You're listening to Fungi Town and this is episode 13: Frogs and Fungi.

[Fungi Town theme music]

[0:00:15]Welcome to Fungi Town, where we swab salamanders, defend frogs, and combat chytrid. I'm your host and mayor of Fungi Town, Jen Parrilli. Today, we're going to talk to Dr. Taegan McMahon about vaccinating amphibians.

[wildlife sounds]
[0:00:37]What if life on this planet...just...stopped?

[ominous music]
[0:00:43]While that obviously hasn't happened yet, there have been five major events in the history of our planet when it almost did. They're called mass extinctions. The first, called the Cambrian Extinction, was about 540 million years ago and killed off trilobites and primitive marine organisms. About 100 million years later, the Ordovician-silurian Extinction, killed about 85% of life on Earth. The Devonian Extinction was about 120 million years after that. It took 70-80% of all living species. Then, about 250 million years ago, came the Permian-triassic Extinction. It was the most severe extinction the planet has ever seen and it wiped out about 90% of marine life and 70% of life on land. After that was the Triassic-Jurassic extinction event. About 200 million years ago, massive floods of lava killed land mammals, amphibians, and pretty much anything that wasn't a dinosaur. That's likely what paved the way for the dinosaurs to flourish. Finally, about 65 million years ago, was the Cretaceous-Paleogene event. That's the one that killed the dinosaurs, and about half of everything else.

Those are the five major extinctinction events that scientists believe caused dramatic changes to the evolution of life on Earth. But many are starting to refer to a sixth event. It's called the Anthropocene Extinction and it's happening right now. In the past 500 years, we've seen an estimated 25% decline in the populations of all species. 25%...that's one fourth, a whole quarter...in just the past 500 years. The "Anthropo" part of "Anthropocene," in case you're not up on your Greek root words, means "human." That means this sixth extinction event? Well, it's probably our fault.

[bats]
[0:02:49]Remember the "White on the Nose" episode, where we talked about the spread of the *Pseudogynmnoascus destructans* fungus killing north american bats? We are probably responsible for bringing that fungus over from Europe.

[cane toads]

How about the episode about Tree-of-Heaven, when we looked at a few of the invasive species that were transported to new areas and then took over, either consuming or out-competing the native wildlife? Yeah, that's us too.

[0:03:18]Another group of animals is also facing extinctions around the world. Amphibians, meaning frogs, toads, and salamanders, are animals that need water to reproduce, are cold-blooded, and can exchange gases and chemicals through their skin. Because they have such sensitive skin, they're really susceptible to contaminated habitats. Add to that habitat destruction, climate change, UV radiation, disease, predators, over-exploitation (meaning that we over-hunt them), and the pet trade, and you've got a recipe for a serious amphibian crisis.

The impact that human beings have on our environment is astounding. Whether it's habitat destruction, pollution, hunting, or climate change, the fact is that you and I are responsible for an amazing amount of damage.

But don't give up hope just yet! A great number of scientists and activists are working hard to save our planet. Maybe you're one of them. Just like Melissa Ingala and Karen Vanderwolf are working to save our bats, and Kristen Wickert is learning to combat invasive species, my guest today is working on saving the world's amphibians. We'll talk to her about hope for frogs, toads, and salamanders after the break.

[0:04:30]**Break:**

And speaking of guests, I am extremely thankful to the guests who visit Fungi Town. Despite busy schedules, they take the time to share their expertise and enthusiasm with us. So I like to show my appreciation by sending them a hand-written thank you card. Even though we live in an age of instant connectivity, it feels pretty good to get a surprise in the mailbox, something you can hold and touch, something the sender put care into. But, sappy, mass-produced grocery store greeting cards are *not* for me. That's why I order all of my notecards from Haley at Lichen Landscapes.com. Each card features a gorgeous, hand-drawn illustration of a different lichen. The cards come in packs of four different designs and are blank inside so I can customize my message. Not only can you find a variety of card sets at Lichen Landscapes.com, but you can also order Haley's beautiful lichen prints. They're a great way to show your fungi love. So get on over to Lichen Landscapes.com and discover your favorite design! And when you enter fungi town in the notes portion of your order, a percentage of your purchase will go toward supporting the Fungi Town podcast! So what are you waiting for?"

