Taegan McMahon	I've always loved frogs, toads, salamanders, all amphibians. And my mother also did, she would bring us out, we didn't really have TV or anything along those lines, we spent our entire childhood running around in the woods which is awesome. And she would take us out every spring to look at amphibian populations in this local state park called Haley Farm. And so we would go out and we knew where to look for the eggs, there were all these little small ponds and we would go out every week and we'd watch the eggs develop into tadpoles and then those tadpoles develop into metamorphs, the little baby frogs and then those would grow up. And we did this my entire childhood. When I became a babysitter that was the activity I took all the kids on, so we'd all go out to Haley Farm and look for these amphibians. And then I taught special needs camps for years, we would do the same thing, bring the kids out and we'd look for the eggs.
	Now as an adult when I go back, the amphibians are not there. You'll see periodically adults but we just don't see the babies, you don't see the eggs, and so they're probably there, they're just deeper in the pond or further out into the woods but the populations are not what they used to be when I was younger. And it's really sad because there's something about going out into the environment and finding a frog in the woods that really fosters a love for that place, like Haley Farm is one of those really special places for me and I think for a lot of people. And now that we can't find the eggs, kids aren't growing up in those state parks finding frogs, they're not finding the eggs, they're not trying to catch frogs which was a huge part of my childhood growing up and I think it was a huge part of what made me become a conservation disease ecologist because I loved that when I was younger and it's just not a thing anymore for kids.
TPWKY	(This Podcast Will Kill You intro theme)
Erin Welsh	Hi, I'm Erin Welsh.
Erin Allmann Updyke	And I'm Erin Allmann Updyke.
Erin Welsh	And this is This Podcast Will Kill You.
Erin Allmann Updyke	Today we're talking about-
Erin Welsh	Chytrid!
Erin Allmann Updyke	Chytrid!
Erin Welsh	Yes.
Erin Allmann Updyke	And you just heard a fabulous firsthand account of some of the terrible effects that chytrid has had on amphibian communities by our friend Taegan McMahon, Dr. Taegan McMahon, I should introduce her properly.
Erin Welsh	And you will hear more from her later in the episode because she was so kind as to share some of her expert experience and knowledge on the subject so we didn't have to do as much work.
Erin Allmann Updyke	Yes!
Erin Welsh	Just kidding. (laughs)
Erin Allmann Updyke	(laughs) No, not kidding though. At least I didn't have to.

Erin Welsh	Only kind of kidding, yeah. But before we get there we have one very important thing to do.
Erin Allmann Updyke	We do.
Erin Welsh	And that means it's quarantini time.
Erin Allmann Updyke	Quarantini time!
Erin Welsh	What are we drinking this week?
Erin Allmann Updyke	Today we're drinking simple Croaked.
Erin Welsh	We shouldn't be laughing at this.
Erin Allmann Updyke	It's not funny.
Erin Welsh	It's not funny.
Erin Allmann Updyke	But it's punny.
Erin Welsh	I'm tickled at the name. What's in Croaked?
Erin Allmann Updyke	There is mango puree, a bit of lime juice, some bubbly fizz water, and rum of course.
Erin Welsh	Delicious. Ron Abuelo if you can grab it.
Erin Allmann Updyke	And the key ingredient in this particular beverage is just a few sprinkles of chia seeds.
Erin Welsh	To look like frog eggs! I love it.
Erin Allmann Updyke	(laughs) You guys. We'll post the full recipe for this quarantini as well as our nonalcoholic placeborita on our website and all of our social media channels so you can find them there. Do we have any business, Erin?
Erin Welsh	I don't think so. We have merch.
Erin Allmann Updyke	We have merch.
Erin Welsh	Go look at it.
Erin Allmann Updyke	You can find our merch at our website thispodcastwillkillyou.com by clicking on MERCH and we've got T-shirts and mugs and pins and the most important of all-
Erin Welsh	Soap.
Erin Allmann Updyke	Soap.
Erin Welsh	That's right.

Erin Allmann Updyke	It smells so good. I have a bar in my bathroom right now and every time that I walk in there I'm like what smells so good? And it's soap every single time. Legitimately.
Erin Welsh	It's amazing, yeah.
Erin Allmann Updyke	It makes the whole bathroom smell good. I didn't know soap could do that.
Erin Welsh	Packaging's incredible. Okay.
Erin Allmann Updyke	Okay.
Erin Welsh	So.
Erin Allmann Updyke	Enough of that.
Erin Welsh	All right. Chytrid biology.
Erin Allmann Updyke	Chytrid.
Erin Welsh	Hit me with it.
Erin Allmann Updyke	I'll hit you with it in just a minute.
TPWKY	(transition theme)
Erin Allmann Updyke	Okay, so listen. Chytrid first off is a fungus.
Erin Welsh	Our first fungus.
Erin Allmann Updyke	Our first fungus. We briefly talked about fungi on The Biology of Superheroes Podcast, right?
Erin Welsh	That's right, we talked about Cordyceps.
Erin Allmann Updyke	Cordyceps, mm-hmm. Okay but this is our first foray into the fungi.
Erin Welsh	Yay.
Erin Allmann Updyke	So let's talk about this fungus itself first. The fungus that causes the disease known as chytridiomycosis in amphibians is called Batrachochytrium dendrobatidis.
Erin Welsh	I'm glad that you attempted that because-
Erin Allmann Updyke	I looked it up and I wrote out a phonetic spelling for myself in my notes.
Erin Welsh	Can you quickly send that over to me because I need to do it later.
Erin Allmann Updyke	Yeah.

Erin Welsh	Okay.
Erin Allmann Updyke	Batrachochytrium dendrobatidis.
Erin Welsh	Okay. We'll cross that bridge when we get to it.
Erin Allmann Updyke	You could call it Bd.
Erin Welsh	And I do.
Erin Allmann Updyke	Okay. And I really hope that this isn't stepping on your history toes too much Erin but I texted you about this because I got so excited and it blew my mind so much because we just did Giardia - which I said correctly.
Erin Welsh	No you didn't.
Erin Allmann Updyke	Giardia, I did.
Erin Welsh	(laughs)
Erin Allmann Updyke	And it blew my mind in that episode that that parasite wasn't fully classified until the late 80s, right. Bd wasn't described as a species until 1999.
Erin Welsh	Yeah.
Erin Allmann Updyke	What?
Erin Welsh	Yeah.
Erin Allmann Updyke	Oh my gosh! I did not know that at all, it was thrilling information.
Erin Welsh	Yeah, it's amazing.
Erin Allmann Updyke	And there's another species that infects salamanders, Batrachochytrium salamandrivorans that was described in 2013.
Erin Welsh	Uh huh.
Erin Allmann Updyke	Oh my gosh.
Erin Welsh	The history is still being written, that's for sure.
Erin Allmann Updyke	Oh big time. Okay so this is a fungus, we'll call it Bd or probably a lot of times through this episode we might just call it chytrid but I do wanna point out that there's a lot of other fungi in the group known as chytridiomycota. So even though we'll be probably bad biologists and call it chytrid, I might slip up and call it chytrid, there are a number of different other chytrid fungi many of which are free-living and happily exist in the environment, digesting cellulose and chitin and keratin, ding-ding-ding, that word's gonna come back.

Erin Welsh	Oh good.
Erin Allmann Updyke	Other chytrids are parasitic on plants or algae or other invertebrates but the one that we're focusing on today is the only I guess two species Bd and B. sal that are known to infect vertebrates, specifically amphibians. Okay. So today we're talking about an amphibian fungus. Fungi have very cool life cycles in general and chytrid, chytridiomycota fungi are no exception. They have two life stages: the zoospore and the zoosporangium. So the zoospore is like a spore so it travels through the environment, that's the point of it and it happens to have an adorable little flagellum and it can swim. So the zoospore stage swims through water, it doesn't go very far, we're talking like a few centimeters but it does swim and it responds to chemotactic signals, so it actually can swim directionally towards a host, in this case an amphibian. When it finds an amphibian it releases a bunch of proteolytic enzymes, so it releases a bunch of stuff that digests that protein on the skin of the amphibian and then it burrows its way into the skin of this, let's call it frog.
Erin Welsh	What cues is it using to find the host?
Erin Allmann Updyke	That's a good question that I don't entirely know the answer to. It's a really good question. But they know that it's not just swimming at random, it swims directionally towards the frogs.
Erin Welsh	Right. Right.
Erin Allmann Updyke	But I'm not sure what about the frogs, like what are they releasing that they're swimming towards. Great question. So once it's at the frog, it burrows its way into the skin, it's forms a little cyst, and then it forms the sessile or the non-motile stage, the zoosporangia underneath the skin of this little frog. That zoosporangia will grow and then produce additional zoospores which will burst forth from the skin and swim along their way. And those zoospores can either reinfect the same host in a new spot or if they're close enough to another frog, they can infect a new host. Ta-da! Life cycle complete.
Erin Welsh	And about how long is this all taking place?
Erin Allmann Updyke	Oh gosh, well I know that the incubation period from when the zoospore first infects to when the frogs start showing symptoms are between 10-18 days.
Erin Welsh	Okay.
Erin Allmann Updyke	So my guess is that that's about the timeframe that it takes for them to start shedding.
Erin Welsh	And I would assume it's variable depending on frog species and temperature, or amphibian species and temperature and etc etc?
Erin Allmann Updyke	Very variable.
Erin Welsh	Yeah.
Erin Allmann Updyke	Okay so let's talk about the symptoms of a chytrid, chytridiomycosis infection.
Erin Welsh	This is gonna make me sad.

