System Design for the Ultimate Native Fish Aquarium

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Photos by the author.

I have a problem. I live in the central-east portion of North America where we share space with part of the most diverse temperate fish fauna in the world. I know where they are and I spend most of my free time looking at them in the field. I've also discovered how easily many of these beautiful animals can be kept in aquaria, where I further enjoy their beauty and learn more about their equally diverse habits, life histories and inter-species interactions.

How is this a problem? It's a problem because I have only so many aquariums and a finite amount of space to devote to these fishes!

In the following paragraphs, I share my experiences and the lessons I've learned solving this "problem," explain the principles behind my solution, and feature the application of these principles in a 100-gallon "ultimate native fish aquarium."

The Aquarium as an Ecosystem

I've been keeping native fishes for a little over a decade, having toyed with aquaria since I was nine and being born with an all-consuming attraction to anything aquatic. The state of aquarium husbandry at the time I entered the world of North American fishes was identical to the conventional aquarium care of exotics: Tank, filter, gravel, water change, water change, water change. This worked well for native fishes evolved to the same functional niche as the popular tropical species of cyprinids, characins and cichlids I had been keeping. However, I found the specialized adaptations of some North American fishes to be more interesting, specifically the benthic insectivore darter and sucker families.

Many darter species are easily maintained by conventional means (and the addition of frozen foods). But I found that subterminal-mouthed species such as greenside darter (*Etheostoma blennioides*) and banded darter (*E. zonale*) are difficult to keep in robust shape in the presence of other fishes. In addition, I was continually servicing their aquariums to account for the excess nutrients and nitrogen that came from the heavier feedings needed to maintain even mediocre robustness. (Since other fishkeepers told me success with suckers in aquaria could be described as "dismal" at best, I overlooked this family despite my fanatical interest in them.)

In 1999, I caught the reefkeeping bug and left native fishes to explore the ecology of the reef tank promoted by Ron Shimek, Eric Borneman and Rob Toonen on the reefkeeping e-mail lists and, eventually, in hobbyist books. These gentlemen and their followers were using deep sandbeds (four inches plus) inoculated with benthic organisms (worms, mollusks, echinoderms, crustaceans) to physically turn the sand, eat the detritus (detritivores), and create a whole living substrate—in addition to using imported live rock as their primary filtration. Shimek et al. believed that the biotic processes of deep sand were just as effective at denitrification (turning nitrate into nitrogen gas, which leaves the system), if not more so, than the live rock-only "Berlin method" touted as the current solution for nitrogen removal in marine aquaria. They also argued that the shape of the small grains of sand provided a far greater surface area for bacteria and unseen film algae (biofilms) to colonize, further increasing the effectiveness of this approach.

Once established, populations of biofilms and detritivores are easily transported to other aquaria to inoculate new and sterile sandbeds and, hence, making the substrate "live." Furthermore, using a deep sandbed also frees up a great deal of space in the aquarium since the prescribed "two pounds per gallon" of live rock formula is reduced to below just a pound per gallon. (I had been using 50-60 pounds in my 125-gallon tank before I tore it down.) This leaves space for the additional uptake, habitat and filtering capacity of marine plants and macro-algae—much like hornwort, *Cabomba* and *Vallisneria* are used in freshwater aquaria. These organisms are far more responsive to assimilating changes in nutrient loads within the system than the bacteria found on hard surfaces, and they help keep unsightly micro-algae blooms in check.

In short, sandbed proponents made the same case for the aquarium that conservationists make for saving biodiversity:

The more biodiversity,
the more stable the overall system.

This idea clicked with me immediately.

How Alive is "Live"?

Early in the marine experience, I asked myself how this approach—sand, biofilms and critters moving them around—could apply to freshwater aquaria. Initially, I was discouraged from giving it a try since many freshwater detritivores have a stage in their life cycle in which they're flying away if you've been able to keep the fish from eating them. (While the prospect of an insect taking flight from my aquaria is exciting, I do have to consider the opinions of others living in the house.) As I studied different reef aquaria, I noticed something peculiar about some of the sandbeds: Little beside biofilms were present, yet the tanks seemed to be working.