[0:05:42][Limited Perspective podcast ad]

[0:06:13]Before the break, I talked about mass extinction events, including the "anthropocene extinction," an event our planet is facing now. But there is some light in the darkness.

My name is Teagan McMahon. I am a Professor of Biology at the University of Tampa. And here I teach mainly our introductory biology classes as well as parasitology. On a research side, I study the Chytrid fungus, which is a fungus that is known to be wiping out amphibians around the world. And I study that fungus in relation to amphibians as well as the other organisms that it lives on. So things like crayfish and there's some other alternative non-amphibian hosts as well.

[0:06:59]**Can you describe the fungus that you study, the Chytrid fungus?**

TM: The Chytrid fungus is a really unique fungus. It's a fully aquatic fungus, so it lives... Out in the wild we tend to find it in fresh water bodies of water. And it is parasitic. So that means it is living and getting most of its resources from a host. And most of the time what we think of as the host are amphibians. But it's also found on things like crayfish. And it's a really funky fungus in that it produces what's called zoosporangium. This is basically a big sac that makes a bunch of little tiny mobile spores. Those spores have a flagellum, so when they come out of that zoosporangium, they swim through the water, and they can either reinfect the host that they came from, or they can infect another host. So if they're in one frog, the zoospore leaves that frog and can swim to another frog and infect that frog, or it could reinfect the one it was in. It's one of the few fungi out there that have these directionally swimming little spores that actually search out host tissue.

[0:08:12]**Say the spore comes off of a frog. Can it then go infect a salamander, or is it species specific?**

TM: For this particular species, so for *Batrachochytrium dendrobatidis* we call it *Bd*, or it's sort of generally known as the Chytrid fungus, but there are a couple different types of Chytrid fungus out there. So for *Bd* specifically, it could go between frogs, it could go into salamanders, that could then go into crayfish or vice versa. So we've found that an infected crayfish can maintain this fungus for a really long time. So the fungus will live on the crayfish and it won't kill the crayfish. But then the crayfish will shed those little spores, and they can then infect tadpoles or other frogs.

[0:08:58]**And so this fungus is just wiping out populations. Like you said, there are some that are now extinct in the wild because of this fungus?**

TM: Oh yeah, there are hundreds that have gone extinct entirely, or been extirpated, so meaning that like, a local population is completely gone. And there are some populations that are able to survive with the fungus. So bullfrogs are a good example. They're what we call super shedders. So they can live with the fungus, the fungus infects their skin, and they just are totally fine with it. They're tolerant of the fungus. And then they sit in a pond shedding zoospores and all the other things around it that are not tolerant get infected and die off.

[0:09:44]**When and how did we first notice it becoming virulent?**

TM: So there were mass amphibian die offs in the mid-1990s. So from a scientific perspective we haven't had a long time to work with this fungus and figure out what's happening. But we were seeing these huge mass die offs. And then that's when they went through and they figured out that it was this fungus. It's a group from Australia that did this work. That this fungus was covering the frogs, and that that was in fact the causal agent of this huge mass die off. And then they started noticing this one genus of frogs called *Atelopus*. And they're this absolutely gorgeous... Most of them are yellow and black striped mottled frogs. They're just really cool looking. So they're really distinctive and noticeable. And they started going extinct all over Central and South America. So there are quite a few research groups that started following, going out and looking for the populations that they've known were there for decades, and now these populations are being wiped out. So, because of that, quite a few groups, like Amphibian Ark, and the Smithsonian Tropical Research Institute, for example, Golden Frog Project went out and started collecting populations before they were wiped out by the fungus. So even though there's about, just a little over 100 species in this particular group, and about 75% of them are extinct in the wild, but many of those populations have been collected and brought into captivity and there are groups of people maintaining them in captivity in hopes that we can re-release them once we've figured out how to say vaccinate or figured out a way to make it so that reintroduction is successful.