Erin Allmann Updyke	It's so sad, it hit me in the feels this one. So you can tell by the way that I described the life cycle that this fungus, it's pretty much just infecting the skin of these amphibians. So human listeners might be thinking something along the lines of how can a simple skin infection be so detrimental to an amphibian, it's just skin? Do you think anyone would say that? Maybe they would.
Erin Welsh	I don't know.
Erin Allmann Updyke	But for anyone who's not familiar with frogs and amphibians, their skin is not just a barrier between the frog and the outside world, it's not for us either but in frogs it's an especially important organ, it's part of how frogs breathe, it's part of how they hydrate, how they thermoregulate, how they osmoregulate, so it's a very critical organ. Okay. So any kind of skin infection in a frog you can assume is gonna be bad news bears and that is very true in chytrid. However because Bd, chytrid can infect so many different species of amphibians, the symptoms really do vary a lot based on the specie and how serious the infection is varies hugely across species and actually Taegan will talk a little bit more about that because we don't fully understand why it is that some species seem to handle infection so much better than other species.
Erin Welsh	Mm-hmm.
Erin Allmann Updyke	But we can talk about some of the generalized symptoms that you see in a chytridiomycosis infection. First off what's very interesting is that you don't see a lot of inflammation. So the frogs themselves aren't mounting a big inflammatory response when they get infected with this fungus. But what you do get is something called hyperkeratosis which means that you're making a whole bunch more keratin which is kind of the protective protein that we have in our skin as well. It's the toughest outermost layer of skin which for a frog because their skin has to be able to interact with the environment so much, this is especially bad because that means that this thick, extra keratinized layer is not gonna be as permeable to water or air or electrolytes.
Erin Welsh	That's really interesting, I didn't know that. Wow.
Erin Allmann Updyke	Yeah. I didn't either. Yeah. And then what you also get very, very commonly is sloughing of the skin. So the skin will just start to slough off in sheets which is really sad. You can get ulceration and multiple cyst formation but you don't always. The skin sloughing is kind of more common than this ulceration formation. Often also the skin will become very discolored. So you might've seen classic photos of frogs infected with chytrid that are bright red on their bellies and their legs.
Erin Welsh	Yeah.
Erin Allmann Updyke	So that's really common is for their bellies to become discolored. And it's also very common that they get infected at the highest rates or the most intense infection on their bellies and their legs, like the undersides which to me kind of makes sense because this is a fungus that's in the environment and in the water specifically so that's kind of the part of the frog that's in contact with water the most and in contact with the soil the most, right. But it can infect any part, any keratinized part of the frog.
Erin Welsh	But does the infection tend to be localized in that way or is it pretty much systemic at a point?
Erin Allmann Updyke	Well that's an interesting question. So it's not systemic in that it doesn't travel throughout their body.

Erin Welsh	Okay, right.
Erin Allmann Updyke	This is a very localized skin infection. The zoosporangia can produce these - I don't know if rhizomes is the proper word but they can sort of spread out a bit where they infect. But really they also just produce a lot of spores that auto-infect that same host on our parts of the skin.
Erin Welsh	Okay.
Erin Allmann Updyke	So you end up with really high burdens of infection where you have spores infecting all over the skin. But it doesn't travel through their bloodstream, it doesn't invade their organs, etc. And I'm gonna talk a little bit more about that in a minute cause it's a really interesting part of the story.
Erin Welsh	Yeah.
Erin Allmann Updyke	Yeah. So any and all parts of the skin can get infected. And then what you see happening in addition to all these skin changes is that the frogs become very lethargic. They stop seeking protection, they stop hiding during the day so you can find them just sitting out and about, they're less responsive to stimuli so if you try and get them jump or do something, they just kind of don't, they just don't really respond. And they can sit in a very kind of characteristic position where they're sitting out and their hind legs, their jumper legs are not poised underneath them like a frog ought to be, like ready to bounce at any second. They hang there kind of loose and gangly and they hold them away from their body. Isn't that sad?
Erin Welsh	It's really sad.
Erin Allmann Updyke	Just this little loose like wamp-wamp of a frog.
Erin Welsh	Just no willingness to live or ability.
Erin Allmann Updyke	Yeah. And then they die.
Erin Welsh	Yeah.
Erin Allmann Updyke	Sorry. There's no easy way to say that. So then they die. And what's interesting is that one very common cause of death is actually heart attack, tiny little froggy heart attack.
Erin Welsh	Is this because they can't regulate water?
Erin Allmann Updyke	Ooh look at you Erin, you're so smart.
Erin Welsh	What? (laughs)

Erin Allmann Updyke	Yeah. So again, this is an infection that's not actually invading any organs in general, it can in some cases but in general it's just in the outermost layer of this frog's skin. And so we don't fully understand exactly how this disease ends up killing frogs but what it does seem to do according to a 2018 paper that I found is that it causes widespread metabolic imbalance. So the electrolytes of the frogs get completely messed up because they're not able to osmoregulate through their skin like they're supposed to, they can't regulate the water and electrolytes moving in and out of their skin. And when that happens, other organs can get messed up so then other important metabolites that your body would normally produce, like say your liver would normally produce these certain metabolites, the liver can't do that because the other electrolytes are so messed up. Does that make sense?
Erin Welsh	Yeah.
Erin Allmann Updyke	So while chytrid itself doesn't invade frogs' livers or hearts, the osmotic deregulation that it causes just by infecting the skin to such a degree ends up affecting processes in their internal organs and that's what ends up causing death.
Erin Welsh	That makes sense and horrible, sad sense, yeah.
Erin Allmann Updyke	Horrible and sad. And it was really interesting to sort of do the research on this because it's so recent because a lot of times when I'm trying to figure out what's the pathophysiology of a disease I just find a paper that's relatively recent like the last 20 years and they've got pretty much an answer. But in this one if you go back just 5 or 10 years, it's all 'here's our hypothesis', 'here's the best guess we have'. And so it's only from these really, really recent papers, like this 2018 paper which I will post on our website where they actually found sort of evidence. Cause it's still not entirely clear how this happens but there is good evidence for this widespread electrolyte imbalance.
Erin Welsh	I would bet that that's also just also a factor of it being a wildlife disease vs a human disease.
Erin Allmann Updyke	Definitely, definitely.
Erin Welsh	Funding, research, etc etc.
Erin Allmann Updyke	Right. And another thing I noticed is that so much of what we study in wildlife diseases compared to human diseases is all population level rather than individual levels.
Erin Welsh	Yeah.
Erin Allmann Updyke	So like the disease process that's happening inside each individual frog is not studied to the same extent as a disease in humans might be if that makes sense.
Erin Welsh	Right. We lack the case studies in wildlife disease cases.
Erin Allmann Updyke	Yeah, exactly.
Erin Welsh	Yeah.

