

Benthopelagic Nematology with Dr. Holly Bik

Ologies Podcast

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Oh hey, it's your basket of yarn that's sad you gave up on knitting, Alie Ward, back with another farm fresh episode we just picked for you, and I hope that you're hungry for worms. So many worms. Why worms? Because before I came down with pneumonia last month, I was at USC Wrigley Institute on the island of Catalina teaching a sci-comm symposium to this group of really enthusiastic and endearing climate scientists and biologists who were just rarin' to get up on these mics. I took advantage of their zeal, and I asked them all about what they do because it's not every day that you get to sit on two twin beds in a seaside cabin with a worm expert. So, I did.

This guest has been a Research Associate in the Department of Zoology at the Smithsonian National Museum of Natural History, an Assistant Professor in the Department of Nematology at USC Riverside, and is now an Assistant Professor in the Department of Marine Sciences at the University of Georgia and runs her own lab looking at deep sea ecosystems and has literally traveled to the ends of the Earth to ask, what is in that mud? I love her.

But I also love you. And thank you again patrons at Patreon.com/Ologies for being so supportive during the break I took to get healthier; we could not do the show without you, and it costs just a buck a month to join and submit your questions before interviews. Thank you also to everyone repping the program via OlogiesMerch.com, we have cozy sweatshirts and hats and all kinds of ephemera. And thank you to everyone who just tells others about the show, I appreciate that. You can go to Ologies.com for a full menu of categorized episodes. And also, thank you, of course, for the reviews. I read every single one to hear about folks who have gone back to school or rediscovered a love of nature, or road-tripped across the continent with us. I love it. This week, thank you for the review, Willow LuvsDinosaurs who wrote:

Even when an episode drops about a topic I'm ambivalent toward or even actively uninterested in, as soon as I press play I'm hooked!

This one's for you! And also, Fiddler To Be, who wrote the review that says:

Thank you for predigesting science for us and lovingly regurgitating it into our ears, like a momma bird with bad aim.

Everyone, it's an honor to be of service.

Okay, let's talk worms. So, *bentho* means deep, *pelagic* means sea, and nematode comes from the Greek for 'threadlike'. So, let's talk skinny little worms at the bottom of the cold, dark sea. What are their lives like? What do they think about? Are they in love? Curl up, my wormies, for a talk about weird little mouths, hairy worms, demon nematodes, Antarctic exploration, mud collections, submersibles, moisturizers, deep sea mining, pork chop risks, and more, with your new friend, benthopelagic nematologist, Dr. Holly Bik.

Alie: [*sings*] Worms! We're doing worms! [*laughs*]

Holly: Normally people aren't so excited about worms.

Alie: That's fucked up.

Holly: I am Holly Bik, I am an Associate Professor at the University of Georgia in the Department of Marine Sciences and my pronouns are she/her.

Alie: I see you have a deck of worms with you. *[laughs]*

Holly: I do have a deck of worms with me.

Alie: You brought a deck of worms! Okay, when I saw you holding these earlier, I thought they were business cards.

Holly: They aren't business cards.

Alie: What are they?

Holly: They are... So, I work on microscopic worms that are extremely hard to see, so when I say I work on neematodes [phonetic] or nematodes – I did my PhD in the UK so that's what I say – people are like, "What are those?" And often I find it easy to carry around this deck of business cards so that after people meet me, they can always remember.

Alie: *[gasps]* Can I see one? What do they have on them?

Holly: Yes. So...

Alie: Ohhh! Look at that. Is that its face or its ass hole?

Holly: That is its face, that's its head.

Alie: Ohhh, it's beautiful. It's very sphincter-esque.

Holly: Yes.

Alie: And then what are– Okay, it looks like I'm looking at a hose of some sort with, like, a claw as a face, and then what are these dingle dangles all around it?

Aside: I really don't know how to describe this gracefully, so I'll just be honest. This particular worm looked like a tube of wrinkly skin with a clawed butthole face, with a crown of ribbed ponytails, just a natural beauty.

Holly: Those are... So we call them setae but they're like hairs that project way far out so that species is special because it has really long hairs all around its head. And actually, the way we describe species is you count. So, the hairs occur in circles, and you basically count how many rows of circles of hairs there are, and then you count how many pairs of hairs in that circle. So, you literally have to go on your microscope and count all the hairs. If a species has six hairs it's that species and if it has ten hairs, it's that species. And we don't actually know whether that means anything because most people don't get DNA sequences from the worms and sometimes worms will look the same but actually be quite different or vice versa, they can look really different but they're actually the same.

Alie: Is this an electron scanning microscope? Or what kind of microscope do you use to see these worms?

Holly: Yeah, electron microscopy.

Aside: She showed me another few worm cards; one that looked like the thick scales of a crocodile but with a slit for a mouth, and another resembling a cactus wearing, like, a cable knit sock. These things, they're just living their lives in the mud in Antarctica. They don't give a shit about you, and I respect that.

Holly: The skin of the nematode can be plate-like so kind of like armor, and then these cuticles, this one is striated, this one is kind of smooth, this one is like, punctured with dots.

Alie: Looks like a sweater.

Holly: This one is like armor. This one has a smooth cuticle so you can't actually see much, it's just... yeah.

Aside: Okay, worms with scales, but let's talk scale.

Alie: How tiny are they?

Holly: Technically they're like a millimeter to five millimeters long but the way it's easiest to picture the worms are the size of an individual speck of dust. So, you can see them if you have a slide and you hold it up to the light it looks like a little speck of dust, but practically we say that they're microscopic.

Alie: And then are all the cards the same or they're all different?

Holly: Nope, they're all different.

Alie: Stop.

Holly: So, this is the next one...

Alie: Who is this?

Aside: A fanged orifice rimmed with hair but wearing Cinnabon earrings? What's happening?

Alie: Oh wait, it's got a spiral on the side of it. That's a perfect spiral.

Holly: Yeah, it's amazing. So, these are actually like Princess Leia buns on both sides of the worm.

Alie: [laughs] What do they do?

Holly: They are sensory pores called amphids and no one knows why they're in perfect spirals, but this is my favorite taxonomic feature of the worms. We don't know exactly what they do but we think they are sensory pores. So, worms don't have eyes, but they live in mud and environments where there's a lot of stuff going on. [*"Got a lot going on right now."* *"Clearly."*] So, the current theory is that it's, like, a sensory pore and it detects chemicals because we know that worms can migrate toward specific bacteria, so maybe they're sending metabolites, or they're basically smelling stuff in the mud and that's what they're using to navigate. And we think it all happens through those pores.

Alie: What happened when you zoomed in and got to see this for the first time in real life? Were you like, "There it is!"?

Holly: Yeah, I mean, the spirals are really obvious. So, they're one of the easiest things to see. But not all the nematodes have spirals, just a select subset of groups do, but they are absolutely perfect, and they can get really big too. So, sometimes when you put them on the microscope, you just see this spiral like a Slinky kind of in the middle of the worm and it's really obvious and it's really cool.

Aside: So right now, as you drink a horchata or do squats, there are these teeny, tiny, itty-bitty noodles, alive, at the bottom of the sea mud with Princess Leia buns and sphincter faces and very weird mouths but she *loves* them and so do I.

Alie: That's so distracting that I almost didn't notice there were, like, kitten claws all around this gaping maw.

Holly: [laughs] Yup, those are the teeth. So, that's a predatory species; they have retractable mandibles with teeth inside so it's kind of like a wishbone on a chicken with a spike in the middle. They have

three of those, they have triradial symmetry, and then they'll extend them out and grab a worm or a bacteria or something, and pull it back in, kind of like a sandworm or some weird sci-fi thing.

Alie: I was going to say, did you ever see *Tremors* or the Pit of Sarlacc in...

Holly: Yeah, I was thinking of the Sarlacc.

[clip from *Star Wars – Return of the Jedi*]

C-3PO: You will therefore be taken to the Dune Sea and be cast into the Pit of Carkoon, the nesting place of the all-powerful Sarlacc.

Hans Solo: That doesn't sound so bad.

C-3PO: In his belly, you will find a new definition of pain and suffering as you are slowly digested over a thousand years.

Aside: Oh my gosh. Okay, and this deck of business cards doesn't just have worms on it, but the back bears her contact info and a very short nematode tiny bio.

Alie: And now, the front of the card, deep sea biology, Antarctica, nematode worms, in the middle of that is Antarctica. Like, there are worms on Antarctica?

