Ask A Biologist Vol 071 (Guest David Hughes)

Zombie Ants

So you think zombies are only on television and in the movies, think again. Dr. Biology learns the details of a nasty fungus and something called the "death grip" from biologist David Hughes. It turns out there are real live, well maybe not live, zombies. The good news is this fungus attacks ants and not humans.

Transcript

Dr. Biology: This is "Ask a Biologist," a program about the living world, and I'm Dr. Biology. Today we'll explore the world of zombies. Now I know you're probably picturing mindless human corpses walking the Earth in search of human flesh, but we know that zombies are not real. At least human zombies are not real, but if you dig a bit deeper into the zombie world it turns out they are real, at least for some animals, like ants.

My guest today is David Hughes, an entomologist and professor at Penn State University, whose been studying a pretty nasty fungus that can turn ants into zombies. Once the fungus infects an ant, it changes its behavior that leads to the death grip that I for one want to learn more about. Besides the work that David's doing with zombie ants, he has another project that I think everyone will want to learn about, and that's called Plant Village.

Welcome to the show David Hughes and thank you for visiting with me today.

David Hughes: It's my pleasure to be here.

Dr. Biology: Before we jump into the story of zombies, ants, and death grips, let's talk a bit about fungus. Fungus is neither a plant, nor an animal. It actually has its own kingdom, fungi, which some people will know that it has yeast, and molds, and a lot of people have seen the common mushroom around.

What exactly is a fungus?

David: We are right in starting up by talking about plants. Often times, people think they are plants. Fungi actually are more closely related to animals. They're a separate kingdom. We have kingdom animals, kingdom fungi, and kingdom plants.

They are micro-organisms, small cells that divide. Although, when you see a mushroom, you'd notice that it's quite large. They have very unusual way of growing.

Unlike plants, they don't photosynthesize, or produce their own food. They're not what we call autotrophs. They require consuming another source of material for carbon and protein. They have something called, this is a big word, an osmotrophic life cycle.

What they do is they literally pump out juices from their cells, which are often called hyphae. They pump these juices out into the environment. Those juices degrade parts of the environment, and then the fungi, suck it back up.

It's a little bit like flies vomiting on a food source, and then sucking that back up. The contents of your stomach, going on to your lunch, and then you sucking that back up. This is called osmotrophic life cycles.

The benefit of this is that fungi have become really adept at colonizing a range of habitats. Many of them are pathogens of plants. They live inside plant material. They're also pathogens of decaying materials. As a forest drops, or a tree falls down, the fungi will colonize that. That's where you see the mushroom's coming from.

Many of them, like the zombie ant fungi, are actual pathogens of insects or other arthropods. They get inside the body and consume it.

Then we have fungi everywhere else on the planet. People have recorded fungi at the bottom of the Marianas Trench, thousands of feet below sea level. They're in the tops of mountains. Fungi are everywhere, operating in spaces we don't typically see or think about.

Dr. Biology: So that we don't ever give the impression that all fungi are actually bad, they're really important. One of their roles is recycling.

David: Were it not for the fungi breaking down the forests, we would be knee-high in trees or even higher. Fungi do a remarkably good job in decomposing material, at releasing a lot of the material back into the environment.

They also play a remarkably important role in allowing plants to colonize environments. It's something called ectomycorrhizal fungi that live on the roots of plants. They have a symbiotic, a mutualistic partnership between the plants and the fungus. The fungus is a place to live, and in return it allows the plant to access nitrogen that it couldn't normally access.

Dr. Biology: David, you used two really great words there, symbiotic and mutualistic. This is where two organisms, working together, benefit from each other. With the fungus we're going to talk about, we're talking about a parasite, and that's a one-way relationship where the parasite benefits and the host usually ends up dead.

Would you tell us about the fungus that's taking control of the ants, and turning them into zombies?

David: This is a group called *Ophiocordyceps* and it's a whole genus within a family. It's a family of fungal species, which are specialized to live inside insects. They infect about nine different groups or orders of insects -- caterpillars, butterflies and hymenopterans, that's the wasps, bees, ants and so on. Very many insects are infected by this group.