In planted freshwater aquaria, the current frontier is to use SeaChem's Flourite gravel substrate, which is a high-cation exchange media good for mineral uptake in the roots of plants. The gravel, when heated by cable heaters buried within, acts as an organic compacting layer that increases decomposition and the flow of nutrients to the roots. Additionally, some aquarists inject carbon dioxide into the aquarium to provide an unlimited source of carbon for rapid plant growth and consequent nutrient uptake. This approach works, but it's expensive. Some aquarists have modified this approach to reduce costs—e.g., running the surface with no agitation to decrease gas exchange, adding Poor Man's Dosing Drops, using clay pot substrates—but these steps are for planted aquaria. I, on the other hand, am interested in *fish*.[1]

Guessing that deep sand works similarly in freshwater aquaria—that is, allowing one to maintain a large bioload by providing surface area for biofilms that reduce organic chunks into nothing—I decided to experiment. I added 120 pounds of bagged play sand from a home improvement store to the $180 worth of Flourite substrate in a 75-gallon rainbowfish aquarium, mixed it all together, and replanted the plants. The experiment worked! Three years later, the tank is still "in production" and is virtually unchanged. In fact, I've moved the tank twice without a problem. Usually, moving a tank, which interrupts the biological filter, forces you to thin out the fish, but that wasn't necessary. The tank currently holds 20 exhibit-sized rainbowfish, 25 barbs and rasboras, six loaches and 15 *Corydoras* catfish. The fish load is around two inches of fish per gallon with room for more.

Despite the great amount of food I put into the tank to reach the bottom-feeding fishes, the system requires little maintenance. I do water changes about once every two months. The water changes are large—around 30 gallons per change, or roughly half the water volume—but I have done up to 50 gallons at a time when my schedule left the system severely neglected. Water changes reduce excess and leftover nitrogen from the plants without any interruption to the biological filter. Hypothetically, I could change all the water without affecting the biological filter in any way. I have since begun adding live sandbeds to the coolers I use for collecting and storing fish on trips, and to the 10- and 5-gallon aquaria I use for educational purposes or quarantine. (Recently, I transported fish in a bucket without any living substrate and saw just how quickly the water became "slimy" compared to a bucket containing live sand.)

A caveat to this method is that the sandbed can literally "breathe" too much during the dark cycle of the photoperiod. During the light cycle, algae and plants are absorbing carbon dioxide and returning oxygen to the system. Once the lights are off, however, the plants and algae stop photosynthesizing but continue to respire, placing a burden on the oxygen budget of the system. The depletion of oxygen levels at night in planted aquaria can actually reach a point that's fatal to fish! This is easily and quickly remedied by adding an air pump and airstone to increase surface agitation and, if desired, putting the pump on a timer to run when the lights go out.[2]

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[1] As it turns out, elevating the carbon dioxide level creates a poor environment for fish because it effects the pH, and the flow of nutrients in these systems must be monitored carefully—both of which conflict with my desire to keep large captive populations of fish in a limited space.

[2] Maybe this isn't such a caveat after all. By allowing the CO_2 to increase on its own, I can do without an expensive CO_2 reactor and the chore of watching the surface level to avoid blowing off "too much" CO_2. And if I don't have enough carbon dioxide for the plants, I can always add more fish. (Wink, wink, nudge, nudge.)

Cycling Up

The extensive bioload space available in deep sand aquaria doesn't accrue overnight. You are still constrained by the rate of growth of bacteria just as you would when you "cycle up" any new aquarium. A simple way to speed the cycling process is to move existing "live" substrates into the new aquaria. These can be gravel, filter media or plants. I cycle my tanks with mulm from filters in other systems. That's right, *mulm*—the nasty brown organic gunk you find in your filters, sweep from your gravel, and ordinarily get rid of is great for cycling a tank.

Consider this experiment I ran with a 30-gallon sandbed aquarium I started from scratch in 2004. I took one cup of nearly solid mulm from a canister filter, dumped it into the new tank, mixed it within the substrate, and observed the ensuing nitrogen cycle. I wasn't able to test ammonia because it was getting consumed too quickly. Nitrite spiked from day one to day six. After that I was unable to test any nitrogen molecule by day nine, including *nitrate* (which was probably present but below the 10 ppm level the titration could effectively test). I was amazed at how fast I could jump start the entire system by using this method. I had it fully stocked with Amazonian fish—at approximately two inches of fish per gallon—by the end of the second month.