Holly: Yes, on Antarctica and around the ocean. So, nematodes are literally... Every handful of mud, dirt, sand, soil that you pick up, there are thousands of nematodes in there. The terrestrial species on land are very different from the marine species. Actually, the terrestrial nematologists don't really talk to the marine ones so there's some kind of drama there. Not really, it's really just the taxonomy is very different. [both laugh] I'm creating drama, that's what I'm doing. Yeah, so they're all the way down in Antarctica, there are nematodes in volcanoes, like, hot soils in volcanoes. There was a nematode that was found a couple of miles below the surface of the Earth in, like, South African diamond mines. Literally, your garden, your lawn, they're everywhere and everyone ignores them and doesn't really know that they're there.

Alie: No one loves worms because they don't know how omnipresent they are, maybe.

Holly: Exactly.

Alie: How recently did science figure out like, "Oh yeah, there's worms on Antarctica. There are worms in volcanoes." How long have people been looking for worms there?

Holly: Well, it's been hard to find them in Antarctica until technology kind of got modern enough. So, maybe mid-20th century we started to find them down there when people started to actually start sampling and bring back the samples preserved in a way that we could look under microscopes. The Antarctic Dry Valleys are actually really interesting. The Dry Valleys in Antarctica don't get rain, they haven't seen rain since the Pleistocene.

Alie: Nooo.

Aside: So, some people call the Pleistocene by its nickname, the Ice Age, and it started 2.5 million years ago up until 11,000 years ago. And you know what? Between you and me, it is fine to have had to look that up. But yes, Antarctica has parts that have been parched since then!

Holly: And you actually find mummified seals in the Antarctic Dry Valleys because it's so dry and what happens is the seals will wander up a mountain from the ocean and then cross over into the Dry Valley and then freak out because there's no food there and no rain there and then they just die. And then because there's no rain, they become mummified. So, when you go to study the worms in those places, you're just traipsing amongst the bodies of mummified seals.

Alie: Why doesn't it rain there?

Holly: It's the climate. I mean, Antarctica is just this really unique climate, and parts of Antarctica get snow and glacier formation but actually, the continent is *super* dry. So, when we went on the boat, the first thing they told you to bring was lots of moisturizer.

Alie: Really?

Holly: Mm-hm.

Alie: How many times have you been there?

Holly: Just once, and I just came back.

Alie: When did you get back?!

Aside: So, she had been back on unfrozen land for maybe two weeks at the time we recorded this.

Alie: Oh, that was like yesterday, essentially.

Holly: Yeah, I'm a little bit jetlagged still, tired from the trip. It was a three-month trip.

Alie: Three months on Antarctica! [*gasps*] Do you send an out-of-office reply? What do you do?

Holly: [*laughs*] Yes. I had an email reply, there's no internet down there. We were on a ship around the Antarctic continental shelf in east Antarctica. So not only were we in Antarctica, but we were in literally the most remote part of the most remote place on the planet where satellites don't really exist. So, if you're on a ship anywhere else in the world, normally you have satellite internet and you can kind of check your email and it's fine. But we had... It was basically like being back in the '90s, so you had, like, the equivalent of a dial-up modem internet speed for your ship internet and then you had a landline phone. [*chuckles*]

Alie: Oh my god. Did you feel like when you left, "I hope nothing goes down," like... You mentioned you have kids?

Holly: Yeah.

Alie: Did you have to prepare emotionally like, "Okay, if something happens, if there's an emergency, they'll tell me." Were you able to put that out of your mind? Or how long did it take to acclimate to the, "It's okay, someone will reach me if they need to?"

Holly: So, I almost made a will before I went to Antarctica. [*laughs*]

Alie: I mean, not a bad idea. Not a bad idea.

Holly: Because I was so worried and I was like, "My husband doesn't know our bank account password, I don't know if he knows where his birth certificate is. What if he needs that?" So, I was over-prepping; I felt like an apocalypse prepper in the amount of notes and instructions that I left for him. And then, things did go wrong when we were down there. So, we had a catastrophic bathroom leak in our master bath and the ceiling was pouring with water. So, you prep for everything and then stuff still goes wrong unexpectedly. So, he was juggling the childcare and also calling plumbers at 3 AM to try to get that sorted.

Alie: To be honest, I'm glad it was at your house and not on the ship. Because at first when you said a catastrophic bathroom issue, I figured it was on the ship and I was like, "Oh, that had to be very smelly." But no, it's just back home.

Holly: Just back home.

Alie: You're like, "Good luck with that."

Holly: But I couldn't do anything about it!

Alie: Being so remote, did you learn anything that you've taken away? I know you've only been back a couple of weeks but was there anything about that kind of remoteness that made you disconnect, now that you've been back home, or did it make you appreciate connection more?

Holly: I would say both. I think I really didn't miss the internet. I didn't even try; it was so slow that it wasn't even worth it. So, I literally brought Tolstoy novels to Antarctica because I was like, "What is the biggest book I can possibly find that is vaguely snowy?" *[both laugh]* 1,200-page Tolstoy novel, that sounds great, about Russia.

Alie: Oh my god.

Holly: I actually used Antarctica to pursue hobbies that I always wanted to do so I bought a really nice Nikon DSLR camera, and I gave myself a project to learn photography and I just *never* have time to do that in my everyday life. So, I was just up whenever it was sunny and there were icebergs, I was just outside in all my polar gear just trying to take pictures and practice my photography, in addition to doing my science. A lot of those days were the days that we were transiting, so you're driving through fields of these amazing icebergs; there's sun and there are penguins and it's just glorious! That was a special way to unplug. It was really rejuvenating.

Alie: How much sun was there per day?

Holly: So, we were there pretty late in the season, but it was actually pretty sunny. So, we also changed... Time zone change is down, so we were supposed to go through 11 time zone changes, and the captain decides when you change the time zone.

Alie: Nooo! That, what an ego trip, that's amazing. Father Time, Captain Time. Holy shit. *["Hey, it's party time."]*

And let's go back to nematodes because a lot of people might be like, "Okay, what is a what? It's a worm." Tell us, what is a nematode? Because there are flatworms and there are roundworms and never the twain shall meet. Right?

Holly: Yes, flatworms and roundworms are different phyla. There are other types of worms too. There are, like, oligochaetes and polychaetes and also, there are things that look like worms in the ocean that are not actually worms. Nematodes are roundworms by definition and I think the easiest one that everyone would know is dog heartworm.

Alie: Oh! I was going to say an earthworm.

Holly: No. Earthworms are the wrong kind of worms.

Alie: Really? What kind of worms are earthworms?

Holly: Earthworms are annelids, so they're segmented worms.

Alie: Oh my gosh. Okay, so we've got roundworms which are smooth, non-segmented, and they're round-shaped. Then there are flatworms, and then there are annelids. Annelids aren't a subtype of roundworm, they're just totally a different thing?

Holly: Totally different thing, separate phylum. Way far away on the Tree of Life.

Alie: Oh my god! This is news to me. For some reason, I would have put an earthworm as a nematode. Okay, so dog heartworm; this is something that we have to give our dogs little pills every once in a while for. So, do they tend to be parasitic? What do they eat?

Holly: What they eat varies depending on what type of nematode they are. The parasitic ones are designed to, well, they evolved to live off the hosts so they will essentially rely on the hosts for their nutrition. I'm not quite sure what they eat because I don't study those ones.

Aside: For anyone with pooches who has taken heartworm medication, good job, I just read way too much about these wiggly scoundrels. They're transmitted by mosquitoes, and they creep around for six months before your dog shows any symptoms. Without any treatment, they may turn its heart into what looks like a dish of glass noodles. If you are not a dog person, they're not the only species that can be afflicted. So, watch out, jackals and beavers and wolves and reptiles and foxes, raccoons, bears, African leopards. Sea lions can get heartworm! Coyotes, yes cats, and humans.

Holly: There's also a human parasite so Guinea-worm, you know that one that lives up your leg? That's a nematode too. Onchocerciasis, river blindness, the one that burrows into your eye, that's a nematode. The parasitic ones are super gross, which is why I don't study them. *[laughs]*

Alie: Ahh! *["I'll pass... Thanks."]*

Holly: So, there are terrestrial and marine, so the majority of nematodes that we don't know anything about are free-living and they eat anything from, like, plant roots and fungi on land to bacteria and diatoms.

Aside: And in case you're not familiar with diatoms, if you visit the very pro-diatoms site, Diatoms.org, you will learn that diatoms are algae and that they live in houses made of glass. They are the only organisms on the planet with cell walls composed of transparent opaline silica. *[gasps]* So, they look like woven crystal baskets but tiny, tiny and they are microalgae that contribute 20 to 50% of the oxygen on our planet we need to survive. The biggest ones are maybe the size of a width of human hair. They live in dirt and, of course, oceans. And nematodes snack on them, probably for the salty crunch.

