Fish Fry Lake: Perspectives from an Inventor on the Application of Created Floating Islands for Water Quality Renovation

Bruce Kania[1], *Floating Island International, Inc., Shepherd, MT, USA*

Today Fish Fry Lake is a highly productive wild fishery, and also a long-term experiment tracking how the resource of nonpoint nutrient-loaded water can be optimally managed. The Fish Fry Lake story has relevance to water stewardship across much of the developed world where water quality is impacted by agricultural-based nutrient loading.

Fish Fry Lake is located on the east side of Yellowstone County in south-central Montana. The lake covers 6.5 surface acres, is 28 feet deep at its deepest point, and contains about 55 acre-feet of water at full pool. Groundwater influenced by agriculture infiltrates to the lake and discharges at a typical rate of 65-85 gallons per minute.

When the lake was converted from a seasonal pond to a perennial one in 2005, it displayed the typical attributes of a eutrophic waterway. The lake surface was occasionally completely covered with filamentous blue-green algae, with occasional patches of cyanobacteria (Figure 2). Accordingly, dissolved oxygen (DO) levels could swing wildly. Not even the ubiquitous fathead minnow could survive in the original lake, as DO levels would drop to as low as 0.1 mg/L during seasonal turnover events. The water would typically stratify at about six feet, where anoxic conditions (oxygen present, but not in breathable form by aerobes) would persist to about a 20-foot depth, then slip into an anaerobic (no oxygen) zone. At least twice a year when the water turned over, anoxic conditions would persist across the entire lake, killing most forms of oxygen-breathing aquatic biota.

FISH FRY LAKE – THE EXPERIMENT

As an inventor and owner of the property upon which the lake resides, I selected it as a demonstration site for a long-term experiment. The primary question being asked was: Can water be made less eutrophic by practical methods of cycling nutrients into beneficial forms of life? In other words, can a healthy food web replace a near-monoculture of blue-green algae and cyanobacteria in a eutrophic waterway? Can we grow fish instead of algae? What other forms of biota could replace the system that was then dominated by blue-green algae and cyanobacteria in Fish Fry Lake? And finally, could tools be developed that would help achieve these ends?

We hoped to answer a range of additional related questions which included:

1. Could the lake be recovered organically, without use of bactericides or herbicides?
2. Since Secchi disk-derived water clarity readings were as low as 14 inches, due in part to the presence of colloidal clay, could water clarity be substantially improved?
3. Could the inflow and inventoried nutrients be cycled into healthy, fast-growing game fish?
4. Given that inflow groundwater total dissolved solids (TDS) concentrations were around 1600 mg/L, and mainly consisted of calcium, magnesium, carbonate and sulfate, could the TDS concentrations present in the lake be somehow mitigated?
5. Could the lake serve as a template for water quality improvement in other nutrient-impaired waterways?

People Who Inspired Us

Environmental journalist, Janine Benyus, published “Biomimicry” in 1997. The book was a compendium of examples of product that copied forms and systems present in nature. This view of nature as the premier inventor inspired much of our ensuing work. With ongoing assistance from a network of scientists and engineers, a wide range of sub-experiments were run over the following decade. Scientists and engineers associated with the Fish Fry Lake experience are too numerous to list, and sincere apologies for any grievous omissions, but did include: Frank Stewart, Chris Tanner, Bob Lusk, Al Cunningham, Bruce Condello, Mark Osterlund, Otto Stein, Tom Maechtle, and scientists from China’s CRAES.

NUTRIENT POLLUTION AS AN OPPORTUNITY

Fertilizer-derived orthophosphate is the primary form of phosphorus infiltrating into Fish Fry Lake via groundwater and runoff (Figures 3 and 4). Typical concentrations are about 0.065 mg/L but can be several times higher, particularly after a precipitation event. Typical total phosphorus concentrations are 0.020 mg/L in Fish Fry Lake

1 Corresponding author contact: bruce.kania@floatingislandinternational.com

outflow. Nitrogen and ammonia concentrations of inflow water are also highly variable but in outflow, are typically near the detection level. We view these numbers as reflective of improved water quality, but still target lower total phosphorus concentrations..