Playing with Mud

In the fall of 2003, I came across a 100-gallon open-top aquarium (no center braces) that had me drooling at the opportunity to illuminate a tank with metal halide lighting. Now I could play with the effects of light in different concentrations over different areas of the aquarium and enjoy metal halide's similarity to sunlight. Likewise, the aquarium was long and lent itself to creating riffle and plant habitats in the same aquarium. The thought of having two habitats within a single tank was exciting. Now I could watch fishes behave as they would in the wild. Maybe they would even partition by habitat niche (e.g., darters on the "riffle" substrate, minnows in the "riffle" water column, sunfish among plants, topminnows moving between patches of slower-moving water at the surface).

I was concerned that the extra PAR (Photosynthetically Available Radiation) from the higher output lighting (2 x 175 watt metal halide) would exceed the nutrient capacity of the plants and sandbed in the presence of a large fish population, and thereby cause undesirable algae and cyanobacteria to bloom. I was also concerned about the plants "browning out" since the light intensity might drive their physiology forward faster than they could uptake and transport the nutrients and minerals necessary for their growth and health. I saw this happen in my rainbowfish aquarium when I tried to light the tank using metal halide lights with the Flourite-only substrate. Although semi-enriched sand works well under fluorescent lighting, I've had difficulty getting it to compensate for the effects of additional radiation.

I recommend Diana Walstad's *Ecology of the Planted Aquarium* for anyone working with planted aquaria. The author makes a solid argument for the use of soil as a functional and desirable substrate for plant nutrient and mineral uptake. Such a technique assumes that the tank contains a moderate population of fish, which, of course, didn't complement my desire to house many different species and maintain them in robust form. So I modified Walstad's technique, placing topsoil where I wanted fast-growing, light-loving plants (such as *Vallisneria*) to take root. I saturated the topsoil with water to compress it in order keep as much of it under the sand when adding water, thereby limiting the amount of fine suspended particles clouding the tank. I then covered the topsoil and filled the remaining areas with wet sand. I used gravel to build up and retain the sand around rocks and wood.

This method has worked wonderfully. I harvest approximately one five-gallon bucket's worth of plants every two months. (It's like a water change you can sell to the local fish shop!) The water cleared within five days after set-up as the biofilms formed and locked up any remaining suspended fine silts. I've even moved the tank twice, loading the substrates in plastic storage containers and simply dumping them back in at the new location. The water cleared even faster—in less than three days. (Some silts are released when you pull rooted plants, but they're gone by the following morning.) I've even had large suckers routing through the sand and soil without disturbing any silts, and I have never even caught a hint of sulfides while in transit or operation.

Saturation Feeding

Did I just say *large suckers*? Yes, I've managed to maintain and, more impressively, *grow* seven large species of catostomids from young-of-the-year specimens. The sand bed method allows me to saturate the tank with food, providing enough for both aggressive feeders such as minnows and sunfishes, and passive or shy feeders such as suckers, subterminal-mouthed darters, trout-perch and pirate perch. Indeed, the suckers seem to benefit from being able to graze at their

Table 1. Fish species successfully maintained together in a 100-gallon aquarium featuring fishes from Ohio.

Minnows
Campostoma anomalum, central stoneroller
Clinostomus elongatus, redside dace
Clinostomus funduloides, rosyside dace
(state-threatened in OH; TN stock)
Cyprinella spiloptera, spotfin shiner
Luxilus chrysocephalus, striped shiner
Luxilus cornutus, common shiner
Lythrurus umbratilis, redfin shiner
Nocomis biguttatus, hornyhead chub
Notropis buccatus, silverjaw minnow
Notemigonus crysoleucas, golden shiner
Notropis atherinoides, emerald shiner
Notropis boops, bigeye shiner
(state-endangered in OH, TN stock)
Notropis hudsonius, spottail shiner
Notropis rubellus, rosyface shiner
Notropis stramineus, sand shiner
Notropis volucellus, mimic shiner
Phenacobuis mirabilis, suckermouth minnow
Phoxinus erythrogaster, southern redbelly dace
Pimephales notatus, bluntnose minnow
Pimephales vigilax, bullhead minnow
Pimephales promelas, fathead minnow
Rhinichthys atratulus, blacknose dace
Rhinichthys cataractae, longnose dace