Holly: And actually, some nematodes eat other nematodes. The ones I did my PhD on are this group of predatory nematodes and they have teeth and jaws and they're really physically big and they're active predators. So, I have microscope images of worms ripping under worms apart. You can find a predatory nematode with another smaller nematode, like, hanging out of its mouth sometimes.

Alie: Augh! Oh, what a slob, I love it. I picture me eating like a chili dog and just covered in beans just like *[growls]*. How did you get into the field of nematology? Because you were in the Department of Nematology at the university. Did you ever introduce yourself as a nematologist? I mean, you must, right?

Holly: I mean, I study worms, so I guess I'm technically a nematologist. Being in a department of nematology is kind of like, "Yeah, okay. Fine."

Alie: If you're not a nematologist, I don't know who is. Also, anyone who studies something is technically an ologist of it. So, if I were to be cracking open a book and studying, I would technically be a person who studies it. You're definitely a neematologist, *[ph.]* and a nematologist, you're both of those things. *[Holly chuckles]*

Now, when it comes to how you got into this field, especially deep-sea nematology, that is a niche that is so, so teeny. How did you find yourself there among tiny worms in the most remote place on the planet?

Holly: Right. So, there is a story here. Actually, there are multiple stories. So yeah, I got into science because I wanted to be a deep-sea biologist. *["You did it."]* I grew up in Massachusetts, so we have Woods Hole Oceanographic Institute there. I'm also a first-generation college student, so none of

my family are scientists and I'm the weird one who likes the ocean. My family actually hates the beach which I discovered last year. *[laughs]*

Alie: Oh! How did you discover it?

Holly: Because we went to the beach and everyone was like, "Oh yeah, we hate the beach. We don't want to go for a walk." And I'm like, "What?! I never knew this."

Alie: How far away from the beach did you grow up?

Holly: Like an hour, in Massachusetts. I would go with my friends in high school, we would go down to the beach all the time. But I also used to go on field trips to the ocean because your school will always bring you to the beach. And I remember we went at one point to Woods Hole Oceanographic Institute. So, they have like, school tours that they host, and they have the submersible, Alvin, down there. And then I remember also going to... They would run these museum events at the Museum of Science in Boston, like *Ship to Shore*. So, you'd sit in this auditorium, and they'd beam in the satellite connection from the ship, it was usually Bob Ballard, who was the one who discovered the *Titanic*, right? And I was like, "Oh my god! Deep sea biology! I want to do that."

So, I got into science really more for the travel and the exploration. I thought I wanted to be an underwater archaeologist but then I realized that I don't like dead bodies and that's kind of creepy.

Alie: Dead worm bodies, not as creepy.

Holly: No. So, I didn't start with dead worm bodies. I actually started with jellyfish because they are pretty. But getting into jellyfish research is actually really hard.

Alie: Really?

Holly: They're like the whales of the invertebrate world and everyone wants to study them because they're so pretty.

Alie: Get it.

Aside: Two people who wanted to study them? Medusology guest Dr. Rebecca Helm and a toxinologist who studies jellyfish venom, Dr. Anna Klompen, links are floating around in the show notes. And for more on sunken treasures, soggy boats, and watery graves, you can see the Maritime Archaeology episode. I'm going to link it in the show notes because it's so good! But back to Holly and her worms.

Holly: So, when I was looking for a PhD, I had three criteria. I wanted to study some deep sea invertebrate. I wanted to get molecular biology skills because I really was attracted to genomics and DNA sequencing in my college courses; I did really well in those courses, and I was obsessed with DNA. And then my third criterion was that I wanted to keep living in London. I did my undergrad in London and I'm really a city person. I love the city, and the fashion, and the theater, and I wanted to stay there. So, the three things that ticked all those boxes was a project on deep sea nematodes at the Natural History Museum in London.

Alie: Oh my god! That's a beautiful museum. What did your parents think when they saw you going further and further toward a PhD? What do they do? And this was rare for your family?

Holly: Yeah. My dad is an HVAC technician, so he repairs oil burners and heating and cooling systems. My mom was a secretary in town government, she stayed home with me for a while. But they just think I'm really weird. *[Alie laughs]* I don't think they understand why I do what I do. I mean, they're really supportive of it and they connect most to the travel aspect I think because, like, working-class families, travel is basically an indicator of success. If you can travel the world and go to these places... So, the fact that I somehow got into a job where my work pays me to go to, like,

Antarctica and Japan and tropical islands, they're just astounded by that. And also, kind of worried for me, they're like, "Can you just stop traveling?" And I'm like, "No. I can't. It's my job." [laughs]

Alie: Do you think there are any good nematodes in HVAC systems?

Holly: I don't know.

Alie: Hot air, cold air.

Holly: There are nematodes in drinking water, which is really disturbing. [laughs]

Alie: [squirms] Even tap water?

Holly: Yeah. So, when I was processing my samples at the Natural History Museum in London– I work with deep sea samples so all the worms I ever saw were dead and preserved. But occasionally, when I'm picking through my sample at the microscope, there would be a thrashing, live nematode there and I would ask my taxonomist mentor, "Why is this worm alive? Where did it come from?" And he was like, "Oh yeah, the piping systems, there are nematodes that come up occasionally from there." [more sounds of discomfort from Alie] And actually, recent studies of drinking water, they do the environmental DNA sequencing and look for the DNA barcodes of things and yeah, you find like, signatures of nematodes in drinking water.

Alie: [spooky voice] Worms, worms, worms everywhere!

Holly: Which makes sense, right, because our drinking water comes from reservoirs, and it's put through pipes and stuff but it's not completely sterile. ["Don't worry about it... It's fine."]

Alie: Now when it comes to– I'm going to say neematodes [ph.] and nematodes this whole thing and I'm going to think I say it wrong every time but that's fine. When it comes to their life cycle, what are they out there doing? How are they fitting in with their environment? Are they cleaning things up? Are they changing the pH of systems? Nematodes... Why? Why are they?

Holly: I will talk about marine systems because that's what I know best, and I'll mention a little bit about terrestrial ones too. They kind of are like earthworms in the marine system but just on a microscopic scale. So, think, you have this patch of mud on the beach at low tide and you just have all these microscopic nematodes wriggling around. So, they're doing things like bioturbation on a microbial scale. They're also eating lots of bacteria, so a lot of nematodes have specific little mouthparts that just suck up bacteria. They can have species-specific feeding preferences so one nematode eats a very specific type of bacteria, and you have some separation there. They eat things like diatoms, so larger microbial eukaryotes.

Aside: Don't be scared of all those syllables. So, microbial eukaryotes are just tiny organisms – like fungi or single-celled little blobby things, or algae, or other little creatures – with eukaryotic cells, that is, cells with a nucleus and usually organelles and some DNA. You are a eukaryote. Many of the animals living inside of your body also are, because we're never alone and everyone living in you mostly loves you.

Holly: They are predatory. So, they're kind of like the base of the food chain so you have the bacteria and then you have the nematodes and then you have the bigger things like polychaete worms; larger worms would eat nematodes or arthropods, or crustaceans. They are the base of the food chain, and probably also important for carbon cycling because there are a lot of them. And some of them do deposit feed like sea cucumbers. So, you have miniature sea cucumber-like species that are just ingesting the sediment, pooping it out, and turning stuff over.

Aside: So yes, in this world, stuff eats stuff that eats stuff. And bacteria at the bottom of that chain, they really get the shaft. So, bacteria, they're just trying to exist and then nematodes come and

gobble them up like kettle corn. Nematodes are acting like the compost bins of the deep-sea mud so thank you for the recycling service, benthopelagic roundworms. But as a thank you, the nematodes get slurped up by polychaete worms which are bristly, segmented things that look like aquatic centipedes, they just come and eat up the nematodes like pasketti.

Alie: How small and how big do nematodes get?

Holly: The smallest nematodes are the deep sea ones because when you get into the deep sea, the food quality and the amount of food is really poor and there's just not much there so that leads to reduction in body sizes. And those can be like, a tenth of a millimeter.

Alie: Oof! ["I'm a wittle baby."]

Holly: Really tiny, yeah. The largest ones, so the largest nematode that we've ever found is actually a parasite of a sperm whale placenta.

Alie: Specific. So specific.

Holly: Yes. And that one is about 30 meters long.

Alie: Nooo.

