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0:00:06.0 Sarah Crespi: This is a Science Podcast for November 18th, 2022. I'm Sarah Crespi. Each week I interview journalists and scientists that publish in Science and the sister journals.

First up this week, the effect of mammoth and mastodon ivory on the illegal elephant ivory trade. Online news editor Mike Price joins me to discuss how melting permafrost has uncovered more fossilized ivory than ever. But there are questions now about whether the availability of this type of legal ivory might reduce the pressure on elephants or make it worse for them.

After that, we hear about making electronics greener through fungus. I talked with researcher Doris Danninger about her Science Advances paper on replacing the bulky parts of chips and batteries with sheets of fungal tissue to make flexible, biodegradable, renewable electronics.

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0:01:04.8 SC: Now we have Mike Price. He's an online editor for our news team. This story is about the ivory trade, which makes me think of elephants, illegal machete killings, all these terrible things. But you first encountered the story at the annual Society for Vertebrate Paleontology meeting. What does that have to do with ivory sales?

0:01:26.2 Mike Price: Yeah, so it's not just elephants that have ivory, their extinct ancient relatives, mastodons and mammoths, had tusks as well. And as the permafrost melts and their skeletons come to the surface, you can recover fossilized ivory, which in a lot of ways is like normal ivory. It looks a little bit different, but it's ivory just the same.

0:01:50.5 SC: So this is bringing ivory from the past into the present. Who was talking about this at the meeting?

0:01:57.0 MP: A guy named Andy Huynh. And he spent a decade with the US Special Operations Forces and served in Afghanistan and Iraq and Syria and has seen a lot of horrors, has spent his life wanting to make the world a better place. After he got out of the Special Operations Forces, he was looking for something to do with his life and happened to join one of his former comrades in Kenya's Maasai Mara National Reserve. And there they were helping some of the local wildlife rangers to protect animals from poachers. And he encountered some white rhinoceroses that had been killed by poachers. And it really struck him. He's seen the horrors of war and all kinds of tragedy, but nothing had really affected him like seeing these animals that had been slaughtered and a whole herd is wiped out. He decided he wanted to dedicate himself to saving these animals. And he started working with the United Nations and Interpol doing undercover operations. He'd go into various illegal wildlife trade markets in China and Vietnam. And at one of these, one of his colleagues pointed out that it wasn't just elephant ivory that was being sold in these markets, some of it was also mammoth ivory.

0:03:23.1 SC: Yeah. And so that brought together the paleontology part of this, the protecting the ivory or the animals that bear ivory part of this and this guy Andy.

0:03:32.4 MP: Exactly. And Andy, the other thing about Andy is he also has been a dinosaur nerd his entire life. As a kid, he grew up really fascinated with dinosaurs, like everyone else was obsessed with Jurassic Park. And he saw a way that he could marry these two interests, wanting to really help animals and make a difference in the world and reconcile that with his other love for dinosaurs and ancient life. And he's also actually currently an undergraduate student. He's gone back to school studying paleontology under the tutelage of a renowned tyrannosaur expert named Thomas Carr, who's also himself kind of a big name in protesting the commercialization of fossils. So he's kind of found himself on this path where he's studying paleontology, he's studying dinosaurs and at the same time, he's involved in this effort to fight against the commercial sale of fossils.

0:04:29.5 SC: What was the reaction like at the meeting that you went to? What did people think about this talk?

0:04:36.1 MP: I had several people tell me that this was the only time in their many years history of attending SVP that they had seen a standing ovation for a talk. So at the end of Andy's talk, he paused for a moment and became emotional as he acknowledged some of his former colleagues that had died in the wildlife protection efforts in Africa. And that kind of brought the crowd to their feet.

0:05:04.7 SC: Was he there to tell people that there is this connection between mastodon, mammoth and elephant ivory, that they all kind of go into the same pot and they're all kind of being funded by the same people and that should be stopped?

0:05:19.1 MP: Yeah, let me kind of set the stage for the connection that he was making for people. The idea is that there's a robust market, especially in Southeast Asia, for elephant ivory. This ivory gets used in traditional medicine, it gets carved into figurines and beads and statues. There's a massive market for it. And it has become more difficult in recent years to source this ivory. Regulators have cracked down on the trade of it. The protection of these animals has increased in recent years, both from private citizens that were, who are out there trying to protect wildlife as well as governments that have stepped in to protect these animals. And as a result, it's becoming harder and harder for poachers to get their hands on elephant ivory. And some people have proposed that mammoth ivory could be an ethical alternative to elephant ivory because...

0:06:18.5 SC: Because you're not gonna be killing the animals, it'll take the pressure off those elephant populations?