Suckers
Catostomus commersonii, white sucker
Hypentelium nigricans, northern hog sucker
Minytrema melanops, spotted sucker
Moxostoma duquesnei, black redhorse
Moxostoma erythrurum, golden redhorse
Moxostoma macrolepidotum, shorthead redhorse

Catfishes
Noturus gyrinus, tadpole madtom
Noturus miurus, brindled madtom

Mudminnows
Umbra limi, central mudminnow

Pirate Perches
Aphredoderus sayanus, pirate perch
(state-endangered in OH; MI stock)

Trout-Perches
Percopsis omiscomaycus, trout-perch

Topminnows
Fundulus diaphanus menona, western banded topminnow
(state-endangered in OH; MI stock)
Fundulus notatus, blackstripe topminnow

Sunfishes
Lepomis gibbosus, pumpkinseed
Lepomis humilus, orangespotted sunfish
Lepomis megalotis peltastes, northern longear sunfish
Pomoxis nigromaculatus, black crappie

Perches
Etheostoma blennioides, greenside darter
Etheostoma caeruleum, rainbow darter
Etheostoma flabellare, fantail darter
Etheostoma nigrum, johnny darter
Etheostoma spectabile, orangethroat darter
Etheostoma variatum, variegate darter
Etheostoma zonale, banded darter
Percina caprodes, logperch