Holly: Yeah, yeah.

Alie: Wait. [Beep-boop-beep-boop] 90 feet?

Holly: Yeah, so at the Natural History Museum we actually have it in a jar [Alie gasps] so it's this giant glass jar with just, like, coiled worm and yeah, from a sperm whale, the placenta of a sperm whale.

Alie: [stifled voice] Specific. How do they reproduce if they have such small niches?

Holly: They reproduce sexually just like a lot of organisms. You actually have males and females of the species. So, fun fact, *C. elegans* is actually, like, the worst nematode.

Alie: What? No. So, *C. elegans*, I know just enough to know that this is a study species for a lot of scientists across a lot of different platforms. Why did they pick *C. elegans*? And is it an elegant worm?

Holly: It is a boring worm. And it's a hermaphrodite.

Alie: Oh!

Aside: Love that. But scientists can get a little flummoxed in the lab.

Holly: Most nematodes are not hermaphrodites; most nematodes have males and females, and they are sexually reproducing so you need the males and females. *C. elegans* is a hermaphrodite, so it can fertilize itself but also, it has no body parts. It's literally just a tube that's pointy at both ends and it has no discerning features and, obviously, according to my cards, there's a lot of stuff on the worm so most of them don't look like that. The reason we pick *C. elegans* is because we can freeze it and unfreeze it and it will survive. So yeah, you have frozen worms and they're kind of hibernating and then you'll unfreeze them and you'll do your experiments. They found it from rotting fruit, it lives on apples, rotting apples in orchards. Someone found it and brought it into the lab one day and now that's our model organism.

Aside: What is this worm? Who is this worm? Okay, first off, it is elegant, and its name means 'recent, rodlike, and elegant', which is an apt description for a teenage supermodel in the '90s. And just like one, it was discovered minding its own business in an Algerian orchard by a worm scout and amateur biologist, Émile Maupas, around the year 1900. And Maupas just loved science and noodled around on worm projects and other stuff as a hobby, eventually getting published multiple

times and being honored with a doctorate and knighted for his contributions to science. [“Proud of you, man.”]

Now, in 1965 there was this guy named Sydney Brenner and he ushered this tiny one-millimeter *C. elegans* onto the science scene, and from there, *C. elegans* fame exploded, its usage rose. And yes, I will link to a publication called *WormBook*, which has an extensive table of studies in which *C. elegans* was instrumental. A few highlights are the discovery of cell death in 1983, the first complete wiring diagram of a nervous system in ‘98, insulin pathway genes, why naps help after physical stress. *C. elegans* was the first multicellular organism to have its whole genome sequenced. Also, *C. elegans* nematodes survived the Space Shuttle Columbia disaster in February of 2003. How did they do that? Nobody knows.

Also, in researching this, I learned that there was a conference called the International Worm Meeting, and apparently, folks, we just missed it a few months ago in Glasgow, Scotland. But luckily, you can catch up on what happened via the hashtag #Worm23. Also fortunate, it’s annual and they gather in different places around the world to talk *C. elegans*, which has been called “Nature’s gift to science.” So, a lot of people love the worm. Others, well, kind of a big begrudging sigh.

Alie: Has anyone ever said, “Hey, what if we switch up the worm, people?” Or no? It’s over? It’s *C. elegans*, that’s it. We got a *C. elegans* tattoo on our back and there’s no going back.

Holly: [laughs] I mean, there is sort of, like, “What if we get the worm that’s most closely related to *C. elegans*, and we work with that too?” And from my perspective, that’s like literally the same thing because it’s on this tiny part of the nematode tree of life, it’s very distant from the marine species because those are the most ancient lineages of nematodes and *C. elegans* is yeah, just a completely different part of the tree. So, I’m not bitter, not throwing shade at *C. elegans*. It’s important. You can order it on the internet with whatever gene knocked out that you want, so it plays an important role, but it’s not representative of the crazy diversity of nematodes that we have in the environment.

Alie: Are you not mad but just disappointed?

Holly: One of my good friends says that I’m motivated by injustice and spite.

Alie: Ha-ha! Well, those are good things, those are good fuels. [Holly laughs] What about the age of nematodes? Can you even find fossilized ones or are they so goeey that they just kind of melt?

Holly: For the most part, we do not have fossils. The oldest fossil that I recall is from the Devonian Age, and I don’t remember how ancient that is, but I don’t think it’s actually very ancient.

Aside: The Devonian age was 400 million years ago, just so none of us have to google.

Holly: So, we have this one fossil of a plant parasitic nematode and some tree sap but that’s it, there’s no fossil record. So yeah, we’re working at a disadvantage compared to most other phyla and that’s why DNA and genomics are really important because a genome is basically like a time machine or the equivalent of a fossil record and that’s what we use.

Alie: And what about the ones in Antarctica that you’re studying? Do they freeze? Or does it just not freeze in the deep sea mud?

Holly: It does not freeze. So, the ocean water in Antarctica is super cold but because of the salinity, it’s so salty it does not typically freeze. The surface will, so you’ll get sea ice but the nematodes that I work with live in the sediments, and the sediments will typically never freeze and if they do, it’s

near a glacier and then you've got other problems like the scraping of the glacier killing all the worms on the sea floor.

Alie: Oh! I forgot to ask what moisturizer you did bring, by the way.

Holly: Oh, that is a good question. I brought a giant tub, I want to say it's like First Aid Beauty, something I get at Target. I got a giant tub of ultra-healing moisturizer. *[laughs]*

Alie: Smart.

Aside: Holly wrote me later to say:

Not only did this cream keep my skin fabulously moist in the coldest and driest place on Earth, but this product lasts forever. I bought the six-ounce tub back in February before Antarctica and I'm still using the same one with a quarter of the tub left. So, 100% recommend for your listeners, especially if you have combo to oily skin like me because this face cream isn't greasy at all.

So, there is her tip, and she is a world-class scientist and because of that she also included a helpful citation, and by that, I mean a link. It's called Ultra-Repair Cream by First Aid Beauty, you're welcome. And no, they're not paying us even one worm for the mention, but when you use it, you can think of worms. It does not contain any worms though. Let's change the subject.

Alie: Now, what about glaciers? You mentioned glaciers. When I think of glaciers, I think of melting and I think of, "Ohhh no!" [*"And it may get hotter!"*] Do you find out anything about climate from studying deep sea worms? Do you see anything change over time? Are there more or less of them?

Holly: That is one question that I have. I would say there are not enough people studying worms and there's not enough data on the worms to be able to tell that. And that's kind of what we're trying to do, we're trying to get a baseline of the biodiversity. Most places in the ocean, we don't even know what's there, so how can we track change if we don't have that data set to start from? A lot of my work is really just a race against time to get a baseline of knowledge.

Alie: Augh, god! If you watch things going hotter and hotter and hotter, you must be like, "I needed to get this information in the '50s or something," right?

Holly: Yeah. Well, we know nematodes are very sensitive to temperature shift so the thing that kills all the deep sea worms when you bring them up on deck, the deep sea is like 2°C [*AI voice, "That's 36.5°F, you daft Americans."*] So, it's like living in a refrigerator. And when you bring that sample onto the deck of a boat, even if you just go into the lab and it's 60°, 60° for a deep sea worm is like the Arizona desert in the height of summer. *[laughs]*

Alie: *[laughs]* Like the mouth of Hell for them.

Holly: Yeah. So, most people ask me if the pressure changes kill the worms but they're fine with the pressure, it's the temperature shift. So, we could infer in a changing ocean where the climate is causing temperature increases, a lot of the species that are really sensitive to temperature are not going to do so well. I think that's a similar thing that we see with corals and other invertebrates is that you have very species-specific responses to temperature change. So, some species just will completely die and never be able to adapt, other species are more resilient to fluctuations in temperature.

So, you know, the worms will survive the apocalypse, I'm never worried that they will go away because there will always be nematodes there. Come on, if they can live in volcanoes, they're going to be able to live in an ocean, but the species composition is going to be completely different because the ones that are sensitive are going to go away and my worry is that we don't really know

what they do in the ecosystem. So, maybe the sensitive worm eats a bacteria that's a keystone species, and then if that worm goes extinct then the bacterial populations will completely change. So, it's kind of like the butterfly effect, we're messing with things that maybe we don't want to mess with.

Alie: What's their lifespan usually?

Holly: It varies. Usually, the marine species I work with are... Nnh, they can live for a couple of months to a couple of years.

Alie: Oh wow!

Holly: Yeah.

