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dispatches from the wild, weird world of humanity and its biosphere

By Sam Matey

Scientist Spotlight #5: An Exclusive Interview with Dr. Theo Willis of the USM Aquaponics Lab

Dr. Theo Willis (pictured, above) is an environmental scientist and fish ecologist working at the University of Southern Maine. He is the primary administrator, coordinator, and researcher for the USM Aquaponics Lab, a veritable Aladdin's cave of biological wonders. Aquaponics is the practice of growing fish and plants in the same system, for reasons that Dr. Willis will ably explain below. The USM Aquaponics Lab is home to dozens of a particular type of cichlid known as Nile tilapia (*Oreochromis niloticus*, also pictured above). Also worthy of note when discussing the USM Aquaponics Lab is Luke Mango, a USM Environmental Science major and a friend of this writer who has devoted countless hours to assisting Dr. Willis in maintaining the aquaponics lab.

A lightly edited transcript of this exclusive interview follows. This writer's questions and remarks are in **bold**, Dr. Willis' responses are in regular type. **Bold italics** are clarifications and extra information added after the interview. For more on Dr. Willis and his work, please check out https://usm.maine.edu/environmental-science/theo-willis.

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Hi Dr. Willis! There are so many things I want to talk to you about! Let's start chronologically, if you will-why did you become a scientist specializing in fish biology and aquaponics? And what is the story of the genesis of this amazing space, the USM Aquaponics Lab, and your involvement with it?

Well, my dad had fish tanks, cichlids, when I was a kid. He'd go around between these 75-gallon tanks with fish in them, and when I was a kid I liked to see them battle over territory and for dominance. That was the beginning of my fish experience. I ended up getting an aquatic ecology degree from the University of Wisconsin at Madison, at the Center for Limnology. That was great, I enjoyed the work. Writing papers, exploring science in the outdoors, it points you in a conservation direction. I moved to Maine and started doing ecology work here, particularly on anadromous fish. I studied alewives, which are kind of like salmon in that they come out of the ocean and spawn in fresh water. ***(This is what "anadromous" means. In comparison, "catadromous," fish, like eels, live in fresh water but come out to the ocean to spawn. "Diadromous" fish encompasses both terms, denoting all fish that live primarily in either fresh or salt water but spawn in the opposite category.).*** So I was doing that work here when this opportunity popped up. A grant that came from Poland Springs came to the Environmental Science Department, and they wanted a project that would teach students something about water and water quality. Our department chair, Rob Sanford, came up with the idea to get an aquaponics system building. We got this big four-by-six bed system, two 150-gallon tanks ***(Pictured: one of the 150-gallon systems).*** And then we finagled to get some smaller 20-gallon systems, with two-by-two grow beds. And now we're up to a total of 10 systems. We got 6 more systems from the Maine Economic Improvement Fund grant to look at the sustainability aspects of aquaponics.

That is awesome, sir! Let's discuss the mechanics of the system. Could you just outline in a few words why it's helpful to keep fish and plants together? What's the flow-through here, the tank, the ammonia-to-nitrate-to plants connection, the swirl tank, and so on?

If you've ever had an aquarium, you'll know that fish will poison themselves eventually with the waste that they produce. There's ammonia in that waste, their bodies can only process so much ammonia, and they're floating in the same system. The plants need nitrogen to grow-they eat carbon dioxide, they produce oxygen, but they also need nitrogen to make amino acids. So there's kind of a logical bridge there to put the plants that need nitrogen together with the fish that need to get rid of the nitrogen. ***(For the uninitiated: ammonia is made up of one nitrogen and three hydrogen atoms, chemical formula NH_3).*** In any given system, you have your organic source of fertilizer, the fish in the system. ***(Nitrogen is the major component of most commercial fertilizers).*** That water gets pumped into a series of tanks, where we have bacteria that convert that ammonia with the nitrification process into nitrate ***(NO_3)***, a form that plants can use. The water goes then into the plant beds, where the plants take up the nitrate and use it. The plants generally can't clean the water completely on a single pass, but by having the bacteria convert the ammonia into nitrate, it also makes what's left less toxic. Fish can only handle a little bit of ammonia, but they can handle a lot of nitrate. The water circulates through over and over, it gets cleaner-that's the recirculating aquaculture part. The object is to have lots of plant biomass, so you're taking out more than the fish are putting in.