Percina maculata, blackside darter
Percina sciera, dusky darter
Percina shumardi, river darter
(state-endangered in OH; AL stock)

leisure. My approach is to feed so much frozen mysis, krill, bloodworms and brine shrimp that every fish gets stuffed and there's still food left over. Another approach is to feed pellets so the greedy minnows gorge on a less expensive food item, and then dump in the more expensive frozen foods for the suckers and darters.

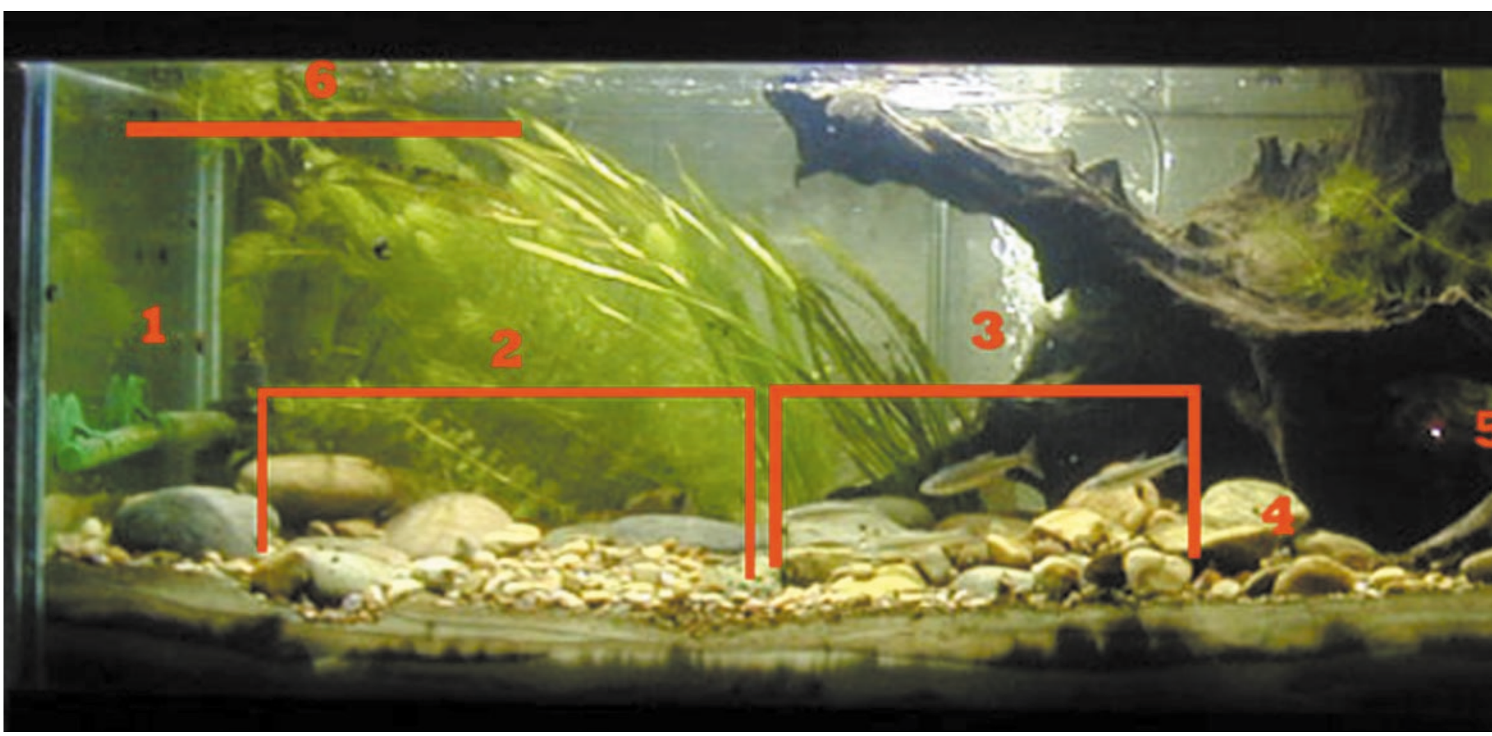
I listed the species I've successfully maintained together in Table 1. Much to my surprise, saturation feeding seems to have caused the large-mouthed species (such as hornyhead chubs and large madtom specimens) I feared would become predators to behave themselves. I did have to remove a male pumpkinseed sunfish, but this has been the only specimen that needed a behavioral "time out." I currently have a well-behaved male and female northern longear sunfish pair going through some pre-spawn motions. It will be interesting to see what happens if the male defends a nest in such a densely populated tank.