[0:11:47]**So they might be saved by these organizations.**

TM: Yes. But it's an extreme amount of work for them to maintain these populations. And so they're maintaining, because you have to maintain a large enough population that you have good genetic diversity, as well.

[0:12:04]**I really like frogs, but some people might ask, why should I care if frogs are disappearing?**

TM: We should care if anything's disappearing because the more biodiverse, the more species we have out there, the more stable our environment is. So as we start to lose species, especially en masse like we are right now, we are losing environmental stability. Every species has a job, and there's a lot of species that do the same job for one another. But if we lose all of them, nobody's doing that job anymore. So that's a really, really scary prospect for things. So if you think about frogs, they eat a huge proportion of the insects that fly around. They eat a lot of our mosquitos, for example, they eat them as larvae, and things like that. So if we get rid of frogs we have way more mosquitoes.

[0:12:56]**Yeah, I think they've often been called the most deadly animal on the planet because they are vectors for so many deadly human related diseases.**

TM: I would argue humans are the most deadly animal on the planet, but mosquitos are pretty close up there. The other thing with frogs is that they're one of the largest sort of biomasses of

food in the environment. So not only do we eat them, but raccoons and possums, and snakes, and birds, and lizards, I mean, the list goes on and on, about things that eat frogs. So they eat them as tadpoles, or the little baby frogs, or adults. So they're a really important food resource. So if we lose frogs we lose this huge mass number of animals potentially that rely on them as their food.

[0:13:46]**So they're kind of like a keystone organism.**

TM: Yeah, in many ways.

If you take them away it kind of collapses the whole system.

TM: Right. Yeah, it's a huge impact. They're also what we call biological indicator species. So they're a species that when their populations start to go down, we know something's happening in the environment. It's like the canary in the coal mine. So, it's sort of the first clue, because they're very sensitive. It's the first clue that we have major environmental problems. And the fact that we're losing them around the entire world really says a lot about the quality of our environment right now.

[0:14:29]**And that's because they absorb so much through their skin, right? That's how we know if they're living in polluted waters?**

TM: Yeah, and they're also, because they're amphibious, meaning that they live part of their life in water, and part of their life on land, for most of them, they're impacted by everything that happens to the water, and impacted by everything that happens to the land. So they kind of have this double whammy. It's not like a fish who just lives in the water. So if you cut down all the habitat around the pond, the fish might still be okay. In this case, a frog goes back and forth between those two habitats. So it needs both to be healthy to survive.

In July 2014, Dr. McMahon published a paper in Nature, describing her efforts to develop a vaccination for frogs against the Chytrid fungus.

[0:15:17]**Okay, that kind of leads me to your publication where you worked on frogs. And in that paper you mentioned something called "learned avoidance"?**

TM: Yeah.

But how can an amphibian avoid something that's so tiny?

TM: So what we found in that paper is that if we exposed... So if you had a little plastic container, and on one side you had a moist paper towel that had the fungus, and on one side you had a moist paper towel with just water. You put the toad in the center. If the toad has never experienced the fungus before, it will just hop around the container sort of willy nilly, and there's no avoidance. So they don't avoid that side, they just move around like normal. Well, we found when we then exposed the toads to the fungus, and in the lab, we can expose them for a few weeks, and before the fungus begins to actually take a really negative toll on

their health, we can clear them of the fungus. So we can expose them for a really short period of time, and then we use heat to kill off the fungus and the frog or toad does just fine. So in this experiment we went through, we saw that they, in the beginning when they're naïve to the fungus, they just hop around all over it, no worries. But once we expose them to the fungus, they have the infection for a little while, we cleared them of it, if we put them back into one of those little choice chambers, they would avoid the side with the fungus.