Alie: The idea of a millimeter-long worm in a deep sea just being like, "I'm 5!" That's nuts, you know?

Holly: *[laughs]* Well, deep sea species, a lot of them live for a very long time and we don't know why. They slow down their metabolic rates because there's not a lot of food. So, think of it kind of like hibernation, they're just really slow and that extends their lifespan. Again, we don't know if this happens with worms because there's not a lot of data and we can't really easily do experiments, but the trend is that the deep sea is just a place where *[speaks slowly]* time is very slow. That's how I think about it.

Alie: What about how you're getting your samples? How deep are you going? And you're on this ship, are you sending an ROV down? Are you going down in a submersible? Are you sending a big PVC pipe and seeing what you can dredge up? A large straw? Siphon it?

Holly: *[laughs]* Ahh, accurate actually. PVC pipes are pretty much the cutting-edge technology in deep sea science.

Alie: *[squeals]* Really? I took a wild- I thought that that was hyperbolic but that's amazing. Okay.

Holly: *[laughs]* I mean, slightly fancy PVC pipes. We use what's called a multicore or mega core, it's like a circle of pipes and they're just really long tubes and then they have some sort of mechanism at the bottom which will kind of seal it and bring up the mud. So, yeah, you send down what we call a rosette because it's a ring, send that down, it pushes into the sediment, the tubes get sealed off and then you bring it up and you can preserve the sediment-water interface so it's actually a really sensitive way of sampling the sea floor. And then we slice little pancakes of mud off the top of the cores, and we put them in the freezer to bring back to the lab to work on the worms.

Alie: Wow. How much product do you get to take home? Your luggage back, is it a Pelican case full of mud? Or is it only like, "We really only can take a couple of cores because it's going to take us ten years to figure out what's in one little slice?"

Holly: So, I have a problem with hoarding mud. *[both laugh]* This has been a problem I have faced for a decade now. *["It's very important."]* Technically, we only need- Most of the worm biomass lives in I would say the top 5 cm of mud, but you do have vertical distribution. So, you have some nematodes that burrow really deep, and the species composition will change as you go in the core. So, we tend to collect everything because we don't know what we're going to find. And we don't process it on the boat, we put it in the freezer and then we send it back to the lab on dry ice. And I am always just like, "All of the mud, let's bring it all back." And I have a problem saying no if somebody hands me a bag of mud.

Alie: *[laughs]* What about, is their respiration- Are they anaerobic? Are they aerobic? Do they breathe through their skin or through their Pit of Sarlacc?

Aside: So, she pulled out another card, and whew boy! Wow. This one, this one really got me. So, imagine a thick, long beard, beard hairs, sprouting from a garden hose made of skin that also has awkward bald patches if you can picture that. Or maybe, like, a weasel with boar bristles that escaped in the middle of a grooming.

Holly: So, this is what we call the Chewbacca nematode. But I would say- Funny story behind this photo. This nematode is basically like Chewbacca's leg and all those little hairs that you see are bacteria, so they're symbiotic bacteria that have attached to the worm. But in this photo, we shaved it because the electron microscope made most of the bacteria, like, fall off and there's only one little part remaining so it kind of looks like a poodle tail which I always laugh at. My graduate student would kill me if she knew I put this on a business card. *[laughs]*

Alie: So yeah, it looks like some of it is shaved and then you've got, like, if you were to forget a patch of a very hairy leg as you shaved it. That's amazing. It's normally covered.

Holly: Normally covered, yeah. So, several nematode groups will have bacteria attached to them. This one is filamentous bacteria, so they're really stringy bacteria that completely cover the worm. And these are sulfur-utilizing bacteria. We don't quite know what they do but the worms that are covered in bacteria tend to live deep in the sediments. And sediments, the reason why it smells is because there's a lot of sulfur.

Aside: Mud farts, we're talking mud farts.

Holly: Sulfur is actually really toxic to invertebrates. So, the species that can live down in that anoxic mud are... they need special adaptations to be able to repel the toxicity and the theory is that these bacteria on this Chewbacca nematode are using the sulfur or physically protecting the worm body from the effects of the sulfur because the bacteria, that's what they use for their metabolism.

Aside: So, the bacteria love the stinky mud, and the nematodes use the bacteria like a mink coat in January.

Alie: How did you shave this worm?

Holly: *[laughs]* So, when you prep stuff for the electron microscope, you need to spray it with gold particles, and I guess the bacteria fell off when you did that.

Alie: Where are you getting the gold particles? Can you re-harvest the gold particles or is it just like, "Buh-bye gold, you served your purpose."?

Holly: I think it's goodbye gold. I think it's gold. I'm not the one who does the microscopy, this is my graduate student, Mirayana who does all this. She's amazing at what she does, and I know she was not happy with this because she shaved the worm.

Alie: Wait, so you're telling me that you work with a grad student who works in deep sea biology whose name is Mariana?

Holly: Yes.

Alie: Is that not the name of a trench?

Holly: Um, Mirayana, she's Brazilian.

Alie: Okay, just wondering, did she get into it because of the trench, like, heard about a trench and was like, "I'm a shoo-in for this."

Holly: I've never asked her that. I might ask her when I go home.

Alie: I mean, if there were a trench called the Alie Ward trench, I think I'd be like, "I'll google that, that's exciting."

Aside: I emailed Holly later and she said that Mirayana grew up in southern Brazil, right next to a glorious tropical beach so that is probably why she became a marine biologist and that she is definitely more of a warm-weather person and the deep sea is very cold. Still, I think it's very cool and that she should tell people it's named after her. Let them Wikipedia it later.

Also, if you must know, when someone has a name that seems to correlate to their job, that's called an aptonym. Let's hear a few good ones such as weatherman Dallas Raines; an in-house technology firm lawyer named Sue Yoo; British hydrologist, Dr. Andrew Drinkwater; Dr. Ted Stankowich is someone I've wanted to have on the show for a while, he studies skunk glands; and there's a Russian hurdler by the name of Marina Stepanova. She's a hurdler, Stepanova. Coincidence or nominative determinism? That means that people choose careers subconsciously because they're kind of already a big name in them. We may never know.

Also, this interview was in the wake of the OceanGate Titan submersible implosion, so all eyes were really at the bottom of the sea.

Holly: Oh, can I quickly talk about deep sea mining?

Alie: Yes, yes.

Holly: So, deep sea mining, if you are not aware of this issue, there are these polymetallic nodule fields in the equatorial Pacific, and it's basically like the rainforest of the deep sea, and if you are at all inspired by the biodiversity of the deep sea or you're concerned about climate change, deep sea mining is the worst thing that we can possibly be doing right now. We don't know if we're even going to need those minerals, we don't even know what's in those nodules. Battery technology is changing, and people want to go and basically bulldoze the microbial rainforest in this beautiful region on Earth. You even have worms living in the metal nodules and it's just this *incredible* source of biodiversity and it really is not getting enough press coverage and it's upsetting because the payoff is not going to be worth it. These ecosystems take tens of thousands of years to recover.

Alie: And who is in charge of the green light on that? Who is saying yes or no?

Holly: The International Seabed Authority which is part of the UN, I believe. There has been this clock that has triggered because certain nations want to pursue deep sea mining, and there's this policy, I don't even quite fully understand the policy, it's complicated. But there's a ticking clock right now to develop a policy that oversees deep sea mining and scientists are not happy about it. The mining companies are using these machines that look like these horrible... I don't know, think of these machines in superhero movies that roll over cities, they look terrible. It's evil! Could you make a machine that looks more evil? *[laughs]*

Alie: *[moans]* Nooo!

Aside: I was like, how evil could it be? And it was more evil than I thought. Picture a steamroller covered in giant *Mad Max* spikes; it makes my crotch hurt looking at it.

Also, Holly mentioned some great activists in this area including a marine biologist and the director of SpeSeas, Diva Amon, Woods Hole scientist and ocean explorer, Julie Huber, and Senior Research Scientist at Bigelow Laboratory, Beth Orcutt. And yes, they are all linked in my website for this episode which is linked in the show notes. So, do follow them.

Holly: We need more press coverage about the horrors of deep sea mining and we need the UN to hear our voices and elevate the voices of the scientists and find out more about those issues. We need

renewable technology; we need to convert our energy sources but it's just not worth it to destroy the deep sea.

Alie: Have you ever gotten to go down? Would you ever want to go down to those depths? What's the difference when it comes to research between ROVs and submersibles? Do deep sea biologists want to get down there or not?