In the ants, what we see played out, is the ability of these fungal species to control the behavior. As the ants are out in the environment, foraging for food, they pass through a

patch of spores. These spores attach to the skin or the cuticle of the ant, and then they burrow through the cuticle over a number of hours.

By which time the ant is back home inside the nest. Over two or three weeks these fungal cells replicate slowly inside the body of the ant. Then they're ready to go on to the next stage of development. That next stage is on the underside of a leaf, outside of the ant colony.

In order to get there, the fungi produce chemicals -- alkaloids, neuromodulators. We originally derived the drug LSD, lysergic acid, from this group of fungi back in the 1930s. They also produce things like ketamine, which is a tranquilizer used in the veterinary industry for horses. These fungi can produce chemicals that affect behavior, that's what they do with the ants.

The ants leave the colony and they go on to the underside of a leaf, they bite firmly into a leaf and that's where they die.

Dr. Biology: The death grip.

David: Uh-huh. The fungus needs a platform from which to grow, because what happens next when the ant is dead, attached to the leaf, is the fungus quickly converts all the muscle and tissue in the ant's body into fungal material, into hyphae, into long-term storage material, and then it grows out of the back of the ant's head.

It explodes through the ant's head, the intersegmental membrane, as it's called, and then it produces a stalk from which spores are produced and the cycle continues.

Dr. Biology: This is something a good horror movie is made from, right?

David: Absolutely.

Dr. Biology: Is this fungus particular, or will it turn any ant into a zombie?

David: They seem to be highly specific, based upon our research. We find that one ant, one fungus seems to be the rule. We find many hundreds of species are out there, and it's going to take many years to describe all of those, but we do find it's highly specific. That makes a lot of sense because, after all, it's producing chemicals that can affect the behavior and that would suggest specialization.

Dr. Biology: Is there a way for the ants to avoid or defend against the fungus?

David: Ants are remarkably good at defending themselves. They have great societies which rely upon what's called a social immune system, where individuals actually patrol the colony, looking for disease and reducing that. They're remarkably good at that. They probably use behavior as a major mode to avoid.

For example, in the forest, we'll have patches of spores from this fungus, and these are infectious, so the ants can move around it.

It's not just ants. Many insects are able to recognize the presence of fungal spores and avoid those. Now the job is upon the fungus to evolve a counter-strategy, so we see this co-evolutionary arms race between the two.

Dr. Biology: We're talking about this fungus that's a parasite. So it's a one-way relationship and, obviously, it's not good for the ant. Are there other cases of parasitism, that's another word, changing animal behavior?

David: Lots of examples and we're realizing this now. There are examples of this whole group of parasites called thorny-headed worms, and pretty much every species in the whole group is manipulating the behavior of crustaceans in water bodies. They make these crustaceans move up to the top of the water, where a bird can more easily pick them off and that's how the parasite transmit from one host to another. That's called trophic transmission.

There is another system which is parasitic insects, wasps, which manipulate the behavior of spiders to build special cocoons, which are useful for the development of the wasps, afterwards. There are examples of crickets being manipulated by worms called hair worms. They jump into bodies of water, because the worm needs to reproduce as an adult in the water, so it makes this terrestrial insect jump into the water, effectively committing suicide.

For mammals, because it's not just a story about insects, we mammals, we're infected by something called *Toxoplasma gondii*, which is a small, single-celled parasite which is similar to the group from where we will see malarial parasites, its apicomplexan. In this case, it gets inside a rat and it controls the behavior of rats, making them lose their normal fear responses to cats, because the parasite needs to go from one host, the rat, into the second host, the cat.

The best way to do is this is to make the changes in the brain of the rat, losing its fear. In a number of studies, people have shown that these rats actually approach a cat, and then the cat eats the rat, because inside the cat's stomach is where these parasites need to reproduce. It's overcome that rather big challenge of causing a rodent to lose its innate fear.

It does that by changing the gene expression in the brain, in the important center called the amygdala of the brain.

Wonderful neural engineering is happening all over the animal kingdom by parasites that have evolved to use their host as vehicles to get around the world from one point to another.

Dr. Biology: Right, and you're actually talking about a single cell.

David: Absolutely.