TECHNOLOGY DEPLOYED

"Floating Treatment Wetlands" (FTWs or floating islands) are a breakthrough technology that addresses several of the major water quality challenges our world faces today. Floating islands are a versatile form of constructed wetland since they can be positioned on nearly any waterway, without adjusting that waterway's footprint. They are modular and can be cost-effective. In fact, today, an embodiment of BioHaven floating islands is designed to leverage Water Resource Recovery (WRR), meaning it can generate revenue in the form of commercial solar electric power, harvestable landscape trees, or forage fish like the fathead minnow, used as biological mosquito larvae control or as a commercial bait fish. Essentially, water quality enhancement could become a byproduct associated with island systems that pay for themselves by providing a return on investment (ROI). This has positive implications for lake restoration internationally, and specifically became the primary tool with which we transitioned Fish Fry Lake.

Nutrients in a waterway, left unmitigated, will limit biodiversity, will enhance for monoculture of extreme biota, and will ultimately result in hyper-generation of greenhouse gases (Floating Island International, Inc. et al. 2016). Fish Fry

FIGURE 1. Aerial view of Fish Fry Lake. (Source: Google Earth)

FIGURE 2. Massive carpets of filamentous algae led to dissolved oxygen deficits early in the history of Fish Fry Lake. (Note: All figures in this article are from Floating Island International, Inc., courtesy of the author.)

FIGURE 3. Soil profile depicting how ground water perks into Fish Fry Lake.

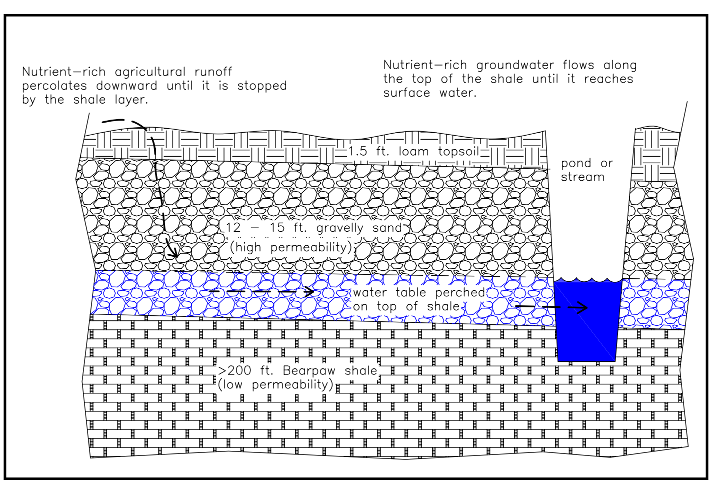


FIGURE 4. Foam associated with phosphorus-rich runoff.

Lake has taught us that these same nutrients can be stewarded – managed by growing and harvesting plants and fish. For example, nutrients can energize a food web when guided into forage, which, in turn, naturally cycles into high-order biota such as game fish. The following examples depict this:

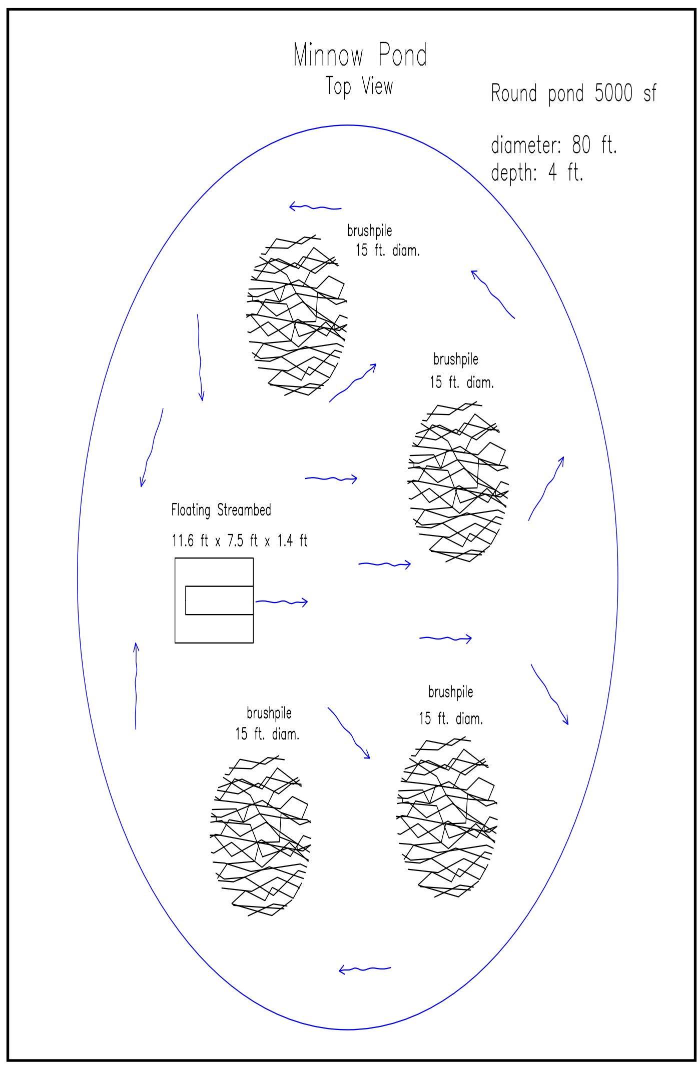
- Floating islands grow biofilm, upon which various forms of phytoplankton, including diatoms occur (Figure 5). This mix, called "periphyton," is the foundation of the aquatic food web; it is colonized by zooplankton, which in turn feed a vast range of other invertebrate life, like damselfly nymphs, mayfly nymphs, dragonfly nymphs and scuds – food for larger aquatic organisms. Plant roots extending through the island feed other forms of biota (Figure 6). Freshwater sponge growing in island matrix filter out total suspended solids (TSS) and TDS, in some instances. Endophytes present in plant roots that grow through islands phyto-extract other nutrients, minerals and metals. Bacteria occurring in biofilm do the same.

FIGURE 5. Sponge colonizes the underside of many BioHavens in Fish Fry Lake.

FIGURE 6. Luxurious root growth on this research BioHaven in France.

- In a 5,400-square foot pond ("Minnow Pond") just above Fish Fry Lake we use an embodiment of BioHaven floating island called the "floating streambed" to circulate end-of-irrigation ditch water through aged, deciduous brush, practicing a variation of Brush Park polyculture (Azim 2005; Figure 7). In the process we grow and harvest on average 400 pounds of fathead minnow, five-prong stickleback cyprinids, and crawfish annually. No feed is associated with this system other than nonpoint nutrients present in the inflow water, and the floating island that provide biofilm reactive surface area with which to cycle nutrients into biofilm/periphyton. The island also provides spawning habitat for the fatheads, which lay eggs on the underside of submerged structure.
- Beds of aquatic vegetation, rock, cobble, tree stumps and other structures, especially when combined with circulation, are relatively passive but highly effective forms of surface area that grow other forms of