In addition to saturation feeding, I also "inoculated" the substrate with fine gravels from local streams prior to stocking the fish hoping for all sorts of invertebrate goodness. The taxa richness decreases quickly as fish are introduced, but I still find water pennies from time to time, and have had short-term success with the exotic Asiatic clam, *Corbicula fluminea*, which mixes the surface of the substrate through its filter feeding and the motion and deposition of pseudofaeces.

Circulation: the Finishing Touch

Well, we now have a box of glass with a bunch of plants and fish. What is going to make this the ultimate native fish aquarium, as promised by my title? The answer is: current! Not just some bubbly "flowing from the back filter" or "bubbling from the uplift tube" current. I'm talking raging, "comin' down the mountain" current!

I've simulated this kind of flow by outfitting a standard powerhead with an unevenly spaced hole spray bar attached to the output. I then place the apparatus at one end of the aquarium to simulate lateral stream flow. **cont. on p. 19**

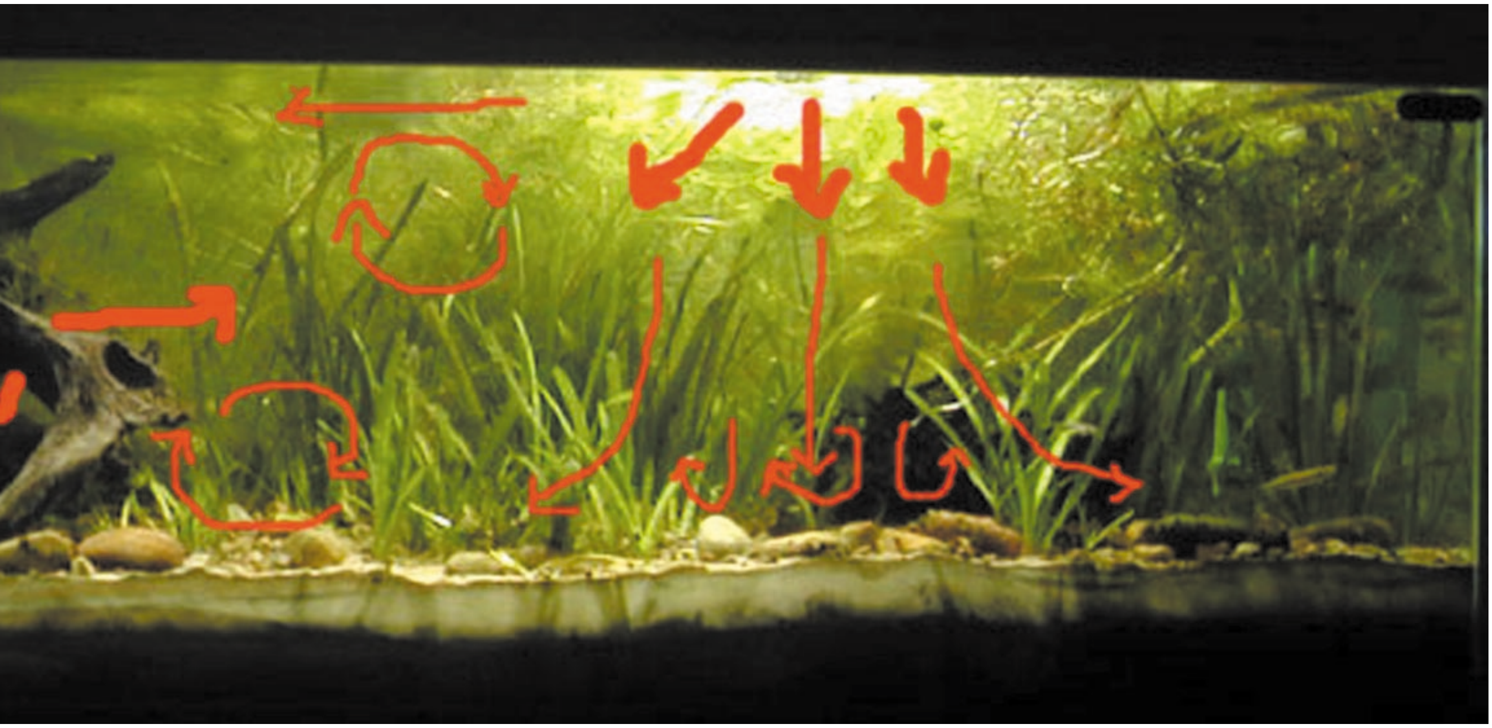


Top: Current schema. At far left, a Rio 2100 pumps into a "spray bar" I crafted out of an Eheim return line (a PVC pipe would work just fine). I drilled 1/4" holes in a random pattern to make the current as variable as possible. At right, the big descending arrows represent current from the canister filter return. The line is pointed directly down the back of the tank. The line is plugged at the end, but the plug contains a small drilled hole to let some current out across the top toward the front. This creates the little vectors swirling at the right side of the tank.

Bottom: Partitioning schema. I've always wanted to play with creating mixed habitat in a tank on a scale wherein multiple species could be observed occupying their niche in the aquarium, with multiple specimens of species able to live within that niche. I believe I have pulled this off (at least with darters).

Zone 1: Like an actual riffle, or shallow portion where rocks are exposed. Home to variegate darters, greenside darters and banded darters.

Zone 2: This is the "fun" zone, dominated by variegate



darters; they own it, defend it, and sit in the current like it's nobody's business. The larger northern hog sucker spends all of its time here. A black redhorse divides its time between here and Zone 8.

