From Phosphorus to Fish:
Beneficial Use of Excess Nutrients

Project Location: Shepherd, Montana

Fishing can be the primary method for transitioning excess nonpoint source nutrients from water, according to recent studies performed by Floating Island International (FII). This case study summarizes results of FII's patented floating treatment wetland (FTW) technology and associated lake stewardship to remove nutrients from Fish Fry Lake, a 6.5-acre lake at FII's research center, along with producing outstanding fishing opportunities. Nearly all of the phosphorus and nitrogen entering the lake from agricultural runoff is now mitigated through a moderately aggressive fish-harvesting program. The next goal is to address nutrients accumulated at the lake bottom in organic accretion.

The primary factors transforming Fish Fry Lake from a eutrophic pond to a productive fishery have been:

- Higher dissolved oxygen (DO) concentrations due to aeration and mixing;
- Lower overall water temperatures and a greatly expanded livable zone for fish due to aeration and mixing;
- Introduction of substrate to support periphyton, which provides a food source for fish; and
- Better penetration of sunlight into the water column from reduced turbidity, which enhances growth of diatom-based periphyton.

The last two factors are directly due to introduction of floating islands, while the first two are derived from features installed with the latest embodiment of floating islands.

Background

As recently as July 2008, Fish Fry Lake was a small pond with low DO concentrations, high summer water temperatures, colorful algae blooms and a small population of wild northern yellow perch. Today it supports crappie, a burgeoning population of perch and possibly the easternmost population of Yellowstone cutthroat trout. This dramatic change was made possible by:

- Deepening the pond to 28 feet and extending its reach to 6.5 acres;
- Strategically locating several aerators throughout the lake;
- Adding and growing 5,200 square feet of FTWs; and
- Introducing crappie and cutthroat.

The FTWs are a mix of BioHavens® (passive islands) and one Leviathan™ (Figure 1). The Leviathan is a new embodiment of FTW with aeration and forced circulation via an airlift directional diffuser. All islands in Fish Fry Lake, which are constructed of recycled post-consumer plastic matrix, have been planted with native vegetation.

Figure 1. Leviathan floating island in Fish Fry Lake

Over 4,400 of FII's floating islands have been launched around the planet over the past decade, with the largest (51,000 square feet) recently installed in New Zealand's Lake Rotorua. Seven other island projects exceeding 20,000 square feet have been launched in New Zealand, Singapore and the U.S. Over $3 million has been invested in research through FII, the Center for Biofilm Engineering at Montana State University and the National Institute of Water and Atmospheric Research in New Zealand. In combination with these pre-eminent research centers, FII has compiled a unique database between floating islands and fisheries enhancement.

By biomimicking nature, floating islands provide the "concentrated wetland effect" that transitions nutrients up the food chain. Instead of nutrients short-circuiting into monocultures of algae, floating islands provide substrate--the enhanced surface area that transitions nutrients from periphyton (the microbial and algae community attached to underwater surfaces) to fish (Figure 2).

Figure 2. Extensive root system for fish food and nutrient uptake

Results

Fish Fry Lake now supports a very productive perch fishery. From June through October 2011, 1,928 perch were harvested from the lake. Experienced fishermen averaged one perch every two minutes, with a typical harvest of 26 lbs/wk. On October 13, 2011, several fishermen caught 166 perch weighing a total of 35 lbs. On March 10, 2012 (shortly after ice-out), five people caught 161 fish in two hours. Two hundred fish were tagged and introduced to the lake in 2011. Six of these tagged fish were among the 161 fish caught, suggesting that about 5,400 harvestable fish now inhabit the 6.5-acre lake. Figure 3 shows a typical perch harvest in 2011.

Figure 3. Typical perch harvest at Fish Fry Lake

In the 2011 study, perch were measured and classified by age, through otolith and scale aging. Perch in Fish Fry Lake were significantly larger than perch in the 95th percentile measured in a study by Jackson and Quist:

Table 1. Comparison of Perch Sizes

	Fish Fry Lake (FFL)		Jackson Study *		FFL/Jackson
	Inches	mm	Inches	mm	Ratio
Age 1	6.7	170	5.0	126	135%
Age 2	8.7	221	7.3	186	119%
Age 3	10.8	274	9.3	236	116%
Age 4	12.5	318	10.4	264	120%

* 95th percentile data for North American yellow perch from Jackson & Quist (1991)

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Fish in Fish Fry Lake consume periphyton and organisms generated by nutrients flowing into the lake, from surface water and groundwater, and are not directly fed. In contrast, aquaculture ponds feed fish to maximize productivity. The fish yield measured at Fish Fry Lake was 26 lbs/wk or 4 lbs/acre/wk. Tilapia yield in fertilized freshwater ponds in Indonesia (Hansen et al., 1991) was measured at about 5 kg/ha/day, or 31 lbs/acre/wk. Therefore, fish yield at Fish Fry Lake is 10-20% of yield in the fertilized ponds. Yield is consistent with the inflow of nutrients, since Fish Fry Lake has about 10% of the nitrogen inflow (0.01 g $N/m^2/day$) as the fertilized ponds in the study.