0:06:24.9 MP: Exactly. So that's an argument that some people have been making for years that as more mammoth ivory enters the market, it will relieve some of that pressure and result in fewer deaths for elephants. But what Andy was saying, and some of the data that he presented at SVP seemed to back this up, is that based on people who have gone into these markets over the years and been tracking the sale of ivory, both mammoth and elephant, over the past couple of decades, what they've seen is that the amount of mammoth ivory has continued to go up as the market for it has increased, but they haven't seen a decrease in the demand for elephant ivory that you would expect if it was actually kind of taking the place of it. What they see is that the appetite for elephant ivory seems to stay about the same even as the sale of mammoth ivory grows. So to Andy, that suggests that it's not necessarily an ethical alternative but what it's doing is just sustaining people's appetite

for ivory in the first place.

0:07:31.4 SC: Can people tell the difference between, do they care if there's a difference between mammoth and elephant?

0:07:37.7 MP: Different people care about different things in the ivory market. And so what I've heard from other researchers that study this is that a lot of the carvers who are working with ivory prefer ivory from elephants. It's much easier to carve elephant ivory into these intricate designs and statues.

0:07:56.8 SC: Versus something that's a fossil?

0:08:00.9 MP: Yeah, exactly. Versus a fossil. And so for the most intricately carved designs, they prefer to work with elephant ivory. But for smaller pieces, for things like beads and smaller pieces, it's almost impossible to tell the difference.

0:08:15.1 SC: Is it legal to sell mammoth ivory?

0:08:17.6 MP: It is perfectly legal to sell mammoth ivory. There are no prohibitions against it. And because it's not, itself a protected animal, the animals are extinct. So they have no protections.

0:08:30.4 SC: But it's not good for paleontology for all of this fossilized ivory from mammoths and mastodons to be exposed by permafrost and then immediately whisked off into the ivory markets.

0:08:42.1 MP: There's kind of two answers to that. The first is that another point that Andy was making is that the same criminal organizations that for years have been involved in the illegal elephant ivory trade, those same organizations are the ones who have now moved into the mammoth ivory trade, paying so-called tusk hunters to find these thawing skeletons and remove their tusks. Again, that's perfectly legal. But Andy's point is that the funds generated from this are being redirected back into criminal organizations who are then using that money to engage in things like drug smuggling and human trafficking and supporting what we say, they are just human atrocities around the world. And then the second part of that is, and this is a point that Andy's mentor, Thomas Carr, has made, is that every tusk that gets sold into the commercial market is a tusk that is unavailable to science. And so it's also a loss to paleontology because as the commercial sales of mammoth ivory increase, that's fewer samples that are accessible to scientists who want to study what was happening to these animals as they lived out their lives.

0:09:54.5 SC: And is that something that people are pushing against, that they wanna stop mammoth and mastodon ivory trade as well for the reasons that we've outlined? Is that what's gonna happen with that?

0:10:04.1 MP: There are various opinions on this. By and large, the Society for Vertebrate Paleontology as an organization has for a long time argued against the commercial sale of fossils and has promoted the idea that scientists shouldn't be publishing any work that contains fossils that are in private collections or have been put on the market for private sale. They only want scientists

to work and publish on samples that are in museum collections, university collections, things that will be forever accessible to future scientists. As a result of Andy's talk, the outgoing president of SVP told me that some of their committees are going to see if they could come up with a new position statement, kind of further strengthening their position on specifically on mammoth ivory.

0:10:56.7 MP: But that's still being worked out. I don't know anything about the details of that yet. But as I said, there are various opinions among paleontologists who are involved in this. The lines between what counts as a private sale and where you get your ivory from for studying can be a little murky sometimes, and it's difficult to paint everyone with the same brush. I think there are a number of paleontologists and people involved, even in elephant conservation and people who study the ivory trade, who say it's an open question whether or not the sale of mammoth ivory actually is supporting the ivory trade. There have been other studies that suggest that mammoth sales have been reducing the number of elephants killed.

0:11:43.1 SC: I was gonna say this reminds me a bit of the Burmese amber study that we recently covered where the fact that it's being sold as a jewel but it has something of paleontological value in it, it actually makes it more valuable. And then that money going back to Myanmar and helping with fighting, that was something that was recently discovered. And it's kind of this very long chain that leads from researchers back to bad actors.

0:12:08.6 MP: Yeah, that's exactly right. There are a lot of parallels to the Burmese amber trade. One of the things that several of the researchers that I spoke to afterward mentioned was that they would like to see more data about whether or not the legal market for these things, whether or not it's for scientific purposes or for private sale, whether or not the existence of the market in the first place allows the more illicit dealings to take place under the surface. So, if you were to have some kind of blanket ban on mammoth ivory sales, then only bad actors would be involved on the scene. But at the same time, having a legal outlet for this also makes it possible for people to operate in the black market as well.

0:12:51.8 SC: Are you gonna keep following this story?