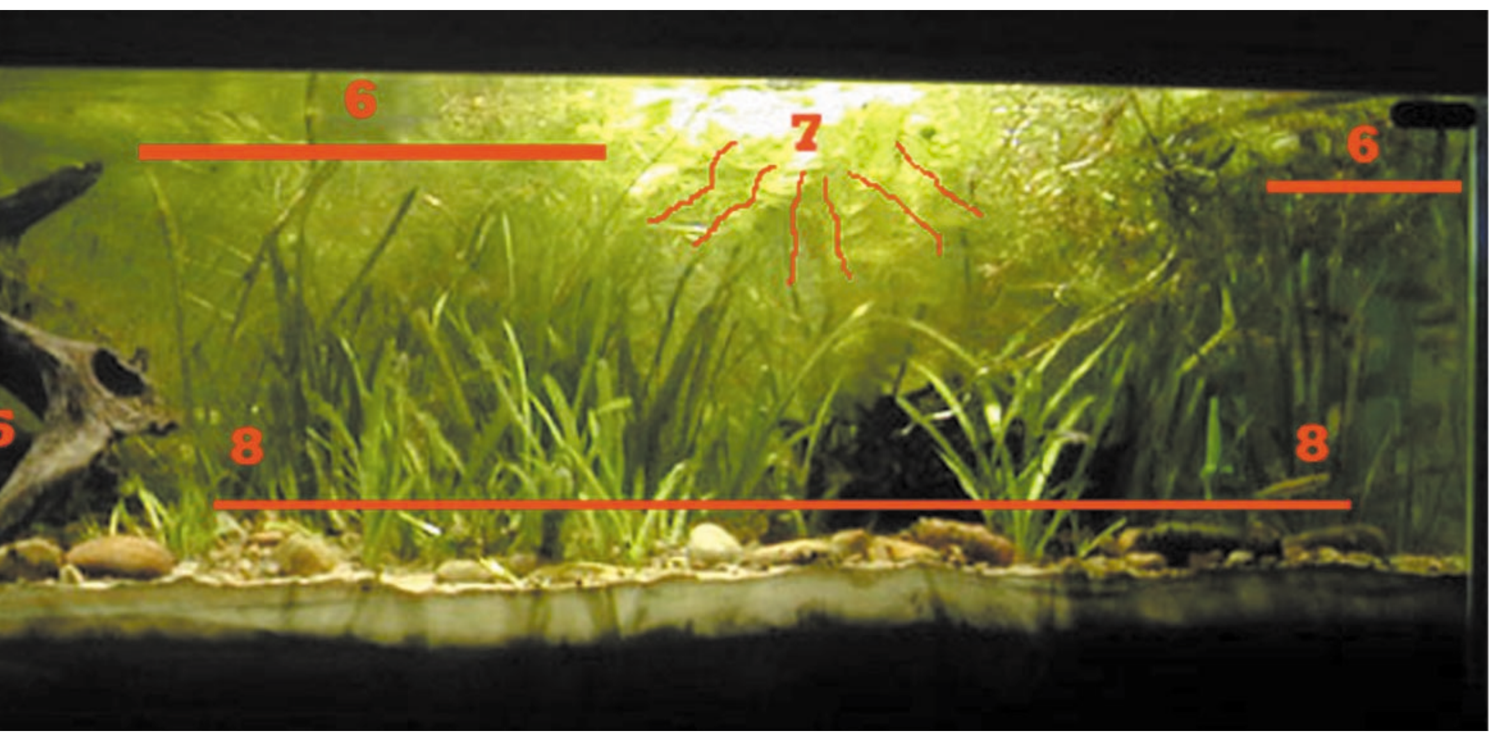
Zone 3: The minnow zone. Also home to greenside darters, large rainbow darters, and logperch. Blackside darters swim in the water column as if they're part of the minnow gang.

Zone 4: This is fantail darter country. You stop in for a visit, you're getting bit. (This includes aquarist fingers!)

Zone 5: My favorite spot in the tank. A large dusky darter sits here, in the water column, all the time. He'll investigate that piece of wood like you wouldn't believe. Smaller dusky darters spend much of their time by the wood in Zone 8.

Zones 6 and 7: The topminnow zones.

Zone 8: This is where the generalists hang out, or species found on riffles in the absence of the other darters, including orangethroat darters, johnny darters, small rainbow darters, and small dusky darters.