Phosphorus inflow to Fish Fry Lake is estimated at 0.28 lbs/wk, based on an average concentration of 0.041 mg/L at an estimated flow of 80 gallons per minute. The average phosphorus concentration in perch is 1.0%, based on measurements by FII and other researchers. This means that the average fish harvest of 26 lbs/wk removed 0.26 lbs/wk of phosphorus. Thus, the amount of phosphorus removed via fishing was 0.26/0.28 or **93%** over the study period. In a follow-up study, FII is now tracking whether the total annual phosphorus load can be harvested during 2012.

An experienced fisherman at Fish Fry Lake can catch perch at a rate of one fish every two minutes. For the average fish weighing 0.25 lb, **3.7 hr/wk** of fishing time is required to keep up with the incoming phosphorus, and to maintain a healthy waterway (Figure 4). **This would require a fish harvest of 110 lbs/mo.**

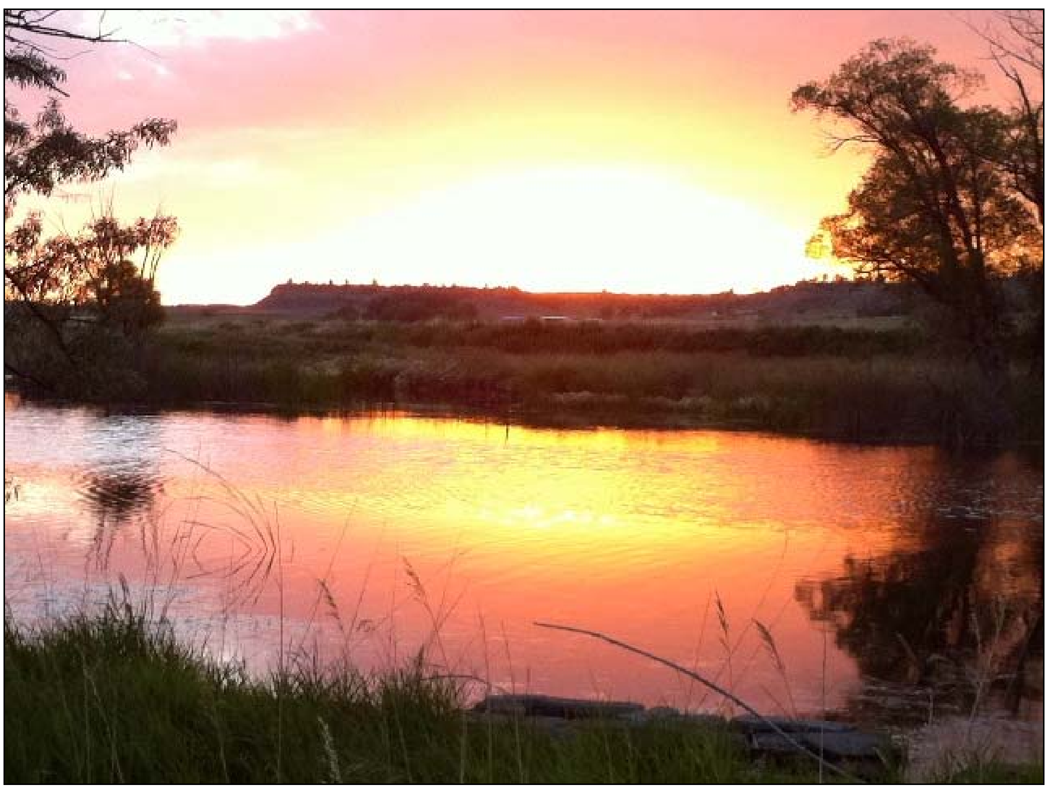

Figure 4. Sunset at Fish Fry Lake

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Water Quality Improvements

During the first 12 months after the lake was filled, water clarity averaged 14 inches via Secchi disk. Introduced substrate, the filter-like polymer matrix comprising the islands as well as plant roots that grow through the islands and their biofilm-based periphyton, reduced turbidity significantly. In December 2011, three-and-a-half years after the pond was filled, water clarity exceeded 19 feet. A summary of the water quality improvements is shown in Table 2.

Table 2. Water Quality Comparison

Parameter	**2008**	**2012**
Turbidity (Secchi depth), ft	1.2	19
Total N concentration, mg/L	0.20	0.01
Total P concentration, mg/L	0.041	0.025
DO at 15-ft. depth, mg/L	0.1	6.0
Habitable zone for fish, ft	8	21
Harvestable fish	200 (est.)	5,400

Similar waterways in the region are typically much more turbid due in part to clay colloids associated with the region's geomorphology. Another contributing factor to regional waterway turbidity has been phytoplankton blooms associated with nonpoint source nutrient loading of nitrogen and phosphorus.

Biofilm present on the island matrix mechanically removes suspended solids, including colloidals and algae that bond to it. Competition for nutrients provided by biofilm-based microbes also reduces the turbidity level associated with algae blooms. Sunlight can then energize additional oxygen and food-generating diatom-based periphyton, even at depth.

In addition to the positive effect of sunlight, laminar aeration has also contributed to higher DO levels at depth. In summary, the combination of sunlight and dissolved oxygen at depth has resulted in the natural transition of excess nutrients into fish via periphyton.

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