Holly: Yes, we do. Going in Alvin is my next bucket list thing. Antarctica was my first so I kind of checked that off. Deep sea submersibles are my next thing that I want to do. I totally want to go down there. I think the research submersibles, the safety procedures are incredible. I mean, they would never send down a human if they thought there was anything wrong with the engineering. And every time they do upgrades to Alvin, they do a lot of test dives and by the time you're going in it, there's not really any question about safety. It's always a risk and I think I would worry about it in the back of my mind, but typically, scientific submersibles are one of the safest things that you can do.

Aside: I was like, "One of the safest things you could do, Holly? Really?" I sat on my ass and did a 1,000-piece puzzle this past weekend and I felt pretty safe doing that. Then again, an hour ago, I was eating yogurt out of a Pyrex measuring cup because all the bowls were in the dishwasher, and I sliced my pinky finger, I bled on my shirt. So, I don't know, I don't know what safety is.

But I looked up some stats and this deep sea submersible ["Alvin."] has completed more than 5,000 dives since the mid-1960s... No deaths! But if you get in a car and go buy some granola you have a one in ten million chance of meeting the reaper, which is not zero. So, less dangerous than buying granola.

Also, how many bones are we talking to board Alvin? Well, between renting the mothership that it's attached to, it's like \$45,000 a day, easy. Also, why Alvin? What does Alvin stand for? I think it's, like, Aquatic Life Supporting Vessel Investigating Nautical Exploration. So, I looked it up because I knew it stood for something bonkers. But no! It's just named Alvin because a guy named Allyn Vine convinced Woods Hole Oceanographic Institute to build it in the '60s. Thanks Allyn! Sadly, he ventured to the great beyond at the age of 79 in 1994, but not in a submersible. Either way, Holly can't email him and ask him for a favor.

Alie: How do you get onto an Alvin or something like that? What kind of research do you have to do? How do you plead your case? Who do you have to know?

Holly: It's really hard. I would say I think there are a lot of people that want to go down in Alvin and it's difficult to get on to those cruises. So, I could get on in one of two ways; I could beg someone to get on their cruise and maybe get on Alvin, or I could write a grant to include Alvin in my research. I have been trying to do that; I have not been successful so far. Even for scientists it's hard.

Alie: How many scientists get to go on it?

Holly: I would say... I mean, a team of scientists on a boat is maybe 20 people and you have multiple cruises per year that go. Sometimes it's the same people that go over again but I think in the actual sub itself, it's two scientists and a pilot.

Alie: Your odds are not zero.

Holly: They're not zero, but it's still pretty hard.

Alie: You'll get on there. [*hushed tone*] Anyone listening to this who has an in? Can I ask you some questions from listeners?

Holly: Yeah, sure!

Alie: Okay, they know you're coming on.

Aside: Get her on that Alvin! Someone pull some strings or some ship ropes, or air hoses or what have you.

We donate to a cause of the ologist's choosing. This week, Holly said:

I would love it if you could support EarthJustice.org. They are a wonderful nonprofit legal organization that tackles environmental issues related to public health, preservation of wild spaces, clean energy, and climate change.

You can find out more about them at EarthJustice.org. So, thank you to sponsors of the show for making these donations every week possible.

[Ad Break]

Okay, let's dig deep. Let's crack open a cold can of worms with your questions including this one that was also asked by Bel.

Alie: Brittany Ruiz has a question: Would you still love me if I was a worm? [Holly laughs] I'm going to guess the answer is yes on that one, right?

Holly: I mean, uhh, obvious yes!

Alie: I'm going to see if that's a song lyric, but it might just be a good question for anyone.

Aside: Of course, it's a meme. Of course! Your dad, me, did not know this but according to the research library, KnowYourMeme.com, "Would you still love me if I was a worm?" originated from a tweet by @ShutYourHell that depicted a scenario of a woman crying at 3 AM, asking her husband if they were both born as worms if he would still like her? Would they even have married? Who hasn't wondered this, honestly? Probably worms.

But if you have a few minutes and you want to hear someone with a fabulous accent recite their original poem about being loved as a worm, look no further than Instagrammer @MissPunnyPennie. [*"Would you still love me if I were a worm?"*]

And many of you, a shocking number, including Samm, Isa Brillard, Emily Stauffer, Lazer Introlegator, Kleb, and Slayer needed to know: Do nematologists cut their worms into pieces? Is this their lab research?

Alie: Samm wants to know: If you cut a worm in pieces, will each of those pieces become new worms or is that only certain worms?

Holly: That is only certain worms, that is flatworms, not nematodes. Although, we do have one nematode that can regrow its tail. And actually, that worm is really cool because it's basically like a tube filled with bacteria. So, it has lost its gut and it's just packed its former gut with these symbiotic bacteria. And it's lost its mouth and it just hangs out. If it loses its tail, it regrows it and seals the bacteria back in.

Alie: And we have nematodes in us, right?

Holly: I hope you don't. [laughs]

Alie: Really?

Holly: I mean, if you ate dirt, you might but we would not. If you had a parasite, you would, or if you drank some drinking water with a worm, you might. But yeah, you should not have nematodes in you.

Alie: Okay, just checking. I wasn't sure if that's one of those things like, "Of course, you have a bazillion nematodes." Or it's like, "If you do, you better call 911 or something."

Holly: *[laughs]* Or you've eaten some uncooked pork. Nematodes are the reason why we cook pork to whatever degree, temperature because of *Trichinella*, the pork parasite. *[Alie squirms]*

Aside: So, if you eat these undercooked pork worms, they start their journey in your guts and then they move to your muscles to make babies. You might experience such sensations as nausea, diarrhea, vomiting, fever, fatigue, and abdominal discomfort before it escalates to headaches, fevers, chills, cough, swelling of the face and eyes, aching joints and muscle pains, as well as itchy skin and constipation. According to the beach read, the *Textbook of Microbiology*, "Enteric nematodes are among the most common and widely distributed animal parasites in humans." And in 1946, apparently, they had a worm meeting via the American Society of Parasitologists and this one expert gave a lively lecture titled "This Wormy World" and estimated a truly gargantuan number of all kinds of nematode infections in humans.

But if you don't want pork cyst infections specifically, the CDC says to cook those chops at 130° for 30 minutes or at 140° for one minute, that's like 55° to 60° in Celsius if you're concerned. Also, please wash your porky hands before eating finger foods, your body will thank you, your toilet will thank you.

Alie: One person, Jennifer Machen asked: Jumping worms? They don't got no legs. Have you ever heard of jumping worms?

Holly: There is a jumping nematode, yup.

Alie: Okay, Zed Shirogane: How come marine worms get crazy adaptations to make them look like wild little aliens while terrestrial worms are normal and boring?

Holly: Well, that is not accurate because terrestrial worms basically have harpoons in their mouths. *[laughs]*

Alie: Whaaat?

Holly: The terrestrial nematodes, I said they eat plant roots and fungi so they have evolved a harpoon in their mouth that they will stick out and puncture a plant root and then suck out the juices. So, I would argue that the terrestrial adaptations are even crazier than some of the marine ones.

Alie: Holy smokes. Samm wants to know: What's the wiggliest worm species? Is there a way to quantify that? Who wiggles the most?

Holly: I mean, my answer is always going to be nematodes.

Alie: Yeah, okay. I'd take it.

Holly: They thrash around in an S-shape because that's the only way they can move because they're lacking some key muscles for wriggling.

Alie: *[softly]* Oh my god.

Aside: When you are a worm, you just whip your worm back and forth.

Alie: Craig Collins wants to know: Would love to know about the research surrounding worm memory – I recall that if you teach a worm a maze and then grind them up and feed them to another worm, *["Oh my dear."]* that will worm will know how to solve the maze. Is this true?!

Holly: Umm... *[laughs]* This sounds like very far outside my area of expertise.

Alie: Yes. That may have been apocryphal, that may not be true.

Holly: I mean, I know *C. elegans* is used in Alzheimer's research. One of the reasons it's a useful model is because it has some of the same proteins and neural pathways for human diseases like Parkinson's and I believe Alzheimer's. Yes, we have a lot of proteins in common with the lowly nematode.

Aside: Can you feed a worm to a worm? [*deep breath*] All right. I looked into this but because there are *thousands* upon thousands of *C. elegans* studies and I have to bathe and eat at some point, my goose was cooked here. I'd never find this study.