0:12:53.0 MP: I would love to keep following this story. One of the things that really came to light was that on both sides of the issue, whether or not it's really an open question, how this mammoth ivory is really affecting the market for elephant ivory. And one of the things I heard over and over again is we just really don't have enough data to answer that question. So if anything, Andy's talk has spurred me and others to want to learn more and actually see if we can find out, quantify what that connection is.

0:13:25.3 SC: All right. Thank you so much, Mike.

0:13:27.3 MP: Yeah, thank you, Sarah.

0:13:29.2 SC: Mike Price is an online news editor for Science. You can find a link to the story we discussed at science.org/podcast.

Stay tuned for my chat with researcher Doris Danninger. She's a PhD student at the Institute for Experimental Physics at Johannes Kepler University. We're gonna talk about using fungus to make greener electronics.

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0:14:00.5 SC: Electronic waste is a growing problem. We're kind of constantly throwing out little pieces of electronics, chips, sensors, computers, iPhones into the landfill. And the bulk of the trash is actually often plastic or polymers. Now we have Doris Danninger. She and her colleagues wrote in Science Advances this week about engineering a greener for electronics using fungus. Hi, Doris.

0:14:25.5 Doris Danninger: Hi.

0:14:27.0 SC: So what part of an electronic device can be replaced by fungus?

0:14:33.3 DD: In our demonstration, the biggest part that we wanted to replace is the substrate of an electronic device. It makes up a huge portion of its mass. So it makes sense to replace that with the biodegradable material. But we did not only fabricate like PCBs and electronic devices with circuits on top, we also made batteries. In batteries, we wanted to also substitute as much of its mass fraction as possible. So we replaced all of the encapsulation by the mycelium material, as well as one key component, one active component of the battery, the separator. One of the layers in between that is important for the functioning of the battery is also replaced by mycelium material.

0:15:11.7 SC: Okay. So let's start with the circuit board part. So this is basically the backing that all of the little fine metallic pieces sit on. This is something that's made of plastic now and you replaced it with a specific part or a specific kind of fungus?

0:15:27.4 DD: Yes, exactly. So usually this is made either of fiberglass with resin coatings or if you're going the flexible way, polyamides or something like that. So all of that is not really sustainable and not degradable. And we used a very specific fungus that has this property that when it grows as a big substrate block, it forms a skin on top, just really a paper-like sheet that you can harvest and then use as a substrate instead of these plastic and non-degradable materials.

0:15:57.6 SC: So this mycelium and you grew that and then you were able to what, dry it and then replace the backing for circuit boards.

0:16:06.9 DD: Yes, exactly. So when you harvest this mycelium skin off the fungus substrate, you can just tear it off using a PE separation grid, a plastic separation grid, and then you dry it, you compress it, and then you have something that is very similar to paper. You can directly functionalize this paper-like material, this mycelium material by evaporating copper or gold, so any metallic layers on top, and then fabricate metallic traces just very analogously to conventional electronics on top of that.

0:16:36.8 SC: So you can use all the same techniques to put circuits onto these boards that you would do with a normal backing. I was really surprised that the temperatures here are so high that

this material can withstand such high temps and it doesn't burn like if it were paper.

0:16:53.2 DD: No, exactly. It's quite flame resistant and fire resistant, which is important when you fabricate electronics on top, right? You need to solder components on top and at certain spots there is a large amount of heat going into the material, but it can sustain that and so you can easily solder conventional electronic components on top of that material and it doesn't damage it.

0:17:14.8 SC: That's like 200 C. That's not a small amount of heat.

0:17:18.7 DD: Exactly.

0:17:19.1 SC: So one thing we kind of have passed over is that, yeah, this is like paper and so that means that it's flexible. Was that an important factor for considering this material?

0:17:26.7 DD: Yes, because for wearable electronics, the conformability of the device is often a very big selling point because when you want to mount those devices on, let's say a soft robot or some other external components, you want them to either conform to the device that you are mounting them on or to just be flexible and adhere to anything. So having them conform to other surfaces is really a big advantage because you're not limited in the place where you apply them basically. So if you have some kind of moving parts in some other device, it doesn't necessarily inhibit the PCBs to be implemented there because they are flexible.

0:18:05.2 SC: And that was something that you saw with the fungus that was post-processed. It was still very flexible?

0:18:10.6 DD: Yes, exactly. So they could be bent for several thousand times before the resistance or the performance really degraded.

0:18:17.0 SC: What makes this greener than the components that would typically go into this part of a circuit board?

0:18:22.7 DD: First off, it's naturally grown. So you can just make a substrate that is fungus that grows naturally. You can harvest the sheets on top of the surface several times. So we managed to get five harvests, five sheets of mycelium off of one substrate block. Then when you use it, it is biodegradable. It doesn't stay in the landfills forever. It is not very resource intensive either to fabricate and also not to degrade. It degrades naturally in composting soil. We tried that with household composting soil and it degraded very fast actually.