Dr. Biology: That's the part that blows me away on this. I started this show about zombies and that human-zombies are not real, but could there be a fungus that could control humans?

David: Not control to get from point A to point B, but affect the behavior, for sure. There's a lot of good historical evidence that the Salem Witch Trials in Massachusetts in the 1600s were caused by people eating rye, which contained fungal material inside it called ergot.

Historically in Europe, for hundreds of years, we've had something called Saint Anthony's Fire, where you've had mass hallucinations and remember LSD has come from this group of fungi and, in fact, came from ergot of rye.

There is a lot of convincing evidence that will see this. The last mass hallucination event was in France in 1952, where the whole town went literally bizarre because they consumed vast amount of alkaloids, which are similar to LSD. In that way, they can affect their behavior. The role that fungi play in human diseases are under-appreciated.

There is something called Valley Fever out west, where fungal material is coming up from the soil. It's getting into people's nervous systems and slowly crawling through out the nervous system reproducing. It's not beneficial.

It's not helping the fungus transmit from point A to point B, but it is nonetheless affecting our behavior. There are examples of fungi, and then more broadly of course other parasites, like viruses, like rabies, certainly do control human behavior.

Dr. Biology: The zombie ants that we have been talking about, do you find them everywhere, or they specific to particular regions?

David: Used to be that we thought they were just in the tropical belt around the world, but in our studies, we've worked all over the planet. I worked in 11 countries and five continents. We find them throughout the tropical belt, of course, Africa, Asia, South America.

We find them in the US. We find we have a big population in South Carolina that we found through the collaborations of citizen scientist, Kim Fleming, who was great natural historian. She has been working with us now for four or five years and is this co-author on our scientific publications.

I am happy to say, we are actually going to name a new species of zombie ant fungus after her, so it is going to be called *Ophiocordyceps Kim Flemingi*, which is great. It occurs in the south of US but right up into the Canadian border, there are records of this.

There could be zombie ants in your back yard, so please go out and look. Sometimes people email me, relatively often, and tell me they have found one. They will send me some samples, which is nice.

Dr. Biology: It's interesting because one of your publications is in a journal called "PLOS," The Public Library of Science, and I find it intriguing because we wanted to sit

down with you and talk about this. We actually have a companion story about this one, but we call it PLOSable [askabiologist.asu.edu/plosable/zombie-ants]. Why I find it intriguing is, this is not uncommon for the citizen scientist to play a big role in research, and in this particular case, you wouldn't have found this ant without Kim.

David: No, not at all. I was in Harvard looking at the collections there, what's called the Farlow Herbarium. From a very notable scientist called Taxter, who is long since dead, we looked into his collection of samples and over the last 140 years, there were simply 49 samples.

It was missed by the entire Mycological community, those people who study fungi, and the entire Myrmecological community, all the people who study ants. It just wasn't on anybody's radar and I understood from that, it doesn't exist in the US.

It's not present, but it was really Kim. It was really that citizen science, that naturalist's flare that she has that was able to see that and then said, "Oh, it is very common here." Literally, four days after hearing that, I was down in South Carolina working with her. Thankfully, we haven't stopped since.

Dr. Biology: We talked about this pretty nasty-at least for the ants - fungus -- but it turns out when I was doing some research, this fungus actually has its own parasite.

David: Yes, you would think that this is a terrible situation for the ants but nature's complex and especially nature in rain forest, and so there is always something out there looking for lunch. In this case, there is something called hyper-parasitic fungi. In fact, there are many of them, there's tens and tens of species.

These have evolved to be specialist on the fungus, which is controlling the behavior of the ant.

Work we haven't published, but I will share it here is that, we see also flies which have evolved. God made flies to evolve to consume this fungus. There is even a parasitoid wasp of the fly, of the fungus, of the ant, on the leaf. Rain forests are wonderfully compact places to see these great theaters of co-evolution being played out.

Dr. Biology: There are people that will find this fascinating just for the basic research. Obviously zombies, just didn't have a title, these days it's great. But there is more to this research than understanding just the interaction of the fungus with the ants. It goes into what we call applied, or for humans, we are always trying to think about what's it going to do for us?