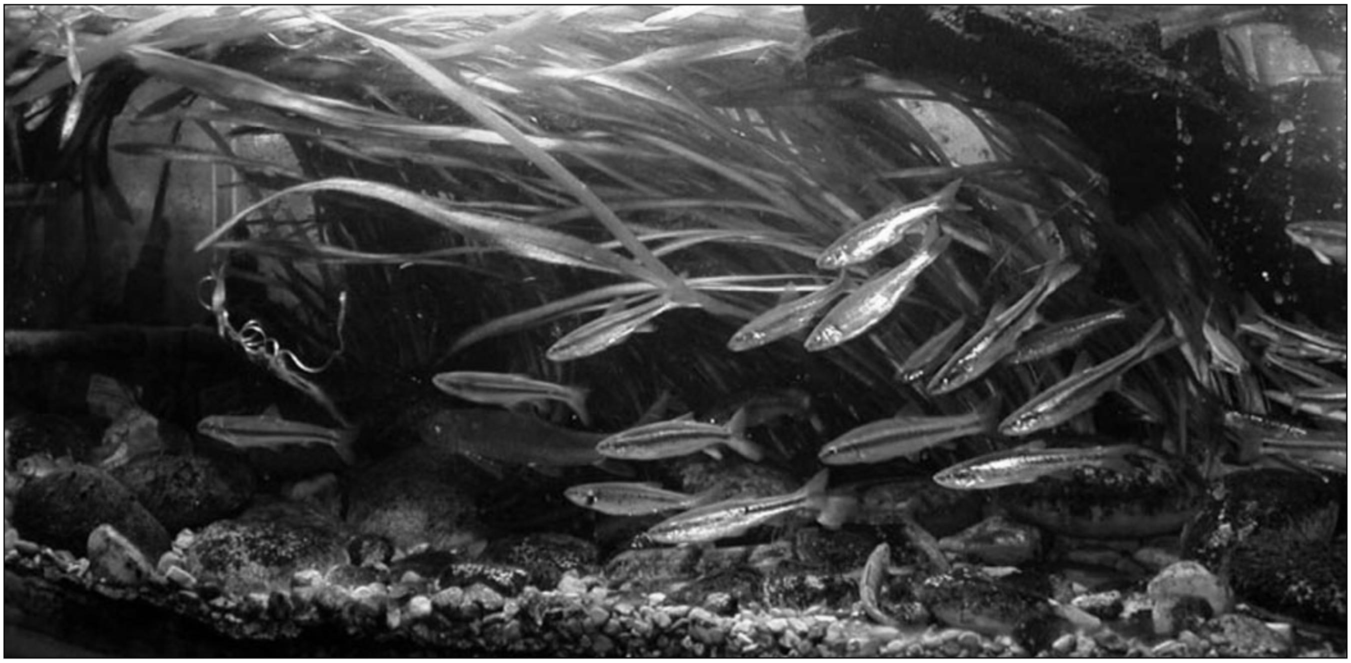


Fig. 1.
The left half of the 100-gallon "ultimate native fish aquarium" a year after set-up.

cont. from p. 16 Drilling holes at different angles along the spray bar creates a pulsing effect that looks like the real thing. You'll see microswirls, counter currents, eddies and sand blowing about. You'll be amazed at how darters and suckers "stand" in the center of the current on bare rock faces and show off for each other, and how other species find and situate themselves in the small, undetectable pockets of calm water in areas of high flow. Most importantly, you'll see the different ways in which species use the entire habitat and interact with one another.

I would argue that an aquarist hasn't truly kept a species until he or she has given it the opportunity to pick its niche and see its behavior!

Final Thoughts

As you may have noticed, I have stayed clear of specifics regarding mechanical filtration and lighting. These are complex topics that require articles of their own. I will say this: I have run my display systems using Ehiem canister filters, which I like for their ability to smash up large pieces of detritus and send them back into the system as nutrients available for plants. They certainly make a difference compared to systems I've run using only back "hang-on" filters, or systems without filtration besides sand and plants. But filters are expensive, and that expense may not be worth 15 extra fish to you as it is to me. As for lighting, I use GE Daylight Ultra bulbs, which can be found at most home improvement stores, and Venture 5500k metal halide lamps, which you can get at any online horticulture and/or hydroponics retailer.

Basically, it's up to you to figure out what you hope to accomplish with the system, find a balance between the light intensity and nutrients entering the system and how the system processed them. Remember, even a cyanobacteria-sided tank filled with green water is processing the flow of nutrients. But I doubt that anyone would call that tank an "Ultimate Aquarium."

Fig. 2.
This spotted sucker, *Minytrema melanops*, is one of six sucker species I've been able to keep–and *grow*—in my 100-gallon "ultimate native fish aquarium."