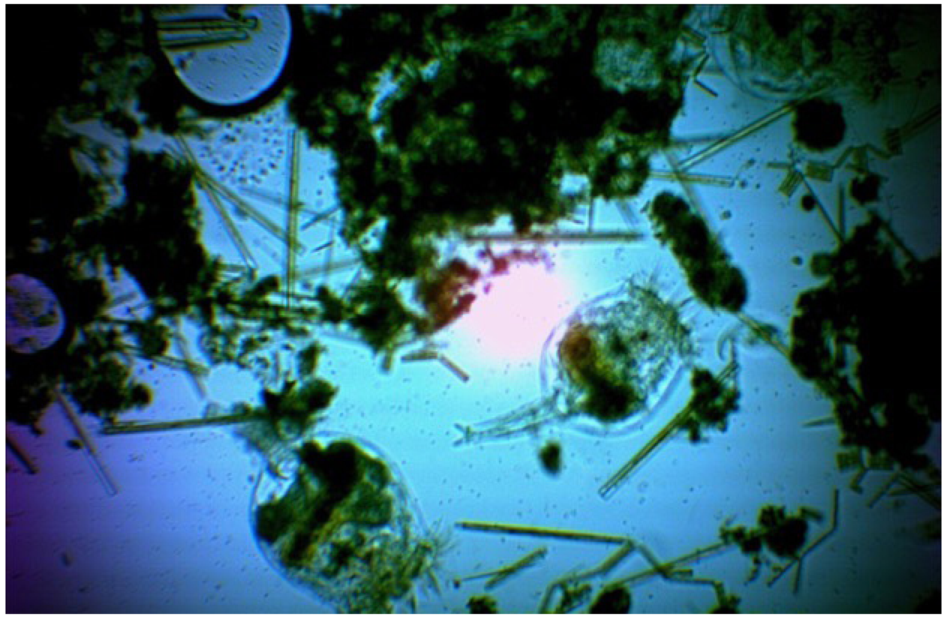
FIGURE 7. Overhead view of Minnow Pond Brush Park configuration.



periphyton. Nutrients contained within periphyton will cycle through a waterway's food web at least four times faster within the aerobic zone than within anoxic or anaerobic zones, which argues for added aeration/circulation, especially in eutrophic settings (Cunningham et al. 2010).

- A plant-like form of algae, *Chara*, naturally occurs in Fish Fry Lake and is used heavily by yellow perch, probably as security habitat. We occasionally harvest other forms of aquatic vegetation to bias in favor of *Chara*. While an indirect strategy, we believe our nurturing of *Chara* contributes to maintenance of a healthy yellow perch population, the harvest of which represents a means by which to cycle nutrients out of Fish Fry Lake.

FIGURE 8. Floating island-derived periphyton viewing with a microscope.



We employ a slot limit harvest program, where year-one, -two and -three fish are consistently harvested, while older fish are released. Year-five and older large female perch can produce as many as 65,000 eggs each, while one-tenth that number is associated with two- or three-year-old fish (Floating Island International, Inc. 2012).

On Fish Fry Lake, small bluegill up to five inches in length are caught by hook and line and turned into cut bait, then fed to black crappie and yellow perch in the form of chum. Currently, an average of 25 of these small bluegill are processed per day during the warmest six months of the year, from a single test location on the lake. Crappie and perch were conditioned to accept cut bait by blending cut bait with fathead minnows, a preferred forage species. A similar strategy has been employed to enhance growth of largemouth bass in other settings and could possibly be applied on Fish Fry Lake. Since our focus has been more on yellow perch that is a unique phosphorus-cycling form of fish and a hyper-accumulator of sorts, we are likely to stay focused on them. It is noteworthy, however, that only a handful of fish species have been tested for phosphorus accumulation, and there could be other species to consider for management.

TRACKING PHOSPHORUS

On Fish Fry Lake, phosphorus is present in groundwater infiltrating into the lake. Since there was no reasonable way to prevent the phosphorus from entering the lake, we chose to cycle it aggressively into a variety of biota which includes native, woody and perennial macrophytes grown on floating islands, fast-growing and prolific warm- and cool-water species of fish like fathead minnows, northern yellow perch, bluegill, sunfish and black crappie, other aquatic organisms like American bullfrog, native crawfish, other invertebrates, and diatom-based periphyton.

