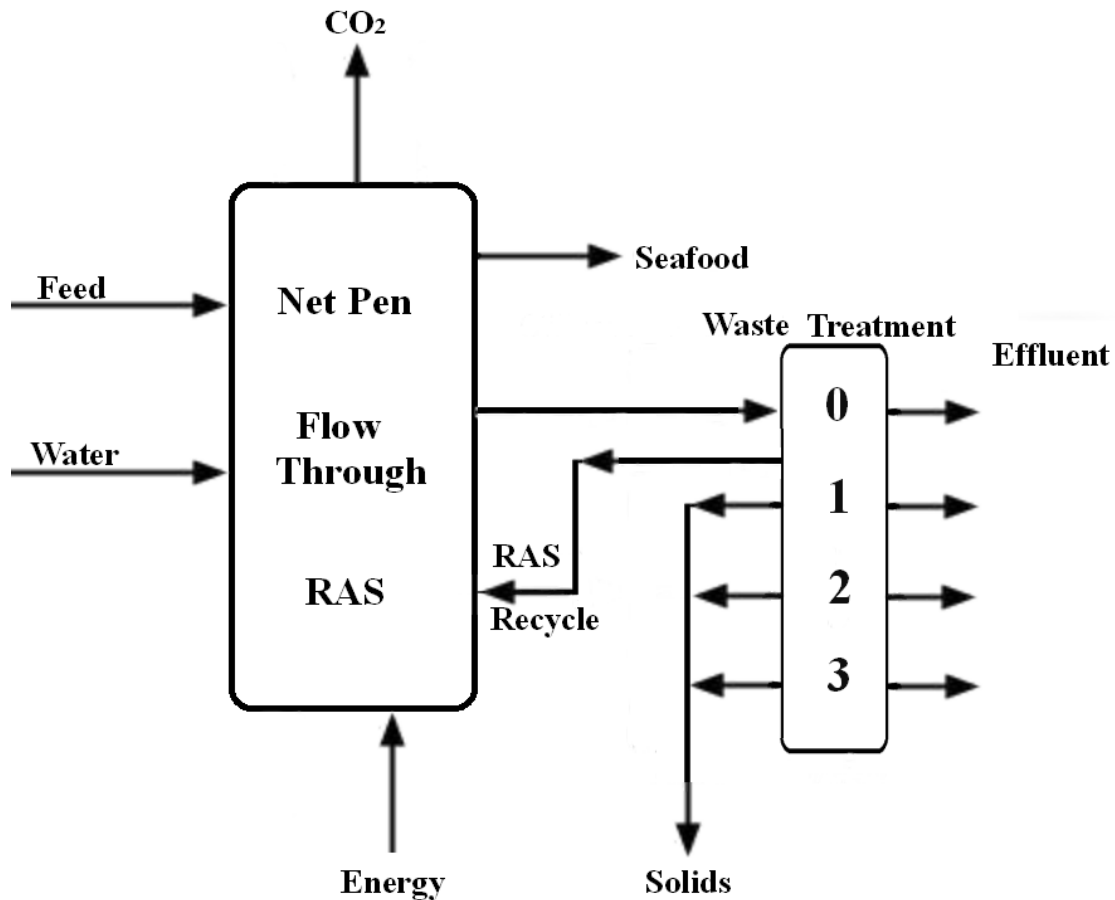
The wastewater was treated by a multi stage bioreactor in the left hand side of the system and worms and fish were raised on the right hand side. Here are typical fish tanks with wood chip biofilters on top for wastewater treatment. Solid wastes were pumped back into the bioreactor on the left. Watercress was growing in the one biofilter.



All of this was consistent with conventional aquaculture in that separate systems were used to produce feed and provide wastewater treatment. The big difference was that we produced the feed from wood.

Then about two years ago the real understanding of the beaver pond as an integral and sustainable ecotechnology process emerged. Now, not only is the feed produced within the system, but the waste and wastewater treatment are also included in the fish raising environment.