Thanks for that great explanation! So could you tell me about all the environmental parameters you measure here, the pH, the nitrates, the DO, and so on? How are you keeping the tilapia happy?

If we're concerned about ammonia, that's something we have to measure. So we measure three species of nitrogen, ammonia, nitrite (an in between species of nitrogen) and nitrate. The nitrite is converted very quickly to nitrate, and then we have a standing "pool" of nitrate that the plants can draw from. We also measured dissolved oxygen, to check that the fish can breathe. We also measure pH, which determines how much ammonia is in the system. We need to balance that. We also measure what's called carbonate hardness, the amount of buffering capacity the water has. The fish are putting ammonia into the water, the bacteria are converting ammonia to nitrate, but to take that step they need oxygen and they need alkalinity in the water, since the process produces acid. If the water has low buffering capacity, it rapidly becomes acidic, the pH gets too low. We ended up having to add calcium carbonate salts to the water to maintain a high buffering capacity, so the bacteria could do their job without poisoning themselves. We also keep track of the temperature, how much we feed the fish…that's about it.

All right! Could you tell me more about your greens output? I see some leafy greens and herbs…What species do you have here, how much are you harvesting, and where is that going?

We mostly produce lettuce here. It's mostly water, and it's resistant to some of the common pests we get. Aphids and thrips do not like lettuce, so growing lots of lettuce helps keep those pest populations on the lower side. We tried growing cucumbers, but we lost most of our cucumber crop to thrips. We also grow bell peppers-they tend to be a little on the small side but very sweet. Kale also-dinosaur kale is only so-so, but red and white grow really well. Bok choy, Asian cabbage, we grow lots of that. Arugula is kind of a struggle…We also have parsley, which chefs really like. We send most of our produce to Sodexo, the on-campus food service company. Once a week, we send them several bags of greens. Last week, we sent over three pounds of bell peppers and four pounds of lettuce.

That's awesome. Could you tell me more about the interactions between the tilapia in the tank?

Tilapia are cichlids, and cichlids are territorial. They generally have a spawning structure where one dominant male spawns with a couple of the females in the tank. In our tanks, we usually have one dominant male that's the largest fish in the tank. Sometimes they try and push the other fish off into different corners of the tank. In our smaller, 20-gallon systems, you'll have one fish taking up half of the tank, and the other fish all shoved into the other half of the tank trying to stay out of the way. This is a grow-out operation, so the idea is the largest fish are the ones that get harvested first. We haven't gotten to that point yet. If you grow a fish in a recirculating aquaculture system, you have to go through a process called a purge. You take them off food, you put them in highly circulated water, and you let them burn off the fat that accumulates some compounds they pick up that give them an earthy flavor. That takes about a week, and a special tank, but we haven't had the space to set up that tank and do the purge in yet. But when that happens, each one of these systems has anywhere from one to three fish that would be ready to be purged and harvested to be eaten.

Awesome! Could you tell me more about your polyculture experiments?