I did find one titled, "Principles for coding associative memories in a compact neural network," about worms' memories to avoid stinky stuff. And there was this other study with this effusive name, "An elegant mind: Learning and memory in *C. elegans*," which detailed worm plasticity of the "tap-withdrawal response" which is just a fancy term for worms doing the backstroke in response to taping the Petri dish containing the worm. They're like, "Dang, earthquake. I'm out." There was also a very recent study, likely the talk of Worm23, about how descendants of worms trained to fear a certain odor, also got stressed out by that odor and that fear was transmitted to the offspring's cell's nucleus via sperm but not oocytes. So, paternal odor trauma affected future generations as a way of a warning system.

And just when I felt dazzled and overwormed by info, I finally stumbled upon that holy grail of worm research I was looking for! I thought I'd never find it, but I found it, folks! My goose was not cooked. So, in 2021 there was a study out of Princeton, and it was called, "The role of Cer1 transposon in horizontal transfer of transgenerational memory," about which Dr. Coleen Murphy, who was the principal investigator on this explained:

We found that one worm can learn to avoid a pathogenic bacterium if we grind up that worm, or even just use the media the worms are swimming in, and give that media or the crushed worm, to naïve worms. These worms now learn to avoid the pathogen as well.

So, there you have it, it's true. 1 mm tiny nematodes transfer warnings, memories, and I suppose trauma to each other by swimming in the same goop or eating each other, or being, I guess, fed each other by scientists.

And yes, this information about worms is interesting, but I hope it opens your heart to the possibility of more empathy for just every living creature you ever encounter, including the bitchy receptionist at my dentist's office. You don't know what her great-grandparents went through. Neither do I.

Now, if you'd like to know more about worms on drugs, you can check out the Planariology episode which is a stunning and charming one with Dr. Oné Pagán, who we love. So, you have more in common with the rest of the world than you ever thought possible. So, welcome. Welcome to unity with worms.

Alie: I mean, we share so much DNA even with yeast!

Alex Ertman wants to know: What is the deepest underground a worm has been found? Also, maybe this sounds strange but do land worms have community? Like, are they down there building nests or networks of tunnels together, or do they just occasionally bump into each other, say a quick hi, and move on? Do worms acknowledge the presence of other worms in marine environments? And yeah, how deep do you think worms go?

Holly: I believe the deepest, and I'm going to talk about nematodes specifically, the deepest that we've found is that one in the South African diamond mine, and I believe it's, like, 3 kilometers. It's pretty deep.

Alie: How did they find a worm? Were they looking for worms?

Holly: Maybe? There's a lot of subsurface microbiology research but mostly what they find down there is just bacteria and fungi. But then they found a nematode and then there was a science paper.

Alie: Did that person have to name the nematode?

Holly: I think they invoked vampires, but I can't remember the exact name. *[laughs]*

Aside: Okay, I got you. So, this worm was found in 2011 in a gold mine over 2 miles below the surface of the Earth. The geoscientist who first saw it described them as half-millimeter "Black little swirly things that scared the life out of me when I first saw them moving."

So, you can read more about their discovery in the paper, "Nematoda from the terrestrial deep subsurface of South Africa." But the long and short of these teenies is their genus and species is *Halicephalobus mephisto*, named after the underworld demon Mephistopheles, whose name itself means, "He who loves not the light."

And if this vibe of darkness intrigues you, please find the link in the show notes with all of our Spooktober episodes including a two-parter on vampire lore with expert Jeff Holdman, a Demonology episode, bats, spiderwebs, bones, body farms, catacombs, forest creatures. We got one on vultures, mortuary makeup, pumpkins, and more. But yes, worms named after demons, what a world! What a beautiful world!

Alie: Have you gotten to name any nematodes?

Holly: Not yet. But we are trying to do that with the Antarctic samples, that's on the radar. It's just really hard to name nematode species because you need some ridiculous amount of individuals from the same species. *["What are we talking?"]* You need 5 females and 5 males and then some juveniles. And usually, sometimes we never find more than one nematode from a given species. So, just getting the checklist of things you need to describe species is actually really hard for nematodes because there are all these rules written in the 1800s that don't make sense anymore.

Alie: Do you have a mentor or someone that you really admire that you would want to name? Or would you name it a Chewbacca nematode or something like that?

Holly: That's a good question. I haven't actually thought about that. I don't know how I feel about naming nematodes after people because there has been some pretty big press about why we name species after people and why that may or may not be a good thing. Maybe I would name one after Buddha because... Well, that would still offend some people. But I feel like that's what I would be comfortable with. *[laughs softly]*

Alie: But that's a problem that- You're going to have to catch a lot more worms to even have that problem.

Holly: Yeah. *[laughs]*

Alie: Curious Cat wants to know: Do worms have a nervous system? Is it species reliant? They don't seem to have eyes but are they like jellyfish and able to detect light? What kinds of sensory organs are we looking at?

Holly: So, I'll give you this card.

Aside: Ah! A translucent, slim-faced baby. It looks like one of those long-nosed Russian wolfhounds but with two little red dots, snugly close together on its snoot.

Alie: *[excitedly]* Ohhh! Wait, what are these two little spots?!

Holly: *[laughs]* So those are ocelli, also known as eye spots. This is a nematode that lives in kelp holdfasts, like when they attach to rock, you have that squiggly mass of roots, and you have a nematode that

only lives in those roots, and for some reason, they have these eye spots. We don't really know why but a lot of nematodes will have these dark patches of pigment that, they're not really true eyes but they're pigmented and they're most likely detecting light. So, some do use light to sense environments but the majority of them use the amphids, the sensory pores on the side of their heads, the Princess Leia buns.

Alie: Does the information that these eye spots gather, does it get processed anywhere in the worm?

Holly: We don't know and that's a good question. I do more like ecology and evolution research, so I don't necessarily study the nervous systems but if we're using nematodes in, like, Alzheimer's research then I'm assuming they have some sensory information that's useful.

Alie: Yeah. Ooh! Can I keep this one too? This one is also adorable.

Aside: So, if like patron Curious Cat, you're wondering where these flesh tubes store their brains, the answer is in a ring around their throats, kind of like an airplane neck pillow full of thoughts and feelings and horniness and transgenerational fears of odors. There was a 2021 article out of the University of Leeds and the Albert Einstein College of Medicine in New York titled, "A multi-scale brain map derived from whole-brain volumetric reconstructions." It found that there's a "Network architecture of *C. elegans* brains that supports sensory computation and brain-wide coordination." Essentially, our brains may have more in common across all kinds of phyla. So, if you ever meet a worm at a party, you already have a lot of similarities you can talk about.

Now, what about getting it on? How is that happening? Patrons Chris McQuire and Sarah King wanted to know. And Sarah, who has such a soft spot in their heart for worms asked: Do they come from eggs? Please give me their backstory, I'm way too emotionally attached. And that's the energy I'm looking for, Sarah.

Alie: Ellen Dumal wants to know: How the heck do they reproduce?

Holly: Okay, so this is fun. *[both laugh]* First of all, I said, nematodes have males and females so, sexual reproduction. Male nematodes, one of their defining characteristics is something called a spicule, which I describe as, like... Picture a stake that you use to kill a vampire, so this giant wooden thing that's pointy at both ends. Male nematodes have two of those and they will eject those and then slam them into the female nematode to pry open her reproductive tract and throw some sperm in there. *[laughs]*

Alie: Augh, a bit rude. Does he... like vampires, does it have to be invited or is it just like- And how do they sense a female? How do they know that there's a female reproductive tract even around?

Holly: That is a very good question, I do not have an answer to that. But another fun fact, they don't necessarily have to put it exactly in the right place. There is this reproductive strategy in nematodes called traumatic insemination.

Alie: Heard about this. Bed bugs do it too, right?

Holly: Yup, yup. So, they may just use those stakes to stab the female anywhere, you know, and just throw some sperm wherever, and then I believe the female will take the sperm and migrate it to the correct place. *[Alie shudders]*

Aside: I don't like it.

Alie: Christopher Blubaugh wants to know: With your work in Antarctica, and then a little flag there, are there worms that can survive the dry climate and extreme salinity of areas like the Dry Valleys?

Holly: Yup, yup. We have a lot of nematodes there. Not a lot. There are many fewer species, and the biodiversity is really low in the Dry Valleys but it's an interesting environment because you have a very strong connection to the microbial communities and yeah, definitely high salinity.

Also, pollution. So, some of the worms I study are in the Port of LA where there's all, like, gunk and DDT that's buried and one of the things that my work is doing is trying to figure out if we have specific nematode species that love pollution and can thrive in environments like that. So, we're trying to use them as bioindicators as habitat pristineness or impactedness and we use DNA sequencing nowadays for that. But the goal is to be like, "This nematode loves pollution!"