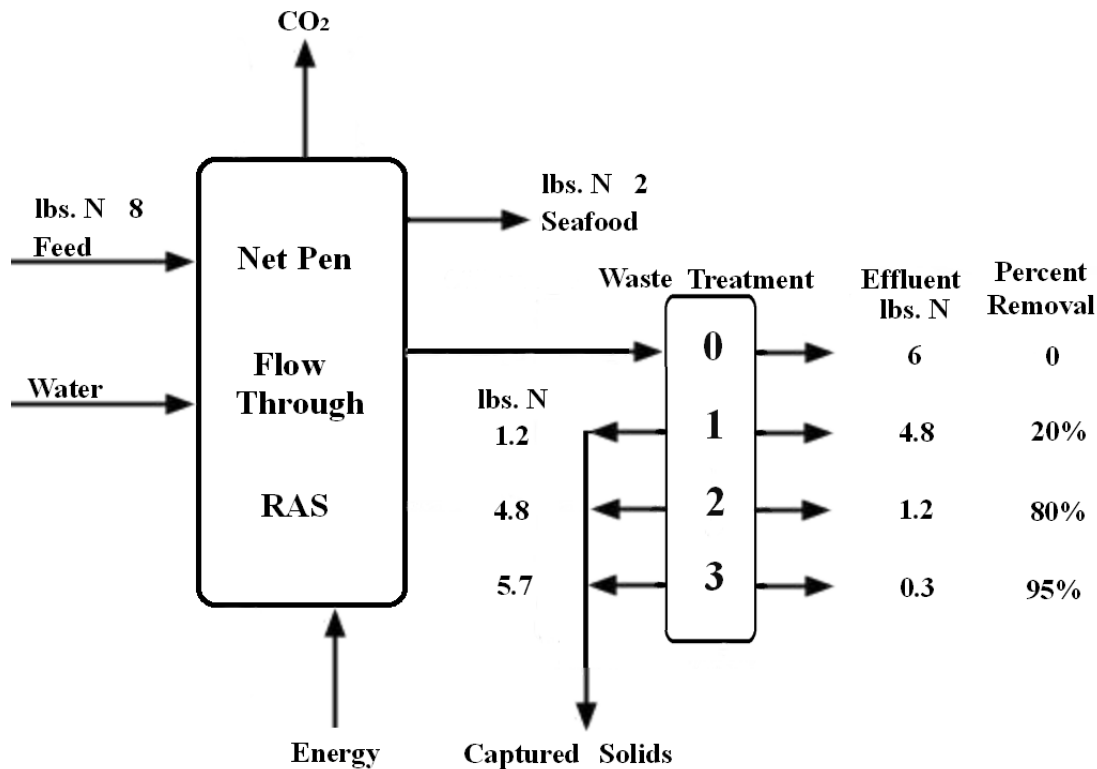
To illustrate, consider the mass and energy flow for current aquacultural systems,