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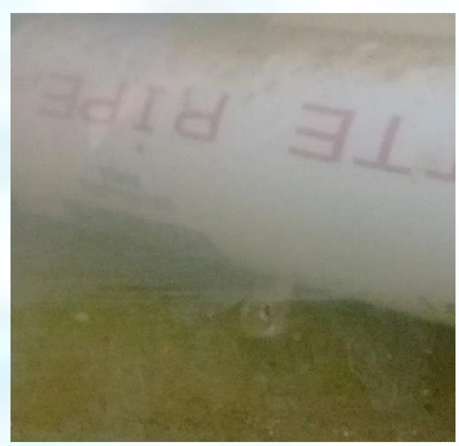
Our plan overall was to work on something called polyculture ***(growing multiple species together)***. We're already kind of doing a polyculture with the fish and the plants, but we wanted to see if we could do additional fish species or fish products. We set up tanks that were fish, freshwater Malaysian prawns, and then plants. The idea being that the prawns, since they are detritivores, could mostly persist off the waste of the fish, with some supplemental feeding, and help break down the larger solids that fish produce and increase the efficiency of our bacterial production. The problem with polycultures is that you have to be very careful about matching the tolerances of the different species. And what we didn't know was that the tolerance of prawns for nitrate was much lower than the tolerance of tilapia for nitrate. Consequently, the prawns got a bacterial infection-shell rot, or black spot disease-that slowly wiped out our prawns. The other thing we learned is that we knew prawns were cannibalistic, so we put in structures to allow them to separate themselves out to get less prawn-on-prawn mortality. That wasn't as effective as we thought. It turns out the black spot slows down the molting process, so the prawns would get stuck in their shells as they were trying to molt, and that would open them up to predation from the other prawns in the tank. That was a lesson learned. I think we started off with about 80 prawns, and now we're down to one. So now we have one very happy prawn who's in his or her own tank and gets fed every day. ***(Pictured: that very prawn).***

Speaking of unexpected stuff that happened, I believe some of the fish actually bred?



Yeah, basically, the cichlids are trying to set up their own little breeding colonies as they get older. They're mouth-brooders, so the female incubates the eggs in her mouth and then releases them when they hatch. If you're a fish that's a couple of millimeters long released into a tank of 45 adult tilapia, you're probably not going to do that well. But they're actually so small they can get sucked up by the pump, so we've actually found a couple of juveniles that have grown up in our settlement tanks, and in a couple other locations. So that was a fun little accidental discovery. We decided to put them in a tank and let them grow up and see how they do. ***(Pictured above: one of the surviving baby tilapia).***

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Could you tell me about your plans for expansion?

So, we're pretty tight in here, so we're set up in a greenhouse. We have six experimental systems, both to try out the polyculture experiment and to try out other foods. You can make fish food from different protein sources, often other fish. The fish meal component in fish food is often pretty unsustainable, since it's from wild-caught fish. But Maine has a pretty big brewing industry, so we're looking into creating a new feed from waste from that. We've also been fortunate enough to be assigned a new room, in addition to this one, that has about twice the size we have in here. So we'll be able to set up the fish food experiment there. We're thinking of introducing an intermediary, starting a black soldier fly colony and feeding the brewing waste to the black soldier flies. They'll incorporate it into their tissues and turn it into protein, and then we can mill that up into food and use it as a protein source.

That's absolutely fascinating. Is there anything else you'd like to share that I haven't covered? Anything you think our readers should know, about your work or aquaponics in general?

Aquaponics is fun to do at home, but it's ultimately an engineering problem. Figuring out whether we have enough nutrients on line for the plants, whether we're cleaning the water fast enough for the fish, are there enough bacteria in this system…A lot depends on your pumps, on the volume of water of your system, and how fast you're moving that water through the system. You need to figure out how to get solid waste out of your system. Light is a big deal-all of our systems are set up inside, so we're running LEDs that are everything from $50 full-spectrum fluorescent lamps to $1000 LED lights with white-red spectrum diodes. Different plants respond differently to those light systems. There's a lot of components-you need to check that your pipes are clear, check that there's enough water in the system because water evaporates out of your system, are you running your lights at the right intensity…There's a lot going on. ***(Pictured: the USM Aquaponics Lab).***

Dr. Willis, thank you so much for sharing your wisdom. Thank you so much for joining this interview. It's been a pleasure talking with you. Absolutely, Sam.