Erin Allmann Updyke	Yeah. So that's pretty much the biology. The other thing I did wanna say that I think is interesting is that Bd, chytrid, amphibian chytrid, only infects keratinized epithelium. So that means that actually tadpoles aren't infected. So tadpoles actually can survive in areas that have Bd. The only part of a tadpole that has keratin is the mouth parts so that's the only part that Bd can potentially infect. But then as soon as a tadpole starts to undergo metamorphosis, as soon as they start to change into adults then they've got that keratin, then they can be infected.
Erin Welsh	Okay.
Erin Allmann Updyke	So even really early, early frogs but just not tadpoles specifically.
Erin Welsh	Right.
Erin Allmann Updyke	But what's also very interesting is that a lot of free-living chytrid fungus also feeds on keratin. And so it's hypothesized that that's exactly what this fungus is feeding on in the frogs and it's interesting that it's causing this hyperkeratotic response where the frogs, they're not mounting an immune response, they're not coming in and fighting off this infection but rather they're making more and more keratin and that's potentially what this fungus is feeding on.
Erin Welsh	Yeah.
Erin Allmann Updyke	So it's like this fungus is creating the optimum environment for itself to survive in this frog.
Erin Welsh	Right. I mean it's ingenious.
Erin Allmann Updyke	Yeah, I know.
Erin Welsh	What else is keratin... Tell me more about keratin.
Erin Allmann Updyke	So keratin is a protein, it's all of our skin, like any skin that you see, it's all keratinized. You're hair is keratin, your nails are keratin, it's a protein, it's like a very tough outer protein. So our skin as it grows and moves from the basal layers and then it moves up, it becomes keratinized so that by the time that it reaches our outside environment, it's like completely just mostly keratin, there's not really any cell left.
Erin Welsh	So why amphibians and not other animals?
Erin Allmann Updyke	Great question. It's a really good question. I'm sure that it's not the exact same keratin, there's a lot of different types of keratin.
Erin Welsh	Okay.
Erin Allmann Updyke	So it might just be that they can infest a very specific form of keratin. That's a really good question though. Yeah.
Erin Welsh	Interesting.
Erin Allmann Updyke	Yeah! So that's the biology.
Erin Welsh	Oh.

Erin Allmann Updyke	That's was it, what do you think?
Erin Welsh	That was great.
Erin Allmann Updyke	It was so fun to learn about. I knew nothing about chytrid coming into this.
Erin Welsh	Oh yeah, no. I knew nothing except sort of like the broad sweeps of it. It's really bad.
Erin Allmann Updyke	Right. Like I knew it's real bad for frogs and it's causing widespread havoc and I've seen pictures of ponds where chytrid is, you know all these dead frogs. That's all that I knew.
Erin Welsh	Yeah.
Erin Allmann Updyke	Oh so Erin, tell me how did we get here. What's the history of this thing?
Erin Welsh	Okay I'll see what I can do.
Erin Allmann Updyke	Right after this break.
TPWKY	(transition theme)
Erin Welsh	In the 1980s all over the world, the forest started to go silent.
Erin Allmann Updyke	Oh no.
Erin Welsh	It's started to become static, still. This was not the vibrant, dynamic forest that we were used to. Something, many somethings were missing and it didn't go unnoticed. Herpetologists across different continents began talking amongst themselves. Where have the frogs gone? Where have the salamanders gone? Where have the toads gone? Where there used to be untold numbers of frogs, toads, salamanders, amphibians, now there were none. Even stranger were the circumstances of this sudden disappearance. Amphibians were going missing in habitats of all kinds from urban streams to remote, highly protected conservation regions and often there were no bodies to be found.
Erin Allmann Updyke	What?
Erin Welsh	Yeah, they just sort of disappeared which makes sense.
Erin Allmann Updyke	Okay.
Erin Welsh	In other places the sad carcasses of amphibians piled up which was in itself maybe even more bizarre because in places like the tropics something as small as a frog can be quickly dismantled by ants or dispatched by a bird within a matter of minutes or hours. So the sight of these corpses was maybe even more worrying than their absence. What could be causing such widespread devastation? Climate change, habitat destruction, environmental toxins, and infectious diseases were all the immediate culprits. Finding out what was causing these amphibians die-offs was top priority if there was any hope of saving even some of the species. Extinction happens but not often like this. This is probably the largest extinction event that modern humans have been witness to so far.

Erin Allmann Updyke	Wow.
Erin Welsh	Maybe this is pessimistic of me but I don't think it'll be the last one we see in our lifetime.
Erin Allmann Updyke	Wah-wah. You're probably right.
Erin Welsh	Yeah. Let's talk about amphibians.
Erin Allmann Updyke	Okay.
Erin Welsh	What does the word 'amphibian' mean?
Erin Allmann Updyke	Oh, good question. Tell me.
Erin Welsh	It comes from the Greek for 'double life' which is a nod to their close dependence on water and moisture and sort of their transformation over their life cycle.
Erin Allmann Updyke	Cool.
Erin Welsh	Many species of amphibians need water to complete their life cycle. Tadpoles swimming around in little ponds, stuff like that. But that's not the only way that eggs develop into tadpoles and then frogs. So frog eggs and amphibian eggs don't have a hard shell like that of a bird so they have to be kept moist or they'll dry out. Frogs can do that by laying them in streams or ponds or temporary pools but some will make their own little foam nest to lay eggs, some carry the eggs around on their backs or on their legs, and some carry their eggs in their stomachs, eventually giving birth to little frogs out of their mouths.
Erin Allmann Updyke	Oh my god it's so cute.
Erin Welsh	Or at least they used to because the two species that did this stomach brooding went extinct in the 1980s and haven't been seen since.
Erin Allmann Updyke	Ugh.
Erin Welsh	I know it was cruel of me.
Erin Allmann Updyke	That was really cruel, are there any in captivity?
Erin Welsh	No.
Erin Allmann Updyke	Ugh.
Erin Welsh	Yeah. As of July 16th, 2019 when we're recording this episode, there are 8043 species of amphibians and that includes frogs, toads, salamanders, and caecilians which don't have any limbs and kind of look like giant worms or very slippery small snakes. They're kinda cute in a weird way, kinda creepy cute. I don't know. Frogs and toads make up the biggest chunk of this and new species of amphibians are being discovered all the time, all the time. So of these over 8000 amphibian species, 501 which is around 6.5% have faced serious declines due to chytrid with at least 90, possibly 122 confirmed or presumed to be extinct in the wild.

Erin Allmann Updyke	God dang.
Erin Welsh	Over the course of a couple of decades.
Erin Allmann Updyke	Right.
Erin Welsh	According to the authors of one of the papers I read, we are witnessing quote, "the most spectacular loss of vertebrate biodiversity due to disease in recorded history."
Erin Allmann Updyke	Wow.
Erin Welsh	It's unprecedented for us to observe.
Erin Allmann Updyke	Yeah. Right.
Erin Welsh	Amphibians have been around since before there were humans, before there were mammals, before there were dinosaurs. There are amphibian species on all continents except Antarctica. There are species that live in the desert like the sandhill frog of Australia, ones that live on mountains, ones that live in rainforests, ones that live above the Arctic Circle like the wood frog.
Erin Allmann Updyke	What?
Erin Welsh	Yeah!
Erin Allmann Updyke	Oh yeah, I knew that. But it's still crazy.
Erin Welsh	Ones that literally freeze solid during winter and emerge again in the spring, little spring peepers.
Erin Allmann Updyke	Wow.
Erin Welsh	The diversity of amphibians is amazing and they're survivors, they have gone through massive extinction events and lived to tell about it. But their long and incredible existence may be coming to an end and the biggest reason is us, humans. It's maybe a bit difficult to say exactly when the great decline of amphibians began but I can tell you when it started to be noticed at least and that was in the 1980s. And similar to how Taegan described, it was a pretty drastic shift. Researchers were coming back empty-handed from collecting trips where they once could barely avoid stepping on frogs. Amphibian populations had been declining over the past century due to things like over-hunting, habitat destruction, etc but it was the recognition that it was happening globally and rapidly that really caught scientists' attention. In September 1989 the first World Congress of Herpetology led to a massive gathering of herpetologists from all over the world.
Erin Allmann Updyke	(laughs) Just imagine that room, man.
Erin Welsh	Herpetologists are some of the coolest people ever.
Erin Allmann Updyke	I was just thinking, I was saying this to myself when I was researching this. I was like of all of the ornithologists, entomologists, herpetologists, ichthyologists, I feel like herpetologists, I would go to that international congress, that's what I'm saying.