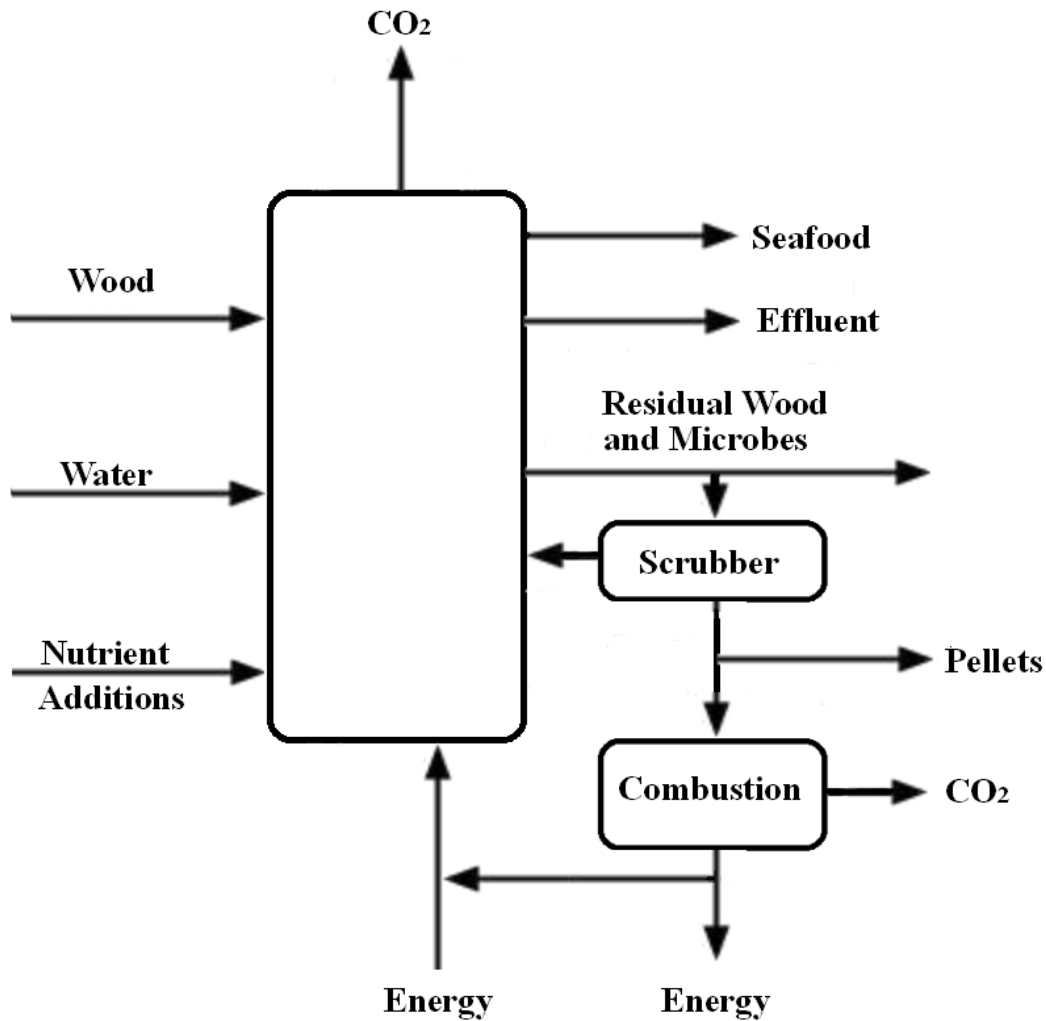
Here we have an enclosed structure, net pen or tank, with water moving through it. The flow will be such that the Hydraulic Retention Time (HRT) for the RAS systems is about 12 days (much less for Flow Through and Net Pen systems). You add fish, feed them, harvest them when they get big enough, and remove the waste, especially nitrogen and phosphorus, preferably with some sort of treatment. No treatment (0), Primary treatment (1), Secondary treatment (2), and Tertiary treatment (3). The nitrogen and phosphorus that is removed is collected in a semi solid sludge, usually about 20 percent solids, and land applied.

We can track nitrogen in the system and show the various quantities of nitrogen that will be discharged to the environment by the various system effluents. The removal percentages for nitrogen from the effluent stream are; (0), zero percent removal; (1), 20 percent removal; (2), 80 percent removal; and (3), 95 percent removal.

Consider a growth cycle for a RAS system with tertiary treatment in a 1,000 gallon tank with a daily influent flow of 83 gallons per day (12 day HRT). Start with 100 fingerlings, each weighing about an ounce. They double in weight every two months and if they are harvested in 8 months will weigh about one pound per fish for a total of 100 pounds. Assuming a Feed conversion Ratio (FCR) of 1.0 this will require the consumption of 100 pounds of feed over the growth cycle. If the feed contains 8 percent nitrogen, dry weight, and the fish contain 2 percent nitrogen, wet weight, and there is no mortality, then the harvested fish will contain 2 pounds of nitrogen and produce 6 pounds of nitrogen in the fish waste. This will be discharged to the environment in the effluent is shown for the various treatment options in Figure 2. This also shows the captured nitrogen in the semi solid sludge that will usually be land applied. During the entire process the nitrogen in the process tank will be distributed between the fish, the uneaten fish feed, and the fish waste.



Now look at how we can do this with Nature’s way, with an Ecologically Intelligent Aquaculture system.



This will be for a process in which a tank (or pond) will be used repetitively for a series of production cycles. Each cycle will start by introducing a large quantity of wood sticks or chips into the process tank. Some of this wood will be submerged in the tank and the rest will be contained in irrigated structures placed above or adjacent to the process tank. This will be similar to where baskets of wood chips were suspended above a process tank as shown in the last photo of the earlier example of the distillery system.