[0:16:49]**How do you think they detect which side is which?**

TM: I believe it's these, basically what we call chemoreceptors in the skin. So they're little chemical receptors in their skin. So similar to how we have chemical receptors in our tongue, for example, that allow us to taste food, they have a similar sort of chemical receptor throughout their entire body, throughout all of their skin. And so they're able to detect chemicals from afar and see that, okay, I don't want to go over there. Anything that causes pain or discomfort, it's a really strong learning tool, basically. So if infection with the fungus was uncomfortable for them they're going to learn that whatever that chemical was, that taste or smell that they're getting through those chemoreceptors, that's going to tell them to avoid that thing because it was really uncomfortable last time. I sort of think about it as, so if you went to a restaurant and you had a meal, and it made you really sick, *really* sick, next time you smell the food, that same type of food, often the human brain will be like, oh no no, don't eat that. That's not for me. And even though that second batch of food in our case could be totally fine, probably, but it's a very strong behavioral response that says last time that made me sick, don't touch it again. And that same thing happens with the amphibians.

[0:18:22]**Also keeping with that paper, you suggest that fungal resistance can be encouraged through "herd immunity"?**

TM: Yeah.

Can you explain the concept of herd immunity?

TM: Yeah, so this is the same idea that we use when we vaccinate human populations against diseases. Basically the idea is that if you can vaccinate a large enough proportion of your population, then the individuals that are vaccinated and therefore not going to get the infection will help buffer the individuals that aren't vaccinated. So if you imagine a crowd of people, and a bunch of people are wearing plastic covers on them, a few people are wearing their regular work clothes, and then there's a few people with bright blue paint all over them. Those bright blue paint people would be our disease people, and the ones covered in plastic are going to be a nice barrier from the people who are dressed in their nice work clothes. So the people in the work clothes won't get blue paint on them.

[0:19:25]**So they kind of can fight off the fungus so that it doesn't reproduce in them and spread to the other frogs.**

TM: Right, so they either are a dead end, meaning that the fungus goes there and then it dies, or they just don't get infected at all. Which is, if they're fully vaccinated then the individual might not get infected at all.

[0:19:48]**How do you vaccinate a frog?**

TM: It's way easier than you would think, which is exciting. So because frogs absorb so much through their skin, what we do is we take the fungus that we grow in the lab, we use liquid nitrogen and we flash freeze it. So we kill off the fungus entirely. And any time we've done this in the lab, we've gone and checked to make sure the fungus is actually dead. So we take liquid nitrogen, freeze, and kill the fungus. And then we take that liquid with the dead fungus in it, and all of the chemicals and stuff that that fungus produces, and we just pour a little bit of that liquid on the back of the frog. We do this once a day for a couple of weeks. And that's basically our vaccination process.

[0:20:34]**So you don't give them a tiny little needle?**

TM: Nope. We just have to squirt it on their back. They absorb right through their skin. So it makes it very very easy process, and it's not very stressful or detrimental to the frogs either. So it's not like we're grabbing them and injecting them every day.

[0:20:55]**You just like, drop some water on them.**

TM: Yep.

As damaging as *Bd* is to frogs and other amphibians, it turns out that they're not the only hosts of the fungus. In 2013, Taegan published another study, about non-amphibian hosts of *Bd*.

[0:21:11]**So in that study, looking at non-amphibian hosts, you looked at crawfish and mosquito fish?**

TM: Yes.

[0:21:18]**Why did you pick those two to look at?**

TM: So, I picked those because they're both species that co-occur with amphibians all over the world. So we wanted, when looking for potential alternative hosts, like other hosts that are not amphibians, we wanted to pick groups that were found globally, and that were found to co-occur with the tadpoles and the adults very often. Because that was sort of our best guess for a group that might also get infected with the fungus. And so the other thing that went along with that is that they're both groups that are huge invaders. So they're ones that have been spread around the world. So this fungus has been spread all over as well. And so we picked two groups that have been moved by humans and other organisms into different habitats. Because it's potential that they were actually what we would call the vector of the fungus. So they were actually taking the fungus with them from the first habitat to the second habitat.

[0:22:26]**So because crayfish are transported for bait and aquariums and things like that, do you think this might help spread the fungus?**

TM: Yeah, absolutely. It's totally a potential. We did some work in farms in Louisiana, where we went out and swabbed crayfish in the farms in Louisiana and found that there were infected crayfish in those farms. So they're being maintained in these huge mass populations, I mean, Louisiana crayfish, that's a huge market. And as they get shipped around the world that fungus goes with them as well.