Erin Welsh	I think it would be the most fun.
Erin Allmann Updyke	It would be pretty fun.
Erin Welsh	I feel like they know how to party but I don't know. (laughs) So at this conference, at this World Congress of Herpetology researchers there began to talk amongst themselves about like, 'Oh yeah, I really had a hard time finding my study species this year.' And someone would be like, 'Oh, me too but I was doing research in this other country, this other continent.' And so one instance of not being able to locate your study organism might not be that surprising because fieldwork is unpredictable and sometimes the animals you want to find aren't where you expect to find them and that just happens. But this was that times 1000. Researcher after researcher had a story about the unexpected disappearance of their study species and people started to pick up on these not being isolated events but part of maybe a larger crisis, one that was taking place across the entire globe.
	And after this congress, herpetologists wasted no time, they got right into action, they started holding workshops to present the most likely causes of the amphibian decline and then they proposed a plan of action to save the frogs. So this plan had basically three focuses. 1: save the amphibians. Conservation. 2: Find out what was killing them. Investigation. And 3: Tell people about it. Education. Cause unless you get people who are not researchers interested and passionate about this subject it's going to be an uphill battle even more than it already is.
Erin Allmann Updyke	Absolutely.
Erin Welsh	So to have any shot at long term success with conservation, scientists had to get work on uncovering what was causing this rapid decline. What were the clues left behind? The first was that species that were suffering were the most similar ecologically. They bred or lived near streams or other water sources and had to spend a significant amount of their lives in contact with water. The second was that it was happening rapidly but still in a wave-like pattern, it would start in one geographic area and then go upwards directionally or go in some direction. The third was the rate of decline which was super fast, really fast. Within a few years the population went from normal or at least what maybe could be perceived as normal to empty, done, extinct. The fourth was in the bodies of the amphibians themselves. So in this book that I read they mentioned how there were some organs that showed widespread necrosis and then there was just the behavior of the diseased frogs themselves, acting sluggish and not being able to move.
Erin Allmann Updyke	Yeah.
Erin Welsh	And the fifth thing is that - these are a lot of clues - was that were were come species that seemed to escape the effects of whatever this was while their neighbors died in droves.
Erin Allmann Updyke	Wow.
Erin Welsh	So all of these things together kind of shouted to researchers this is an infectious disease. All of those things are very characteristic of a widespread virulent pathogen. And a couple of years after this disease hypothesis had been fully fleshed out, researchers across different continents detected a fungal pathogen on the skin of dead and dying amphibians. Amphibians from different continents, from Australia, Europe, North America, all seem to harbor this pathogen and so the researchers who were like, 'Hey so do you see this thing? Cause I have a fungus on my frog, do you have a fungus on your frog?'

Erin Allmann Updyke	(laughs) I just wanna say this, Erin is suing her phone hands like she's calling someone on the phone to chat across global waters.
Erin Welsh	(laughs) Well. And they didn't have to chat across global waters much longer. They were like you know what, let's meet up in person, let's take a real peek at this.
Erin Allmann Updyke	As in another herpetology meeting?
Erin Welsh	Another herpetology meeting, this one in Champaign, Illinois.
Erin Allmann Updyke	No!
Erin Welsh	(laughs) Yeah.
Erin Allmann Updyke	Stop it.
Erin Welsh	In 1998 a bunch of researchers who had found this pathogen gathered in Champaign to compare their findings.
Erin Allmann Updyke	Oh my gosh.
Erin Welsh	To say is my fungus the same as your fungus?
Erin Allmann Updyke	That's adorable. I also should say I didn't mean to throw shade on the other ologists earlier. They're all cool.
Erin Welsh	You're gonna get in trouble for that.
Erin Allmann Updyke	I know, right? Especially for other entomologists. We're all cool! Nerds.
Erin Welsh	Everyone's cool in their own nerdy way. That's just how it is.
Erin Allmann Updyke	Yes. Anyways. We're in Champaign, we're comparing fungi. I love it.
Erin Welsh	Well the fungi - I always say 'fun-ji'.
Erin Allmann Updyke	I think it's supposed to be 'fun-ji' that's what my high school biology teacher would kill me for saying 'fun-guy', maybe that's why I say it.
Erin Welsh	But these fungi were all the same. They looked and they were like but how is this possible? These look to be the same species. And they were like okay well what kind of fungi is this? Chytrid. And that's not that surprising maybe because chytrid is everywhere so okay, that makes a little bit of sense. But like you said, this was unprecedented in its ability to infect and cause disease in vertebrates. And the other thing was that it looked brand new, like this was a different kind of chytrid. And so not only was a new species named, it was a new entire genus that was created to house this Bd species.
Erin Allmann Updyke	It's so exciting.
Erin Welsh	Yeah.

Erin Allmann Updyke	It's so exciting.
Erin Welsh	This chytrid fungus seemed to be an unstoppable force. It tore through populations and then just sat there waiting because chytrid doesn't need amphibians to survive. It's content to just chill, waiting. Finding out what was responsible for at least a good bit of the amphibian declines was great news, right but it also raised a ton more questions and even some skepticism. No single pathogen had been the cause of so many extinction events or population declines in modern history. And blaming the decline on chytrid might make people ignore the other causes of amphibian decline such as environmental pollutants and climate change. And it still left this massive question of how do we stop it? The story of amphibians and chytrid shouldn't be looked at in isolation because it's raised all kinds of questions about what the role of humans is in conservation intervention. Some people have argued that chytrid is a natural pathogen so maybe these extinctions and population declines are natural as well. Yeah, that expression you're making I'm also like no, I don't buy that.
Erin Allmann Updyke	(laughs) It's a highly skeptical expression, everyone.
Erin Welsh	Well because what it does is that viewpoint fails to consider or acknowledge the role that humans have played in the spread of chytrid around the globe.
Erin Allmann Updyke	Like diseases don't just pop up everywhere at once out of nowhere.
Erin Welsh	Nope.
Erin Allmann Updyke	That's not...yeah.
Erin Welsh	Nope. And there's also some chytrid emergence and climate change seem to be in some cases acting in conjunction with each other.
Erin Allmann Updyke	Yeah.
Erin Welsh	So again this is human-induced climate change, humans have caused climate change.
Erin Allmann Updyke	Right. That's a fact.
Erin Welsh	Anyway. But the other reason that you can't tell the story of amphibian decline as one single event is because it's part of a massive and terrifying trend that's happening globally right now. We're in the middle of and the cause of this sixth extinction. I wanted to talk just a little bit about extinctions.
Erin Allmann Updyke	Good, let's make this a more depressing episode. Dead frogs isn't enough.
Erin Welsh	One of my favorite courses in college was called Dinosaurs and Disasters so this has really gone back to my roots.
Erin Allmann Updyke	Yeah.

Erin Welsh	Okay. So you might've heard this term the sixth extinction or the Holocene extinction used a lot quite a bit lately, particularly in talking about climate change impacts or exploitation of natural resources and often along with the word Anthropocene. But what is the sixth extinction? Basically since the first vertebrates evolved there have been five massive extinction events and we can see these in the fossil record. The first one took place 450 million years ago which is just an incomprehensible amount of time.
Erin Allmann Updyke	Yeah.
Erin Welsh	And the most recent one happened at the end of the Cretaceous period around 65 million years ago, that's the one that wiped out all the dinosaurs and pterosaurs and plesiosaurs and all the other cool animals. And based on the population declines and extinction rates of not just amphibians but many other species, some researchers believe that we're in the midst of the sixth great extinction event. And really the only debate that seems to be left is where to actually put the starting point of that because a lot of people believe that humans were responsible for the extinction of the prehistoric megafauna like the giant ground sloth and mastodons and all of the amazing cave bears and Irish elk. I love prehistoric megafauna.
Erin Allmann Updyke	Erin's face is getting so sad talking about this you guys.
Erin Welsh	Ugh. I wish I could time travel so much. But what makes a mass extinction because animals do go extinct for various reasons occasionally, by looking at the fossil record paleontologists can estimate about how many species of a certain group of animals like let's say mammals go extinct over a long period of time. And that is what we would call a background extinction rate, just a normal baseline level of extinction. And it's when that extinction rate skyrockets beyond the normal background rate that we call it a mass extinction, particularly if there are multiple groups that are undergoing higher extinction rates at the same time.
	So I'm gonna borrow a metaphor from paleontologist Michael Benton. He suggests you think of it as the tree of life. As the tree grows you have little twigs or branches that may break off along the way just as part of the growth process, part of the normal weathering. And a mass extinction event is like a tornado coming through and ripping off an entire half of the tree or huge branches at random, places that won't grow back. The background extinction rate for amphibians is hard to estimate since there are fewer fossils than there are for something like mammals but researchers think it's very low, probably around 1 amphibian species going extinct every 1000 years.
Erin Allmann Updyke	Wow. Whoa!
Erin Welsh	That's...yeah.
Erin Allmann Updyke	Oh dear.
Erin Welsh	The extinction rate currently is estimated to be 211 times higher than the background rate or if you take into account endangered species, as much as 45,000 times higher.
Erin Allmann Updyke	Oh no.
Erin Welsh	Yeah.
Erin Allmann Updyke	Assuming that endangered species are very unlikely to bounce back and are gonna go extinct imminently.