0:18:55.9 SC: Wow. Is that a concern now for electronics if this is sensitive to water or if it degrades easily, is that gonna be a problem if you want it to function over a long period of time?

0:19:08.3 DD: Well, no, in general, not because when you implement it as wearable devices or other kinds of electronics, you usually don't get them in touch with water. That is generally not good for electronics.

0:19:16.6 SC: True. Yeah.

0:19:18.7 DD: And the PCBs that we fabricate out of it, they are stable in air. So air itself is not a problem. Only when higher humidity is coming into place, it eventually, when you add some microorganisms, it would start to degrade. But for every common application that you can think of of everyday use it would not be a problem. It would only degrade when you throw it away. When you put it on your composting place at home, then it would degrade.

0:19:43.9 SC: Why use this fungus or this part of fungus and not say a plant or some other biological source material for this backboard?

0:19:52.7 DD: There is quite a lot of research already going into plant-based materials like cellulose fibers or things like that, but they often are quite intensive in the fabrication. And the sheets that we use, the mycelium skins, they grow naturally and you really do not have to do a lot of it. So you just let the mushroom grow, you harvest the skins, dry it and compress it and you're done. And you can do that several times. You can get five sheets of mycelium off of the same substrate out of it and it is naturally grown then.

0:20:22.5 SC: Is there anything difficult about growing it? Is it smelly or can it get contaminated by other microbes?

0:20:27.5 DD: Yes. Contamination is a big part. So you have to store them quite clean and control the humidity of it otherwise it either grows very in-homogeneously and the samples that you get out are not really nice. So you have to control some parameters in the growth process. But other than that, it's quite easy to do actually.

0:20:48.1 SC: We also talked about using this fungus as components for a battery, both the separator and also the container. So how big was this battery and how much charge was it storing or providing?

0:21:00.7 DD: So in terms of size, we can basically arrange that however we want. For single cells, we made two by two centimeter large cells, but then they were very thin. So just two or three millimeters of thickness. So a very flat battery. We also made like dual cells when you need higher voltages. You can just make the whole cells already in several cells in links to each other and then get higher voltages and higher currents out of it. And we were at about eight milliampere hours for the two by two cells, which is not that much, but for the small form factor, it is perfectly fine for any untethered small sensor patches or things like that, which was the goal that we were trying to demonstrate here.

0:21:42.6 SC: Right. So you were able to combine the board that you made with the battery that you made to make these little devices. Can you talk about that a little bit?

0:21:50.5 DD: Yeah, sure. So we made a small sensor board which incorporated a sensor that can be both used as a humidity sensor or as a proximity sensor. So basically a touch sensor. And it also had a Bluetooth chip and some data logging component on top. And all of it was powered by the

mycelium battery. So when you look at the full device, a huge portion of its mass was substituted by the mycelium skin instead of otherwise the non degradable components that you would use. And this whole thing can just operate completely untetheredly and then send the data that it logs that it measures from the sensor to external devices.

0:22:27.3 SC: Now that you've shown this works in this particular setting, what are the next steps for this work? Are you thinking different fungus, bigger pieces, other uses? What are you looking to do next?

0:22:39.3 DD: First, because you touched on the thing with bigger pieces and one of the advantages of the method that we use now is that it is easily scalable. So growing larger pieces of mycelium skin and making the whole process scalable is easily doable as of now already. So that's not really a concern for us right now. One thing that we are looking into is to just improve the characteristics of the mycelium skins. If you think about paper and fabricating electronics on top of it, the surface roughness for example, would be kind of interesting to improve further. As of now, we left the approach to be as simple as possible to ease the fabrication process and make it more accessible to other types of fabrication methods. But if you want to make more sophisticated layers on top and more sophisticated metals on top, you might want to have a smoother surface. And for that, you would need some more post-processing methods of the fungus skin, for example.

0:23:37.2 SC: Okay, that's great. Well, thank you so much, Doris.

0:23:40.2 DD: Thank you.

0:23:41.7 SC: Doris Danninger is a PhD student in the Division of Soft Matter Physics at the Institute for Experimental Physics at Johannes Kepler University in Linz, Austria. You can find a link to the paper we discussed at science.org/podcast.

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0:23:56.8 SC: And that concludes this edition of the Science Podcast. If you have any comments or suggestions, write to us at science podcast at aaas.org. You can listen to the show on the Science website at science.org/podcast or search for Science Magazine on any podcasting app. This show was edited and produced by Sarah Crespi with production help from Podigy, Kevin MacLean, and Megan Cantwell. Jeffrey Cook composed the music. On behalf of Science and its publisher, AAAS, thanks for joining us.