[0:23:05]**If I go down to Louisiana and eat a big plate of crawfish, I'm probably eating some of this fungus, right?**

TM: For sure.

But that doesn't have an effect on humans?

TM: No. So this fungus, one, it would never survive through cooking, right. And I would highly recommend to never eat raw crayfish. There are lots and lots of parasites that live in crayfish that you don't want to eat. But the fungus would never survive that heat process. But also it does not infect humans at all. So we're too warm blooded. Our bodies are just too hot all the time in order to be able to maintain that fungus. So there's no worry about it infecting us.

[0:23:53]**So if I've got this plate and I'm peeling these crayfish and I discard, the fungus is already dead, so that's not helping spread the fungus, right?**

TM: Correct. I can say though, if you bought Louisiana crawfish, I've purchased them here, in fact, we purchased some for some research. But if you bought them, you buy them in a 50 pound bag and you have a big party and there's 20 left that you didn't eat, if you release those in a pond or stream locally, wherever you lived, then you would be spreading the fungus to that new pond.

[0:24:29]**I know that there's a lot that we still need to look at, but how long do you think it might be before we have something that may be like, parks services or any federal programs can broadly apply a spray that we can give to them that they can all go out and squirt the frogs?**

TM: It'll be quite a while. I wish that I could say, oh, you know, like next week. The vaccine process that we have is very simple. But we're still in the process of figuring out whether or not it is something that can be used on many species, whether using this vaccine and spraying it in a pond would work, whether we can vaccinate the early stages or the later stages. In fact, I just received an NSF grant to do all of this work. Which is really exciting. It's really, really exciting to get a large grant to go out and ask these sorts of questions. Because it gives us a really good chance of being able to develop a vaccine campaign. If it's a potential thing, we now have the funding and ability to go out and develop it.

[0:25:36][Defunked theme music]
It's time for de-funked, a segment where I debunk fungi myths and misconceptions. While this isn't a question about fungi, there's something about frogs and toads than I've always wanted to know.

[0:25:48]**This may seem like an easy question, or a weird question, but what's the difference between a toad and a frog?**

TM: I love that question. It's kind of a language thing. So, there's no real biological difference between a toad and a frog aside from the fact that they're in two different families. So they're closely related to one another. People often say, toads that have bumpy skin and it's dry. But there are frogs that look like that, and there are toads that have smooth skin and it's wet. So it's like the difference between two different kinds of bird. Right, they're related to one another, they're really similar, but they're just two different families. It's a common name thing, though, because in Spanish they came up with a word for toad, but it was never part of the language originally. They only came up with it because we have it in English.

[0:26:50]**Okay. So they didn't have a word that differentiated between what we consider frogs and toads.**

TM: Right. They were all just, what they call rana, which would be a frog.

If I find a little hopping amphibian, how do I know it's a toad or a frog?

TM: So, good rule of thumb, though not always, if it's stuck to a wall or up on a tree, it's probably a frog. That means it's a tree frog, if it's arboreal, so living off the ground. If it's directly around the edge of a pond it's probably a frog. If it's jumping through the grasses and toads often, they have drier skin and arenbumpier, so if they're jumping through the grasses, have dry, bumpy skin, they're probably a toad.

[0:27:41]**And some toads burrow, don't they?**

TM: Yep. Yeah, and there are some frogs that burrow, too, though.

[0:27:48]That wraps up episode 13 of Fungi Town. Thanks to Dr. Taegan McMahon from the University of Tampa for sharing her expertise on frogs, fungi, and crayfish.

[0:27:59]Fungi Town is written, edited, and produced by me - Jen Parrilli and hosted by Podbean. The theme song is by local Athens band Shehehe. You can find all of their awesome songs on their BandCamp page at Shehehe.bandcamp.com. Episodes of Fungi Town are released every other week. Be sure to subscribe so you don't miss the October episodes, where I talk about fungi with a Halloween theme. You can join the conversation and share your fungi photos with Fungi Town on Facebook, Instagram, and Twitter @fungitownpod. If you'd like to contribute your version of "Fungi Town" for the show, email your mp3s to fungitownpod@gmail.com. If you're enjoying this podcast,

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