There will already be a microbial biomass, and some invertebrates and minnows from the previous cycle in the process tank. The residual wood that was not consumed in the previous cycle will have been removed along with some of the microbial biomass. The process will use a Hydraulic Retention Time (HRT) of 100 days or more and this will result in a very small influent flow which will lead to a

comparably small effluent flow from the tank. Note that the HRT for this system is much larger than for any of the conventional aquacultural systems in Fig 1.

The wood will be comprised of cellulose, hemicellulose, lignin, and ash. The fractional distribution will vary considerably over various species of wood. For purposes of this example comparison assume that, on a dry weight basis, the wood will comprise 50 percent cellulose, 20 percent hemicellulose, 20 percent lignin and 10 percent ash and water.

Once the new wood is in the tank, fingerlings of the desired product fish will be added. These fingerlings, and the holdover invertebrates and minnows from the preceding cycle, will start consuming the holdover microbial biomass. This consumption will produce soluble waste nitrogen and phosphorus which some of the holdover microbial biomass can then use to begin degrading the new wood. Since microbes reproduce much faster than invertebrates and fish a ready supply of new microbes will be available for future growth of invertebrates and fish. The relative scarcity of soluble nitrogen and phosphorus compared with the available food supply and microbial population will result in very low concentrations of soluble nitrogen and phosphorus in the tank, and hence in any effluent leaving the tank.

The insoluble fish wastes will be filtered out of the water in the irrigated wood zones which act as biofilters. These captured insoluble wastes will then be consumed by the microbial biomass attached to the wood in the irrigated zones. The entire system will thus contain a significant amount of nitrogen and phosphorus in the bodies of the microbes, invertebrates, and fish but virtually no soluble nitrogen and phosphorus in the water column itself.

The minnows and larger invertebrates will accumulate in the tank until the product fish become large enough to eat them. At this point their respective populations will decline while the product fish grow. The total amount of nitrogen and phosphorus in the tank at the start of the cycle will be balanced so that when the product fish are harvested most of the invertebrates and minnows will have been consumed, leaving only enough to provide for the initial inoculum for the next cycle, and a small fraction to be harvested with the residual wood.

The residual wood at the end of the cycle will have an elevated energy content compared with the raw wood. This will occur because the microbes will consume the cellulose fraction of the raw wood before the lignin fraction. Since lignin has a higher ratio of carbon to water than cellulose or hemicellulose, the residual wood

will have a higher heating value than raw wood. After harvesting, a portion of this residual wood can be scrubbed so that virtually all of the microbes attached will be removed and returned to the process tank for the next cycle. The resulting high carbon residual in the scrubbed wood can then be dried and used for pellets for wood stoves, a substrate for the pyrolytic production of biofuels, or combusted on site for energy production.

The residual wood not used for energy production will be harvested with some microbial biomass. This will comprise a salable product for landscaping, soil amendment, potting soil or organic fertilizer. The distribution into these categories will be a function of the percentage of biomass included with the residual wood. Because the nutrients will be contained in the microbial biomass they will be available for plant growth on a slow release basis for optimal plant uptake. This should reduce or eliminate loss to atmosphere or runoff of these nutrients.

These systems will be located in or close to forests to minimize costs for obtaining and transporting the wood. Consequently, the carbon dioxide emitted by organisms respiration and scrubbed residual wood combustion will be easily recycled back into the forests for incorporation into new plant material via photosynthesis. Enough energy can be produced from the residual wood to eliminate the need to purchase energy from the outside and so these systems and the forests can be carbon and energy neutral to negative.

To illustrate the difference between conventional aquaculture and this system consider a comparable example to the tertiary treatment version of RAS that is described in Figure 2. This will require that 100 one ounce fingerlings will produce 100 pounds of product fish in 8 months with no mortality. To comfortably meet these requirements we would use a 4,000 gallon tank and load it with 5,000 pounds of dry weight wood, equally divided into 2,500 pound submerged and irrigated fractions as described earlier. Assume that the wood will contain 0.01 percent nitrogen (5 pounds) and 0.002 percent phosphorus (1 pound). Thus 2 pounds of the nitrogen and 0.4 pounds of phosphorus will end up in the harvested fish, and the remaining 3 pounds of the nitrogen and 0.6 pounds of phosphorus will end up as microbial biomass in the harvested and removed residual wood.