Erin Welsh	Right. Yeah. Amphibians are the most endangered class of animals. And even though this episode is about chytrid in amphibians, I want to bring us even further down by mentioning that they're not the only ones in an extinction crisis. So this is basically taken pretty much verbatim from 'The Sixth Extinction'. An estimated 1/3 of reef-building corals, 1/3 of freshwater mollusks, 1/3 of sharks and rays, 1/4 of all mammals, 1/5 of all reptiles, and 1/6 of all birds are headed towards extinction.
Erin Allmann Updyke	Oh no. Oh no.
Erin Welsh	Yeah.
Erin Allmann Updyke	This might be one of our top most depressing episodes cause it's like everything on the planet is going to die.
Erin Welsh	Yeah. I know that I'm sounding alarmist but there's cause for alarm. This is happening and humans are the cause of it and it's going to cascade I think much more rapidly and much more powerfully than we could possibly anticipate. At the root of these extinctions is humans. But you know I also just said that extinction is a natural process, right and there were five massive extinction events before humans existed. So maybe we're just due for another extinction event and humans aren't to blame at all. That's wrong, flat out wrong. (laughs) There's no such thing as being due for extinction. Let's look at the case of chytrid in amphibians. Climate change, human-caused. Habitat destruction, human-caused. Environmental contaminants, human-caused. These have all contributed a ton but the key role that humans have played in this particular event is transport.
Erin Allmann Updyke	Yeah.
Erin Welsh	Chytrid itself doesn't seem to be brand new to amphibians and I mean like we found it in the earliest museum specimen is from 1938 and it's probably been around longer than that. But what is new are these massive global die-offs. For these extinctions to happen over such a short period of time with such widespread geographic distributions, something must have brought chytrid from point A to point B. Amphibians can't cross oceans but humans can. For a while the leading hypothesis of where chytrid came from was that during the 1950s and 60s the African clawed frogs that were being shipped around the world for pregnancy tests carried the fungus. Did you know that they were used for pregnancy tests?
Erin Allmann Updyke	(laughs) You know I didn't until I started researching this. I knew rabbits were used, I didn't know that frogs were used. I found that very interesting.
Erin Welsh	Yeah. Very interesting. These frogs are one of the species that can carry the fungus without being negatively impacted, so it would've been harder to detect that there was anything going on.
Erin Allmann Updyke	Right.
Erin Welsh	More recently however, so in a paper that came from 2018, seems like the evidence is pointing towards East Asia as the point of origin of the Bd fungus.
Erin Allmann Updyke	I read two of the same papers as you, Erin.
Erin Welsh	Aha!

Erin Allmann Updyke	That doesn't happen very often.
Erin Welsh	It's doesn't. Well I mean we don't have a pathogen that often that is discovered in the past 30 years.
Erin Allmann Updyke	That's true, yeah.
Erin Welsh	With this ease and speed of travel, we are basically living a new Pangaea and that's a very serious threat to the planet's species.
Erin Allmann Updyke	Yeah.
Erin Welsh	Because species evolve in geographic isolation and invasive species are a hugely, hugely troublesome problem.
Erin Allmann Updyke	Pangaea, for those who may have forgotten their science class from 5th grade when we learned what Pangaea was, was when all of the current continents were one giant massive supercontinent that was known as Pangaea. So now we're saying that it's like all of the continents are touching again because humans move things across bodies of water.
Erin Welsh	Yep.
Erin Allmann Updyke	Yeah.
Erin Welsh	So researchers estimate that around 5-15% of earth's species have been described.
Erin Allmann Updyke	Wow.
Erin Welsh	So there are 85-
Erin Allmann Updyke	Most of the undescribed ones are like bugs.
Erin Welsh	Probably. Probably bugs, bacteria, etc. Who knows? Archaea. But probably many of these will live an entire existence before ever being described.
Erin Allmann Updyke	Yeah.
Erin Welsh	But why do we care about biodiversity, Erin? If someone were to ask you, 'Why does biodiversity matter?' What would you say?
Erin Allmann Updyke	Oh gosh, don't ask me to answer that on a podcast because I need a scripted answer and I don't have one.
Erin Welsh	That's the thing, it is a hard question to answer because it seems so self-apparent, it seems so obvious that of course biodiversity matters.
Erin Allmann Updyke	Right.
Erin Welsh	Like why does the 'why' matter?

Erin Allmann Updyke	Right.
Erin Welsh	Why do you have to know why it matters? Of course it matters.
Erin Allmann Updyke	Yeah.
Erin Welsh	But unfortunately it does matter because we need to convince people that maintaining or improving biodiversity is important.
Erin Allmann Updyke	Important and worthwhile and worth their money and their time.
Erin Welsh	Right, that's the only way to get funding or enact the policies that will actually protect biodiversity or improve it. Basically humans have to be convinced not to kill off other species.
Erin Allmann Updyke	Isn't that sad?
Erin Welsh	Yeah, it's sad. And the other sad thing is that the most common line of reasoning is that you should care about biodiversity because biodiversity benefits you economically.
Erin Allmann Updyke	Right. It's like oh, that's how we find new drugs or that's how we find new whatever and we can make money off of that so that's why we care about biodiversity. I hate those arguments.
Erin Welsh	I hate those arguments too. I hate them.
Erin Allmann Updyke	Yeah. It's so anthropocentric.
Erin Welsh	I understand that they are what is needed but it's just...yeah. It's very difficult.
Erin Allmann Updyke	Yeah.
Erin Welsh	Okay so let me ask you a slightly different question.
Erin Allmann Updyke	Okay.
Erin Welsh	Why should we care about amphibian species going extinct?
Erin Allmann Updyke	Ooh, amphibians are good sentinels aren't they?
Erin Welsh	Actually so I read something that they're not.
Erin Allmann Updyke	Oh okay.
Erin Welsh	So that the image of the frog as the canary in the mine is actually not a good indicator because they are pretty resilient.
Erin Allmann Updyke	That does make sense, yeah.

Erin Welsh	And also that their baseline levels aren't well established in anywhere so it's hard to detect change, there's often a lot of seasonality in their population densities, etc etc.
Erin Allmann Updyke	Then how about they're important parts of the ecosystem and they do a lot of things, that's why they're important.
Erin Welsh	There you go. Ecosystem services, nice.
Erin Allmann Updyke	Yeah.
Erin Welsh	When I was looking into this there were four reasons that were proposed as to why amphibians-
Erin Allmann Updyke	Why are they important?
Erin Welsh	Why do they matter, yes. And I'm sure that you could find a whole number of different listicles for this kind of thing.
Erin Allmann Updyke	Yeah.
Erin Welsh	But one is economic. So we use tons of amphibians for medical and teaching purposes and also for consumption, pets. Ecosystem services like you mentioned, amphibians help cycle nutrients and they're really great prey species, they transfer energy upstream and they're also great predators, eating tons of insects and insect eggs, arthropods and whatnot. Another reason that was proposed is aesthetics.
Erin Allmann Updyke	Yeah! They're adorable.
Erin Welsh	They're cute, yeah. And they've inspired thousands of years of folklore and mythology and tales. And also the final one which is my favorite is ethics. As humans with our big brains and our ability to manipulate the environment, we have a responsibility not to destroy the things around us.
Erin Allmann Updyke	I feel like that's a really, really good argument actually. That's the one I'm gonna use from now on, I think.
Erin Welsh	Right.
Erin Allmann Updyke	Because yeah, it's like yeah sure you can say it doesn't matter how much we destroy, the planet will keep going. But it's like dude, are you kidding me? That's a crappy argument. Like be better.
Erin Welsh	Be better. Yeah.
Erin Allmann Updyke	Care a little bit.
Erin Welsh	Just why is it better to rejoice in your power over things rather than respect things around you? It just is baffling.
Erin Allmann Updyke	Yeah and appreciate them.

Erin Welsh	Yeah.
Erin Allmann Updyke	Yeah.
Erin Welsh	But I think that the sad truth of all of this is that we're only going to know how important biodiversity is to humans once it's too late. There's a great quote from Paul Ehrlich that puts this nicely: "In pushing other species to extinction, humanity is busy sawing off the limb on which it perches." In the scheme of things and I mean like the big geologic scheme of things, humans are nothing. Go watch The Cosmic Calendar from Carl Sagan's Cosmos to give you an idea of just how brief a moment in time humans have occupied and yet we've had this enormous impact on everything around us reaching before humans and extending long into the future when humans are gone. And there are consequences that we are only now beginning to see and feel.
	By the time that chytrid was identified as the great amphibian killer, it was already clear that there was no way to stop it but at the very least an escape attempt could be made. A huge effort was started to establish amphibian populations in labs and conservation centers and freezing tissue to create this ark preserving species while populations died out. But that's not a long term solution. The goal of conservation should not be to have a species exist solely in a zoo for the rest of eternity or in a freezer but to reestablish it in the wild, to restore ecosystem functionality and health. But with chytrid still there and not at all bothered by the absence of its hosts, it's not safe to release these amphibians back into the environment. So what do we do now, Erin?
Erin Allmann Updyke	Oh just that small question you want me to answer? (laughs)
Erin Welsh	Just a small question.
Erin Allmann Updyke	Okay. Well I might need a break first.
Erin Welsh	Okay. (laughs)
TPWKY	(transition theme)
Erin Allmann Updyke	So that was depressing. So we'll do a quick little recap, bring it back to chytrid specifically, focus just on the depressing parts of amphibian decline rather than everything.
Erin Welsh	Okay. Yeah.
Erin Allmann Updyke	You know, small things. So like you had mentioned, it's estimated that at least 500 species have declined at least in part due to chytrid. And one thing - this is the paper that we both read, Erin - that I thought was really interesting in this paper is that this puts Bd, chytrid fungus, among the most destructive, invasive species of all time ever.
Erin Welsh	Yeah.
Erin Allmann Updyke	Like more destructive than rodents, more destructive than cats who I love but are the worst.
Erin Welsh	By the way, so this is outdoor cats. Outdoor cats, people who keep their cats outdoors and feral cats and so on have caused the extinction of 63 species.