It turns out that you have some interesting links with your research in a couple of areas.

David: Yes. If you spend a number of years working on parasites that have evolved to get in and out of the insect nest that sort of tells you ways in which we might be able to ourselves get chemicals in and out of those nest to perhaps destabilize them.

We all worry about colony collapse disorder, and rightfully so, but in many social insects species, we will be happy if they did collapse. Like the fire ant in the southern US, which

costs an annual cost of $6 billion, and all the damage it does. If we can get something into the colony center that kills the queen, this will be effective especially because that little pest is now going to China, Australia, and is a difficult thing to control.

We can learn lessons from these co-evolutionary advances between parasites and their host. The fungus I work on, *Ophiocordyceps*, has long been used in the medical arena. It has been used in China for the last 1,500 years, from species which infect caterpillars in high Tibetan Alps.

It has demonstrated antimicrobial, so it kills bacteria and stuff, and anti-TB, and anti-malarial properties. It's a good therapeutic but you have to go to the top of the world to get it. To Tibet, in South Carolina it's a dime a dozen, it's more or less the same species.

There's lots of untapped potential in controlling injurious diseases of humans like cancer. Remember that the whole basis of our antibiotic industry is fungal species like penicillin. We need more of them, the more searching the better.

Dr. Biology: David, I want to ask you about another project you have going. It is very intriguing. It is called Plant Village. It's a nice cross of science, citizen science, and social networking. Can you give me a short rundown on Plant Village?

David: I have traveled around the world and worked in rain forests. Every time you come out of a rain forest, you're coming through a farm. These are poor farmers who are subsisting and growing crops on marginal value. A lot of the crops are being hammered by infectious diseases. I had a good fortune to be traveling with a guy called Dr. Harry Evans from England and a world expert on plant diseases.

Every time I came out of a forest, I walked into a farm and I got this master class in plant pathology or how diseases are transmitted. I realized, as a society in the UK, in the US, or anywhere else on the planet, we are not training people like him. We should but we are not.

Still the farmers are losing 40 to 60 percent on average of their annual production each year in these developing countries. We need to do a better job and everywhere in the world you go, you see phones. All farmers have phones.

What we did, very simply myself and my colleague who is really excellent on this space called, Dr. Marcel Salathe at Penn State, was made all the world's content on growing food freely and openly accessible to anybody in the world with a phone. We just gave away a library of information. We also wrote it with the farmer in mind.

Lindsay recommended me as a plant scientist on the project and she just really is good at writing content. Now it is the largest social network around food plants in the world. Almost a million people have come to the site, and we are going further. We are going to leverage the power of the phone and your camera to automatically diagnose the diseases.

A farmer either in Ghana or Georgia can point at a plant and get an automatic diagnosis. What we want to do is nothing less than fundamentally transform the way agriculture is done and the way diseases are diagnosed, by using the hundreds of millions if not billions of farmers around the world who have these phones in their pocket, which remember have more than a million times the processing capability than the computers that sent the man to the moon.

Dr. Biology: On Ask A Biologist, all my guests get three questions. I suspect a couple of them will be somewhat familiar. Here we go, let's go with the three questions, when did you first know that you wanted to be an entomologist?

David: I describe myself a biologist, and I knew right from the get go. Right from four years old, I greatly enjoyed David Attenborough. I grew up in Ireland and that was a big thing on BBC TV. Every Sunday I would really devour these programs that came through the TV, and I was lucky in that regard. I guess that I was unlucky that I didn't have a lot of opportunities.

I got kicked out of school at the age of 15, and I came from a poor environment in Dublin. Nobody in my family had ever finished high school.

Four or five years of going around and doing relatively dead end jobs -- horse farms, cycle courier, building site. But, I had always wanted to be a biologist. So I got back into university, and I took the chance. Then, I was able to become a professional biologist. I was lucky in the regard that I knew I wanted to be a biologist but unlucky and that I was a poor kid with not many opportunities

Dr. Biology: Was there a mentor or someone that actually turned the...?