The system will operate with a HRT of 100 days which results in a daily influent and effluent flow of 40 gallons per day. Since there will be very little soluble nitrogen and phosphorus in the tank water this effluent will consistently meet tertiary treatment water quality standards of 4 mg/l for total nitrogen and 1 mg/l for

phosphorus. Thus the total environmental load from the water effluent over the entire growth cycle will be 0.3 pounds of nitrogen and 0.075 pounds of phosphorus. This is comparable to what is expected from the best conventional RAS with tertiary treatment as shown in Figure 2.

The core of this process comprises the microbial biomass which is attached to the wood. This is a variable that can be managed by nutrient additions to the process tank. These additions can vary widely as long as they do not contain any toxic materials or nutrients that are not readily biodegradable. They can range from fish feed, to clean waste and byproduct streams from food and beverage producers or processors, to wastes from other aquacultural or animal raising systems, to inorganic fertilizers.

Such additions will be made if the nitrogen and phosphorus in the raw wood is insufficient to produce the target weight of fish. They also can be made to influence the nitrogen and phosphorus concentrations in the harvested residual woods. Varying these concentrations can determine the economic viability or desirability of these saleable byproducts.

The microbial biomass in the system will comprise an extensive diversity of different species. This will allow the system itself to respond to a wide range of environmental fluctuations and different harvesting preferences. We can interact with the system but it will be by suggestion and not by calculated demand. The system will function as an ecologically intelligent entity and not as a programmable machine.

We and the substances moving through the system will periodically, and usually inadvertently, be introducing new microbial inoculations. But the system will decide if they are worth keeping, and if so, by what fraction of the resident population. It is a sort of “Field of Dreams, if we build it, they will come”.

This system can be scaled up for more production. Because the system will operate with tertiary treatment water quality or better earthen ponds can be used. However, the need for large quantities of wood will usually restrict the size to less than a million pounds of fish production per year because of the economic advantage of having the wood supply within 6 miles of the production facility.

The system can also be used in conjunction with the other forms of conventional aquaculture and this may represent some of its most useful applications. For example, consider a net pen operation that is close to shore. Place bundles of wood

sticks around the pens in a manner where by they can be easily removed and replaced. Removal of these bundles and their associated microbial biomass when a significant fraction of their wood has been degraded can show that some of the fish waste nutrient has been recovered and removed. Consequently it will not have been discharged into the water environment and this can be reliably documented.

To get a better understanding of how this ecotechnology works it is easy to build and operate a small version in your home, school, business, or community. These can range from 10 to 20 gallon table top units to backyard/basement or classroom units holding from 50 to several hundred gallons. Detailed descriptions for these units are presented at [econet | Econet / TimberFishTechnologies](#)

Since this comprehensive ecotechnology understanding has only been formally incorporated into the Timberfish Technology in the last two years, it has not yet been applied at a large scale. However, it has been running at my home for the last 8 months. We almost had it back in 2008 when we ran a version in a woodland pond, sort of a semi beaver pond system. A perched brush pile, a submerged brush pile and fish, all together. But we only saw this as a proof of concept for the wood to microbes to snails to trout process. We didn't connect it to a production aquaculture ecotechnology.



Then last year I decided to apply it to a goldfish pond at my home that has been running for over 30 years. Historically I would feed the fish, remove them to the basement for winter, clean out the pond with waste and wastewater going to a flower garden, and repeat for next year.

But last August I bundled up some wood sticks from our maple trees,



Put some more sticks in a basket,



Put them in our pond and stopped feeding the fish.



The fish thrived and spawned and so in November I collected some more sticks and put them in a 2 gallon milk crate,



Put this in a 55 gallon drum in the basement with some aeration stones.



Added more sticks to a 5 gallon pail with holes in the bottom and put it on top of the sticks in the milk crate.



Filled it with water, started the aeration and a recycle flow, and put the fish in for the winter. I would daily siphon out the solid wastes from the bottom, decant the collected water, and return the solid wastes back to the top of the 5 gallon pail.



Here are the fish that were added to the system. Three large goldfish and a dozen tiny fry hatched in the pond in late summer.



And it worked great all winter. Ammonia nitrogen was consistently undetectable, less than 0.24 ppm with a test kit. Here is the full system.



The fish all survived over the winter and the fry grew significantly. They all were returned to the pond in May.

It is easy to build and operate, and you can do it too. Prove to yourself that it works.