Erin Allmann Updyke	And they threaten 430.
Erin Welsh	Yeah. So please if you have an outdoor cat, don't have an outdoor cat. Bring your cat inside.
Erin Allmann Updyke	Train it to be on a leash and only let it out on a leash like Mr. Norris or build a catio.
Erin Welsh	Yeah.
Erin Allmann Updyke	Yeah. Feral cats, man. So anyways yeah, so chytrid is major. It's way more major than the other high profile wildlife pathogens, things like white-nose, West Nile, etc. Like this has affected hugely more species which is very depressing and all but one, it's specifically Bd. So batr...no, I'm not gonna do it again. Bd.
Erin Welsh	I didn't even attempt it if you noticed.
Erin Allmann Updyke	You know we said it twice at the beginning so it's fine. And one of the things that's so interesting about this pathogen is that because it's so, so new, we know still so little about it. There are so many open questions that still remain. One of them is how old is this really? So like you mentioned, the most recent paper from 2018 estimates that this fungus likely originated in Asia. So based on their data which seems to me even though I'm not a geneticist and I don't know how to read these papers that well, it seems pretty comprehensive. They sampled samples of chytrid fungus from every single continent where it's found and hundreds and hundreds of samples. And based on their studies it seems like the Korean peninsula is likely where chytrid originated, so that's where it's from. And they estimate that in the early 1900s is when it likely began spreading across the globe. And they specifically point to the pet trade out of Asia that is a driving factor in spreading this fungus.
Erin Welsh	Yeah.
Erin Allmann Updyke	So one of the things that a lot of people are working on and that they pointed out really needs to happen even more is to sequence more species in Asia to really understand what the genetic diversity of chytrid is where it originated so that we can get a better handle on how old it is and how long species in Asia might have been co-evolving with this pathogen.
Erin Welsh	Yeah. There's that really interesting map in that 2019 paper that shows continent by continent the number of depressed populations or extinct populations or near threatened, etc etc.
Erin Allmann Updyke	Yeah.
Erin Welsh	And you can see how much that varies across these continents and it makes sense that there would be an East Asian origin because that is one of the lower rates of population declines.

Erin Allmann Updyke	Right, yeah. It's really interesting. But since the early 20th century, if that's when Bd began spreading, it has spread everywhere. Australia and Central America and South America seem to be overall the most hard hit in terms of population decline but the fungus itself is found across the globe and has contributed to declines in populations across the globe as well. So there are a few major questions that are still unclear in terms of the ecology and understanding this pathogen. First obviously is where it came from but I just talked about that. So it's also very unclear what the impact of amphibian biodiversity and the impact of humans and human-mediated environmental changes have been on chytrid in amphibians and what they will continue to be on chytrid abundance and distribution. We don't really know. Does amphibian biodiversity help spread chytrid and make it a worse pathogen? Or is it protective in some way like the dilution effect? It's unclear at this point.
	The effects of climate change which as we talked about is human-mediated though not the only human-mediated environmental change but a big one, the overall effects of climate change on amphibians are not great likely but the effects of climate change and Bd combined on amphibians also seems to not be great in a lot of cases. It's really complicated and at this point we don't fully understand what the combination of climate change, so increasing temperatures and more variable temperatures on top of this fungal infection are going to have on amphibian populations. But there are some studies that suggest that for some populations, it's really not good and the combination of increasing temperatures and infection is actually really detrimental. So that's a bummer.
Erin Welsh	Makes sense.
Erin Allmann Updyke	Yeah. What else do we not know? A lot of things. In fact there are so many things that I just feel that I am not gonna be able to do a good job of explaining it and on top of that I actually don't want to end this episode on a really depressing note. And there are some aspects of research on chytrid that are really exciting and promising. So at this point I want to introduce who you heard in our firsthand account, Dr. Taegan McMahon from the University of Tampa who's been studying chytrid for a number of years and from a multitude of different perspectives. She's gonna tell us more about the status of chytrid research including the importance of understanding the effects that chytrid has had on other species. Cause guess what folks? As it turns out, chytrid can infect more than just amphibians. What? Does that blow anyone else's mind? It blew my mind.
Erin Welsh	(laughs)
Erin Allmann Updyke	She's also gonna talk about work on understanding why some populations are so detrimentally affected and other populations seem to do okay when they're infected or seem to even clear the infection entirely and what that means for conservation efforts and some really exciting work on vaccine development just so we can end on a happy note.
Erin Welsh	Take it away, Taegan.
TPWKY	(transition theme)
Taegan McMahon	My name is Taegan McMahon and I am a biology professor and parasitologist at the University of Tampa and I've been there for about 5 years now. But I've been doing amphibian decline research for about 10 years and I have been in love with amphibians, frogs and toads especially since I was a really little kid. There's something about frogs that are just extremely charming, they're really diverse in color, they're these little gems in the rainforest and out in New England you find these bright green frog colonies. I think they're just wonderful creatures.

Erin Welsh	So you work with chytrid fungus and so that's obviously what this episode is going to be about. So could you tell us what chytrid is exactly and why people like you are studying it or why it's being researched?
Taegan McMahon	Chytrid fungus is a very weird fungus. So typically when people think of fungus they might think of portobello mushrooms or the type of mushroom that makes the little mushroom caps that they see in the forest growing out of a tree or out of a log. And this is sort of the same group of organism but it's a particular kind of fungus that lives in water and specifically is attacking frogs and living off their frog as its food resource. The fungus has probably been around for an extremely long time but in the last few decades we've noticed that it's been causing massive declines in amphibian populations. Some populations are able to handle the infection relatively well while other populations are totally decimated and/or completely wiped out in a matter of weeks. So there are a handful of groups of amphibians for example Atelopus is a particular genus of frogs that has been completely and totally decimated by this fungus, so it's wiped out dozens and dozens of species within this group completely out of the environment. So now being maintained in captivity but you don't find them in the wild at all.
Erin Allmann Updyke	Wow.
Erin Welsh	So I have a 'how' question and a 'why' question for you. The how question is how did it all of a sudden, you said it's been around for such a long time, what was the sequence of events of how did it all of a sudden become more prevalent or causing these I guess pandemics almost? And then the why question is why some groups seem to be more vulnerable to chytrid than other groups? Big question, sorry.
Taegan McMahon	Absolutely. Unfortunately I can't give you the super concrete answer on those questions. We'll start off with the idea that it's probably been around for a really long time and yet recently has been causing massive decline. There's a lot of groups doing research on this in a whole variety of different ways. When you have a huge conservation crisis like this you have dozens of scientific groups that are looking at how and why questions surrounding this particular disease outbreak. What we found is that we find chytrid basically globally, anywhere you find amphibians you find the chytrid fungus. And in addition to that people have looked through historical records and been finding these preserved amphibians with traces of chytrid fungus on them from the 1800s. And so it's been around for a lot longer than we had originally predicted when we first saw the big massive declines in amphibians and discovered that a lot of those declines were due to the chytrid fungus.
	Connecting that history to what's happening today is really difficult because we weren't searching for the fungus that whole time so we don't have a very good story as to why it's been around forever but suddenly it's now wreaking havoc. One of the main ideas is that amphibians are sort of threatened with a whole bunch of different challenges because they're found both in the water and on land, so anything that's contaminating the water impacts them and anything that is contaminating or destroying the land also impacts them. So the thought is that with habitat loss and habitat fragmentation, over-exploitation of our population, introduction of exotic species that are eating the native species, pollution, climate change is a huge one, and other diseases all coming in where amphibian populations were very strong might've been able to handle one parasite infection coming in like chytrid. But now that they're dealing with pollution, climate change, and the disease their populations aren't resilient enough to be able to handle all of those threats at the same time.