David: No, it was brute force and ignorance, I would say. I lived in the inner city in Dublin. I would climb into abandoned buildings, looking for bird nests. I would try go out in the countryside, as much as possible. I kept a veritable menagerie of animals in my house, from snakes to gerbils and everything else in between.

I just loved animals. I always did, and I just kept going, until, thankfully, I got to where I am today.

Dr. Biology: We know how you got here. It was a little more challenging than some of our biologist, who have been here. I am going to take it all away from you. You can't be an entomologist/biologist. What would you be? What would you do, if you could pick any other career?

David: I like the life of the mind. I think one of the greatest things we do in our society is think about ideas. It wouldn't be a great challenge for me to think about doing history or arts or the humanities. Are you telling me that I can't be at the university that I have to go?

If that was the case, I would open a bookshop. I wouldn't aim for money. I have very little interest in it. I would just enjoy the opportunity to surround myself with books,

which I have always done. I love books deeply. So, a librarian, bookshop keeper, some sort of explorer of ideas. We have such a short life of 70 to 100 years and such a store of knowledge to find.

I would engage myself, if I couldn't do this. That would be not a great challenge.

Dr. Biology: The last question is what advice would you have for a young entomologist, again, or biologist or, perhaps, someone who doesn't like their job and wants to shift to another career? They have always thought they would be a biologist. With your particular focus, I think you might have some great insights for those students out there that don't think they have a chance.

David: If you think you don't have a chance, understand you are completely and utterly wrong. There are lots of chances. Find the book, find the Web series, find some information and just consume it. Consume it for pure joy of consuming it, and that's the great scientist throughout the ages from Galileo to Darwin and the contemporaries today, people who just want to discover things.

Go and engage with all the great content on the Webs and great information. If you can get into a community college or stay in school or find somebody who can kind of push you please do that. But, stuff like Ask A Biologist is great because the Web really opens up these communities.

If you realize you are doing it for its own sake, that's the very best. Be curiosity driven. Find out the information, and that, even if you stay in the job that you have or the conditions you have, that will enrich your life immeasurably. Then you will never be satisfied. You will always want more. You will always go on, and that's the true mark of a scientist or a curiosity driven mind to constantly go on.

At the end of the great story of your life, you will be happy having done that and you will have learned a lot more.

Dr. Biology: We get a lot of questions from students that say they want to be a biologist, but they have this hang up. They say, "But I am not good at math. Do I have to know math?" How did you do in math?

David: I was terrible, and as I was kicked out of school. I have a terrible, terrible education. I went to Oxford and Harvard and Copenhagen and all the fine, fancy pants places around the world, but, in terms of the basic, in terms of English writing and math, I don't think that's a barrier. What is important is the passion for a topic and that can be any topic. It can be the history or the civil war.

It can be biology. It can be anything in between. Then, you have to have great determination to put away the distractions of life like the phone and the alerts. Just to open a book or to look at the great content on the Web and just sit down and say, "What is this person saying to me?" and "How can I understand this?"

Put in the hard work with the passion, you will go far. I don't do mathematical biology myself, but I collaborate extensively with people. If you can bring to the table this understanding of biology, you will find collaborators. That's the beauty of science, because it's a collaborative exercise. You can find really good fruitful exercises at the boundary.

Dr. Biology: David Hughes, thank you very much for visiting with me today.

David: My pleasure, thank you.

Dr. Biology: You have been listening to Ask A Biologist and my guest has been David Hughes an entomologist and professor at Penn State University. For those of you who would like to explore more about zombie ants, you might like to visit the companion possible article on Ask A Biologist. The address is askabiologist.asu.edu/zombie-ants.

Don't worry, if you couldn't write that down. We will have it on the page that also hosts this podcast. Those of you that would like to learn more about Plant Village, that's an easy one. It's plantvillage.com and you can check out all the things that David has been doing with that project.

The Ask A Biologist podcast is produced on the campus of Arizona State University, and it's recorded in the grassroots studio, housed in the school of life sciences, which is an academic unit, of the college of liberal arts and sciences. Remember even though our program is not broadcast live, you can still send us your questions about biology using our companion website.

The address is askabiologist.asu.edu or you can just Google the words Ask A Biologist. I'm Dr. Biology.

Transcription by CastingWords