Note that biofilm in the floating islands is the base material of periphyton (Figure 8), and biofilm-generating bacteria are one of the few forms of life capable of out-competing cyanobacteria and filamentous algae for phosphorus (personal communication, Dr. Al Cunningham, Montana State University, Center for Biofilm Engineering). And further note that both these forms of phytoplankton are limited by sunlight, while a primary limitation of biofilm generators is surface area. The BioHaven floating island essentially responds to both of these factors by blocking light from the waterway while providing surface area for biofilm generating microbes.

Every living cell will contain a fraction of phosphorus, and it can be stored in sediment as well. Under some circumstances, it can be released from sediment. When this happens, it can trigger a phytoplankton bloom. To circumvent these issues on Fish Fry Lake, floating islands are used to function as biofilm reactors, and compete with the free-floating forms of phytoplankton for phosphorus. Without this, Fish Fry Lake would experience massive algae blooms, like it did before the islands were deployed. Without the islands, Fish Fry Lake would be just another eutrophic waterway poised for periodic fish kills.

Diatoms are a low-light capable form of phytoplankton, and are thought to also be a relatively stable net positive source of dissolved oxygen (Azim et al. 2005). Biofilm-based periphyton occurs on and within BioHaven matrix in the low-light setting that is beneath and within BioHaven floating islands.

WATER STEWARDSHIP REQUIRES BROAD-SPECTRUM SCIENCE

In the U.S., much of our water stewardship has been delegated to engineers. But only a fraction of engineers have accompanying life science in their educational portfolio, with biofilm engineers being one example. Fish Fry Lake has utilized both engineers and scientists. Our list of contributors includes biofilm engineers, fisheries biologists, civil engineers, horticulturists, plant and soil scientists, geomorphologists, limnologists, entomologists and environmentalists, as well as environmental engineers. The lesson is clear - no single science or engineering field is sufficient to steward a waterway optimally. And if the current movement toward "Water Resource Recovery" becomes mainstream, the blend of science with engineering will become even more fundamental.

Invention occurs across the spectrum. Design engineering, and what is gleaned from science, can come together as invention. Here at Fish Fry Lake, invention resulted in BioHaven floating islands, the airlift Floating Streambed, BioCoral, and much more (Figures 9 - 11). As an inventor, I must acknowledge that both engineering and science are fundamental. Does this mean that the creative energy around invention is a fundamental stewardship requirement? As I think back on the numerous conversations I've had with water stewards, my sense is that "yes." As we face a rapidly-changing environment, creative solutions are required.

THE FUTURE

My hope is that Fish Fry Lake inspires creativity. The idea of cycling nutrients into fish instead of algae was our starting premise. Now we are going beyond that…we are asking just what are the limits of biodiversity, beauty, and productivity for the lake? Can large waterways like Lake Erie or Chesapeake Bay also be transitioned back to health? Can this be achieved via projects that pay for themselves? Is it appropriate to consider commercialization of stewardship, which is essentially what "Water Resource Recovery" targets? Such questions represent the next phase of research and development here on Fish Fry Lake. As we consider how to cycle nonpoint-sourced orthophosphate into appropriate forms of autotrophic life like diatoms and perennial native aquatic vegetation, we must also consider nature's staircase design, which we can facilitate by incorporating two primary variables, surface area and circulation, to ensure ample heterotrophic cycling of organics. Today we have many new tools, we have the science, the engineering, and potential commercial systems. Integrating these factors and scaling up suggests that providing a green, sustainable solution for all waterways may be possible. While Fish Fry Lake is a microcosm, it will continue to serve as an experimental model targeting sustainable water resource stewardship. ■

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FIGURE 9. Pollinator islands on Fish Fry Lake exemplify a form of water resource recovery.

FIGURE 10. BioHaven streambed, where aeration and circulation through biofilm reactive surface area are combined in one system.

FIGURE 11. BioHaven floating island launched in 2004 still going strong in 2019 (photographed in year 9), Shepherd, MT.