There are other ideas that are out there that the strains that were around earlier in time were less virulent meaning that they were less damaging to the host when they came through host populations, that they didn't destroy entire populations of amphibians. And that now we're having this really virulent strain that has moved around the world. There's a whole bunch of theories out there as to how it's been around for a really long time but we're only really seeing these massive declines in the last few decades.

Erin Welsh

And some of these groups are completely wiped out and some seem to be immune. Is it immunity or is it something else? And does the existence of immunity suggest a longer history of exposure over time or anything like that? Historical epidemics maybe?

Taegan McMahon

Yeah. This is sort of a newer line of research in this field. As I said the conservation crisis, everybody's focused on what is happening and why and now that we've had enough time to answer some of those questions we have a lot of researchers who are starting to ask some of these other more tangential or connected questions about immunity and things along those lines. What we're finding is that some groups are either tolerant of the fungus or resistant of the fungus. So if a group is tolerant then they can have the fungus in their skin, the fungus does just fine, it gets nutrient from them but it doesn't kill the host.

So there are a few groups that are really well known for this, one are the African clawed frogs, the Xenopus laevis for example, they're the frogs that you see in pet stores all over the United States that are fully aquatic and so they swim along under the water. That particular frog totally does fine with chytrid fungus. So it can have a really strong infection but it's absolutely tolerant and it doesn't harm the frog at all. That means that if that frog were to get into the wild, it would be shedding the fungus out into the wild and then the less tolerant species might be impacted by the fungus. We also have species that are resistant meaning that if they come in contact to the fungus or come in contact with the fungus they don't really get the infection, it's something about their system, maybe it's the bacterial fauna on the outside or their immune system is able to identify and get rid of it before it can establish and those populations just don't ever really get strong infections. So again those populations are resilient and able to move through that epidemic and not be destroyed.

And there's some really cool research just starting to come out now that there are populations many of which are in Central America that we saw were basically totally wiped out. Either species that had really big populations, chytrid came through, wiped them out to essentially nothing and in some cases we thought they were extinct. And now we're starting to see those populations come back. So my hope is that those populations as they come back are going to be either resistant or tolerant of the fungus, the idea there is that everybody, all the individuals in the population that were susceptible to the fungus were killed off, the few that could handle the infection are the few that completely resisted the infection, survived, and those were the few that were there to make the next generation. See the hope is that we're seeing some potential reestablishment of populations that will be long-term reestablishment.

Erin Allmann Updyke

Wow! It's like antimicrobial-resistant frogs.

Taegan McMahon

Yeah, yeah. In the best way.

Erin Allmann Updyke

Yeah.

Taegan McMahon

We should be really excited about.

Erin Allmann Updyke

Yeah that's so cool.

Erin Welsh	That's cool.
Erin Allmann Updyke	And so you mentioned briefly too that you've worked on a number of different communities, not just amphibians even though frogs are maybe the most well known for getting infected with chytrid. So can you tell us a bit about what it is that you've seen in terms of the effects that this fungus has had on other communities aside from amphibians?
Taegan McMahon	This is a really exciting line of research because for so long we have focused strictly on the chytrid fungus and amphibians and to the extent where in a lot of the papers you'll see the chytrid fungus being called 'the amphibian chytrid fungus'. And the reality I that it's found in other hosts which changes how we have to handle that whole system from a management perspective. If it's only found in one host, you can focus on that one host. If it's found in several or even potentially dozens of hosts that are all pathognomonically different you have to really focus your models in a much broader affect.
	So the main host that I have done work with so far are crayfish or crawfish or crawdads and this is a group that is also found co-occurring with amphibians. In many cases crayfish will dig burrows and then frogs will overwinter in those burrows, so they'll actually crawl down into the crayfish hole and hang out with the crayfish in that whole over winter and then they reemerge in the spring. So these frogs end up spending an extreme amount of time really interacting with crayfish. In addition to that the tadpoles of amphibians will eat the feces of crayfish and things like that. So what we found is that you have crayfish that are infected with the fungus and they actually poop out the fungus and then the amphibians go on and eat that poop and then they become infected themselves.
Erin Allmann Updyke	What?
Taegan McMahon	Right. So that changes the system and how we think about it, right? If it's only in amphibians then we have to worry about amphibians. If it's in crayfish that can be a really, really huge change to our management scheme.
Erin Allmann Updyke	Yeah. Does it have like a detrimental effect to the crawfish communities as well of do they just seem to tolerate the infection?
Taegan McMahon	So we have only looked at one genus of crawfish, we've looked at a handful of different species within that but what we found is that in the lab about 35% of individuals that were exposed to the fungus died.
Erin Allmann Updyke	Wow.
Taegan McMahon	The ones that did not die maintained the fungus for a really long time, so they were a viable host and a pretty strong host, and then they just kept living and living, there was no issue at all with them.
Erin Allmann Updyke	Wow.

Taegan McMahon	So they ate and had no trouble, they gained weight, they were totally healthy. So about 35-36% die and then the rest are just fine. One of the other issues with the system is that crayfish are invasives around the world. So we've moved crayfish populations all over the world. And for example when I lived in Costa Rica I'd go hiking, sometimes you would see people who had put a dozen crayfish into a big plastic jug basically, like a big juice jug for example and they'd close the juice jug and they'd carry it to the top of the mountain and they'd dump all the crayfish out into the stream at the top of the mountain and within the next year that entire stream would be populated with crayfish. And they do this cause they're a good food resource for people and they're really good for fishing, so people collect them and use them as bait.
	And so that becomes a really big issue if we're not tracking those invasive expansions of the crayfish population. And because the population is already invasive, generally speaking in many places people aren't out there actively tracking how strong that population is. So we don't know if 35% of the individuals that were there died off because nobody's actually looking at those numbers. So it's possible we're seeing a decline in the crayfish population from the fungus but there was no one out there to ask those questions.
Erin Allmann Updyke	Wow.
Erin Welsh	Wow. That's fascinating.
Erin Allmann Updyke	Yeah.
Erin Welsh	I also really love the image of a little crawdad and frog just holed up together, yeah.
Erin Allmann Updyke	In a burrow? Me too! It's adorable.
Erin Welsh	There's gotta be a kid's book about this.
Taegan McMahon	They're really cute. They're really, really cute little cray-frogs that typically get on it in those burrows.
Erin Allmann Updyke	Oh my gosh.
Erin Welsh	That's very adorable. That's fascinating.
Erin Allmann Updyke	So to thank you and maybe end on a slightly happier note, I saw that you've done some work on vaccine development which is really thrilling. So can you tell us a little bit about that research and where vaccine development might be in the whole process and scheme of things?
Taegan McMahon	Yeah. This is sort of a newer line of research course and I'm really excited about it partly because when you work on a really sad topic like amphibian decline, it feels like you are helpless a lot of the time, everything you look at is dying, declining populations left and right. And this particular line of research gives me a lot of hope that we will be able to help some populations reestablish. So we're basing it off the idea of herd immunity which you guys did an amazing job describing in your vaccine episodes, I was really excited about that. But it's the idea that if we could vaccinate enough individuals in the population then they will protect the sick and unexposed individuals from any individuals that are sick and contagious.

So the first sort of bit of research we did with this, we took amphibians and we gave them the live fungus and that fungus as I said burrows into their skin and it takes a few weeks in many groups for the infection to ramp up enough to actually cause really strong damage in the frog. So we can let them have the live infection for a few days and then we move them over to a hot chamber and that kills the fungus but doesn't harm the frog. So the labs will basically give them the live disease and then clear them of the disease. Sot he first round of this vaccine work was giving them actual infections and clearing them. And so challenge the body, their immune systems made a nice robust response to the fungus so when we gave them the fungus again they had a lower infection.

So that was really cool work, it was amazing to see that they could acquire this immune response to the fungus. However we're not gonna be able to effectively do this in a while because we can't give them the fungus, clear them of it, give them the fungus, clear them of it in the wild. That's just not feasible. So we developed a noninfectious vaccine. From the beginning we were using the dead fungus, so we took it and we killed it with liquid nitrogen and we just squirt it on the frog's back. It's the easiest vaccine to give anything cause you just have a frog and a little container and squirt this liquid on their back and they absorb it through their skin. When we vaccinated them that way they got just as strong a response immune system-wise and they had a lower infection when they were exposed to live fungus.