Alie: Well, yesterday we were about to go snorkeling, we were on the dock, and I was like, [*speaks through the corner of her mouth*] "Hey guys, did you guys hear there are some DDT barrels buried off the coast of Catalina?" And you were like, "Oh yeah, I'm trying to get some samples of it." I was like, what is the likelihood I'm standing on a dock with someone who's like, "Oh yeah, I got someone." Number one, where are those barrels and how do you get access to the gunk that might be leaking out of them?

Holly: I believe they are somewhere off the coast of San Diego. It's kind of as easy as emailing researchers that are going out there. I actually may have an email waiting in my inbox about the DDT barrels.

Alie: But they're not like, right off the coast here?

Holly: Well, they're off the coast of San Diego somewhere, they're not that far off the coast. You could get in a sailboat and go there but they're deep, so you need the deep sea coring equipment. You need an ROV or something to like, go down there and gingerly push the PVC tube into the gunky spot where all the DDT leaked out.

Alie: Oof. So, if you can find if there's a higher population of certain worms, then you can kind of figure out "If we get a lot of these worms over here, chances are we got a lot of this gunk."

Holly: Yeah, and one of the things we're also trying to do is look at the genome of those worms. The idea is that if you can persist in such a toxic sludge pool then you have certain things in your genome, like maybe upregulation of certain proteins or certain metabolic pathways that basically help you to survive in that environment. That will help inform research in other extreme places like volcano soils or Yellowstone hot springs, things like that.

Alie: [*gasps*] Oh my god, those are going to be the apocalypse worms.

Holly: Yes.

Alie: Trend forecast: If things keep going poorly, these are going to be really hot. [*Holly laughs*]

What about the hardest thing about what you do? What sucks? What is something that's just hard about worms or life, your life?

Holly: So, my answer to this is bureaucracy because... Okay, I run a lab. So, I kind of see myself as a CEO of a startup company and I have to do a lot of this paperwork and it really sucks the life out of me if the paperwork is not efficient. [*Alie laughs*] Right, like, I just want to get reimbursed for this research trip to the beach, but I have to upload receipts for like \$0.50 because I bought three Cokes and I don't understand why things can't be more efficient sometimes, or forms that don't make sense. You know when you have a PDF form and you try to fill it and then, like, yeah... Just it's hard.

Alie: Oh god. They're so expensive, focus-wise, and then by the time you get to the work you want to do you're like, "I spent all my focus filling out receipts."

Holly: Yup, yup. What about what do you love the most? What do you love about nematodes, nematology?

Holly: I love the sense of looking at something that no other human on Earth has ever seen before and that's really what motivates me. I can pick up nematodes from outside, in my garden, and still, maybe there's a new species that no one has ever laid eyes on before. So, I travel to these remote places and it's really hard and expensive and I don't go there often but I can bring the samples back. So, when I'm looking at, like, an Antarctic worm under the microscope, I still feel the joy of the travel to those places. Even though that worm kind of looks the same as the one that I got from my garden, sometimes, just the fact that "This came from Antarctica, and I went there. This is amazing. Life is amazing." And that's just my favorite part of my job.

Alie: What does the mud smell like? Smells like farts?

Holly: Yeah, it smells like... yeah. *[laughs]*

Alie: *[laughs]* That's good to know, that's good to know. Let's say that you are a backyard or a burgeoning nematologist, what kind of microscope do you need to see them?

Holly: You don't even need anything fancy, you can get away with a cheap stereoscope. Even magnification like 10X, if you go to your garden and you put that in the petri dish, you'll be able to see worms wriggling, you can't see them to the stage of what we get on our fancy microscopes that cost \$50,000, but you can see them wriggling and you'd be able to experience the joy of them thrashing around. And then iPhone cameras mounted on the microscope, you can even take some videos.

Alie: Ahh! You can share the world of worms!

Aside: Dr. Bik just got tenure, which is a huge deal and has explored Antarctica, and has a robust mud collection and well-moisturized skin. What else is on her agenda?

Holly: I'm doing things like experimenting with TikTok to tell stories or just even more thoughtful tweets. It's not science writing so having an artistic side of my scientific career that's focused on communication and spreading that joy and getting everyone excited about worms, I'm feeling really excited about doing that.

Aside: The sea, just swimming with so many souls of tiny and giant creatures, maybe there are water ghosts, who knows?

Alie: A beautiful thing to think of what a party it is.

Holly: Yeah! And actually, I want to be buried in the deep sea.

Alie: Do you? Really? How do you do that?

Holly: Well, I don't have a concrete plan yet. But I definitely want my remains to be fed back into the ecosystem, maybe like scattering of the ashes. I don't know if they could just throw my body over the side of the boat, I'm sure there are rules on that but definitely, like, scattering the ashes then my ashes will be marine snow and it will feed the worms and *[sings]* the circle of life!

Alie: Would you want it to be in Antarctica in particular?

Holly: No, I'm not picky. Any deep sea, any deep sea. And the coast of California gets pretty deep pretty quickly, and I love California so...

Alie: Worm food, I think that's beautiful. Thank you so much for talking to me!

Holly: You're welcome. This was fantastic to meet you and join you on your first-ever snorkeling trip!

Alie: Do you think I have nematodes in my hair from yesterday? I rinsed my hair... *[Holly groans]* Probably.

Holly: Again, I hope not, but maybe.

Alie: Yay!

Holly: But your hair looked amazing anyway.

Alie: Why, thank you.

So, ask worm experts wiggly questions about cold mud because there is no question that is too unsmart. Look at how much weird info our brains now have! Thank you, Dr. Holly Bik, for being on. You can find links to her TikTok, website, and so much more, plus a link to EarthJustice.org in the show notes.

More links are up at AlieWard.com/Ologies/Nematology. We also have *Smologies*, which are kid-friendly shorter versions of episodes that are classroom-safe, those are linked in the show notes or at AlieWard.com/Smologies. A full list of full-length episodes is organized by category, that's up at Ologies.com. You can stay tuned for a full month of Spooktober episodes starting next week; they're so, so good and creepy and cozy.

Thank you to Zeke Rodrigues Thomas, Jarrett Sleeper, and Mercedes Maitland for editing *Smologies*, Erin Talbert for adminning the Ologies Podcast Facebook group, and Emily White of The Wordary for making our professional transcripts. Noel Dilworth is our scheduling producer, and Susan Hale is our managing director, also handles merch. Kelly R. Dwyer handles our website, and she can design yours. And someone who should not eat worms because she is well-liked is lead editor of Mercedes Maitland of Maitland Audio who assembles the show. Nick Thorburn made the theme music.

And if you stick around until the end of the show, I tell you a secret and maybe you're like, "Why hasn't the handsome man Jarrett Sleeper been editing for a bit?" And the answer is that I adore him so much and he will always be your PodMom but I lovingly released him from his husbandly podcast duties so he could pursue what he really loves which is writing and acting. And boom! Within two weeks, he got two parts in movies, which are beginning to shoot soon, especially now that it looks like the strikes are coming to an end! So, I'm very excited for him. And also, it's nice to not have to talk to your spouse about work all the time and you can just sit around goofin' and doing thousand-piece puzzles on a Sunday. I'm loving this. I think he is also.

So, thank you again, everyone, just for the patience as I was out for August, retraining my brain to not fear things like shaking Petri dishes or mysterious odors. I can say, I think I'm the happiest worm I've ever been and it's just only making these episodes more fun to make. It's just a delight to be back. All right, that's enough sincerity out of your dad for one day, or is it? Is it? ... Okay, I love you. Berbye. Spooktober! Let's get it on, you creeps.

Transcribed by Aveline Malek at TheWordary.com

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[Antarctic nematodes and climate change](#)

[Nematode succession at deep-sea hydrothermal vents after a recent volcanic eruption with the description of two dominant species](#)

[Mud volcanoes in the Mediterranean Sea are hot spots of exclusive meiobenthic species](#)

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[Antarctica's McMurdo Dry Valleys](#)

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[Wikipedia: Pleistocene \(Ice Age\)](#)

[Leo Tolstoy bibliography](#)

[Dirofilaria immitis \(dog heartworm\)](#)

[Man's best friend: How humans can develop Dirofilaria immitis infections](#)

[Keep the Worms Out of Your Pet's Heart! The Facts about Heartworm Disease](#)

[WormBook: The Online Review of C. elegans Biology](#)

[A little History via C. elegans II. 2nd edition.](#)

[Whole apple extracts increase lifespan, healthspan and resistance to stress in Caenorhabditis elegans](#)

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