So that's super exciting cause that means that we can expose individuals to noninfectious vaccines and then they'll have less infection when they're exposed to the actual fungus. So we now have an NFF grant which is super exciting to work on all of this, so we're looking at the most effective form of the vaccine. So how can we most effectively and efficiently vaccinate individuals? We're looking at different species to make sure that we can actually vaccinate across a wide variety of different species, we're looking in the field to se how effective it is in the field cause you don't want to ever say, 'Hey everybody go out and dump a bunch of dead chytrid in the pond, it's gonna save everything' without actually knowing that it's gonna be effective and do what we expect it to do. So we're looking at the impact on other organisms in the pond and really trying to make sure we have a good idea of what's happening out in the field before we start promoting this vaccine itself.

Erin Welsh

That's so cool.

Taegan McMahon

It's really promising work and we've had some really fantastic responses from the different species we're looking at. And so there is certainly the possibility that we could go out and vaccinate some of these frog populations that have been removed from the environments, that live in really small isolated ponds, we could vaccinate those groups and then repopulate those ponds back to their more natural species levels which would be absolutely amazing.

Erin Allmann Updyke

Wow, that is so cool.

Erin Welsh

Oh my gosh. So I have a question that's a little bit more general or maybe a little bit more about you. So you describe yourself as a conservation disease ecologist which is the coolest job title, it really is. So what kind of advice would you have for somebody, I would imagine a lot of our listeners would be very interested in pursuing a career like that or at least learning a bit more about it. So do you have just like a brief snippet of advice on how you would go about to either learn more about that field or to become a conservation disease ecologist?

Taegan McMahon	Yeah. I love my job, if I could've described to you as a young person what kind of work I wanted to do, this is it. It's fun and exciting, it's very hard to keep my brain really stimulated and it feels really meaningful cause you get to see actual changes happening in the field and in the environment due to your work which is absolutely incredible. My suggestions as where to go from a more practical side is reach out to people who are doing research that you think is cool. You can find out what people are doing by googling scientific papers, by looking at articles, if you see an article in National Geographic and you think it's amazing, look for the author that they interview and look at their research. Reach out to them, most people doing this work want to talk to you about it and they're really excited to share what they're doing. And if your happen to be living near those people, you can ask if you can volunteer and help.
	If you are in school reach out to your faculty and find someone to do research with. It doesn't have to be the research that you wanted to do or that you want to do in the long run, just getting experience in a lab, getting experience in the field will tell you do you like fieldwork, do you like lab work, will let you know what you find exciting and what you don't find exciting and that will help you sort of decide what career route to go.
Erin Welsh	Great. Great pieces of advice.
Erin Allmann Updyke	Absolutely fantastic.
Erin Welsh	Are there any organizations or websites or anything like that that you would like to give a shout out to in regards to chytrid or your research?
Taegan McMahon	There are a lot of research organizations and a lot of conservation organizations that are doing a ton of work with amphibian decline and with chytrid fungus. One of the groups the Smithsonian Tropical Research Institute, they're a part of the Smithsonian which has some connections in the U.S. as well as in Panama does an incredible job of connecting scientists to permits and to the environment, getting them out into Panama, that's the group that I work with when I go down into Panama. They also have this huge facility of amphibians that have been pulled from the wild because the populations were in rapid decline due to the chytrid fungus and their maintaining these populations in captivity in hopes of being able to rerelease them at some point in time back to where they're supposed to be.
Erin Allmann Updyke	Wow.
Taegan McMahon	There's an incredible amount of money and an incredible amount of time and effort put in to try to maintain this diversity and it's something I think a lot of people don't realize is happening. I'm very hopeful that some of the vaccine work will be valuable in that space. There are other groups like Amphibian Ark and Save The Frogs, they do a lot of work as well trying to promote amphibian conservation.
Erin Allmann Updyke	Excellent.
Erin Welsh	Excellent.
Erin Allmann Updyke	(laughs) Jinx.
Erin Welsh	One last question, this might be an unfair question. But do you have a favorite frog species?

Taegan McMahon	Oh man, yeah. I get asked this question a lot and it is a really hard question because I wanna tell you yes but then I also wanna list 5 or 6 different species and the longer I think about it the list gets longer and I am well known for having many favorites in my life. I think I have favorite groups that I've worked with, generally speaking all my favorites come in the tree frog group. But one of my very favorites is the common toad. There's a picture of me as a 2 year old kissing the toad and the facial expression is me being very aware that maybe I'm not supposed to be kissing a toad but I figured it was back in the days of film and my mom ran inside to get the film camera, she probably wasn't very happy for kissing this toad. (laughs) So I think I'm gonna go with the common toad, I think that's probably my favorite of all of the groups.
Erin Welsh	I love it.
Erin Allmann Updyke	That's adorable. (laughs)
Erin Welsh	Yes. (laughs) Excellent. Erin, do you have anything, any other questions?
Erin Allmann Updyke	No, this was so much fun, oh my gosh.
Erin Welsh	Thank you so much for coming on and chatting with us about this and also we have to give a big thanks to Umat for being Umat and putting us in touch in the first place. Yeah.
Taegan McMahon	Awesome. Cool, thank you guys so much.
Erin Allmann Updyke	Thank you, thanks so much.
Erin Welsh	Yeah, thanks so much.
TPWKY	(transition theme)
Erin Welsh	That was great. She's amazing.
Erin Allmann Updyke	She's so fantastic, it was one of the funnest. We've had a lot of really fun interviews on this show.
Erin Welsh	We have.
Erin Allmann Updyke	How thrilling for us and you, listeners.
Erin Welsh	Yeah. (laughs) I am glad that we ended it on a bit more of an upbeat note. And that's the thing is that it's really easy to get very bogged down and fatalistic and sort of like well nothing matters, the world is gonna end, etc etc.
Erin Allmann Updyke	Yeah.
Erin Welsh	And I get that feeling, I get it when I think about climate change, when I think about what humans have done to the earth. But I think that there's also so much to give us hope or at least give us some sort of optimism.
Erin Allmann Updyke	Yeah.

Erin Welsh	You know there are people like Taegan working on these amazing systems, there are species that are being turned around, there are people who are making an effort.
Erin Allmann Updyke	Yeah.
Erin Welsh	And if you want to make an effort, if you want to do something there are many different outlets or resources for you to do that. Conservation societies, volunteering, just reading more about it, talking to people about chytrid, it's great.
Erin Allmann Updyke	Yeah. If you wanna learn more about Taegan's work you can find her lab Instagram @mcmahon_lab, she also curates the parasitology Instagram @uoftampa_parasitology. So fun. And another one @wanderingecologist which is a lot of really fun watercolors of wildlife and diseases and things like that.
Erin Welsh	Yay. Go check those out.
Erin Allmann Updyke	Yeah, definitely. And we'll post a bunch of her recent papers on our website as well so that you can read some of her work. And then if you live near her, bother her to go volunteer with her cause she's awesome.
Erin Welsh	Yeah.
Erin Allmann Updyke	Other sources?
Erin Welsh	Okay, sources. Yeah. So I wanna shout out a couple of books I read, one is called 'Extinction in our Times: Global Amphibian Decline' and this was an invaluable resource, even though it was published in 2009 there's such amazing information in there on the emergence of chytrid and also just the global amphibian crisis in general, and that's by James Collins and Martha Crump and Thomas Lovejoy. And then I also read 'The Sixth Extinction' by Elizabeth Kolbert and that was great, a very interesting book. And then a few papers quickly. Crutzen from 2002 paper, Skerratt et 2007 paper, Wake and Vredenburg 2008 paper, O'hanlon 2018 paper, and Scheele 2019 paper. Some of those are et als.
Erin Allmann Updyke	I have several other papers as well and we post all of these as well as links when we can on our website thispodcastwillkillyou.com, under each episode you can find the sources from this and all of our episodes. So check those out.
Erin Welsh	Yes, please do. And we also have a Goodreads list so you can find these books on our Goodreads list These Books Will Kill You.
Erin Allmann Updyke	Yeah.
Erin Welsh	Also a link to it on our website. Well thank you first to Taegan for agreeing to be on the podcast and sharing her amazing brain with us.
Erin Allmann Updyke	Yes. Yeah.
Erin Welsh	We loved it.
Erin Allmann Updyke	It was so much fun.

Erin Welsh	And listeners, thank you to you all for listening and for being you. We really love doing this and you make it worth it all.
Erin Allmann Updyke	So much more fun than talking just to ourselves.
Erin Welsh	Yeah.
Erin Allmann Updyke	And thank you also to Bloodmobile for the music in this and all of our episodes.
Erin Welsh	And wash your hands.
Erin Allmann Updyke	You filthy animals. Wash your hands before you touch a frog. Ooh, that's a good one.
Erin Welsh	Yeah. Don't touch a frog.
Erin Allmann Updyke	Don't touch a frog.
Erin Welsh	Don't pick 'em up.
Erin Allmann Updyke	(laughs)
Erin Welsh	Just leave 'em there, they're chilling.