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0:00:05.8 Sarah Crespi: This is the Science Podcast for January 14th, 2022. I'm Sarah Crespi. Each week we talk about the most interesting news and research published in Science and the sister journals. First up this week, we have news intern, Rachel Fritts. We talk about using cloning to bring back genetic diversity in an endangered species. Next, we have researcher Rick Kraus. His group used a powerful laser to compress iron to pressures similar to those found inside some rocky exoplanets. If these so-called Super Earth's cores are like our Earth's core, they may have a protective magnetosphere, which increases their chances of hosting life.

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0:00:52.9 SC: What do you do with an endangered species that has a tiny population and very low genetic diversity? Basically, the whole population is made up of genetic first cousins or siblings. One surprising solution to this involves cloning. Rachel Fritts is a news intern for Science. She wrote about the first endangered species that has been cloned in order to be integrated into a conservation program. Hi, Rachel.

0:01:18.1 Rachel Fritts: Hi, thanks for having me on.

0:01:19.8 SC: Oh sure, I'm excited to talk about ferrets, even rare ones that I'll probably never run into in the real world. [chuckle] Black-footed ferrets have actually been on the ropes for a long time. Basically since the US started protecting endangered species, these have been under threat. How big is their population these days?

0:01:38.7 RF: Right now as a species, they are still really dependent on captive breeding, so there are usually about 300 ferrets in captive breeding programs in the US and Canada at any given time, and about the same number in the wild.

0:01:58.4 SC: They're not a lot and unfortunately, there's a serious lack of genetic diversity in these guys, is it starting to cause problems with the population with breeding?

0:02:07.0 RF: Every ferret alive today is actually descended from just seven individuals who were captured from the wild in Wyoming in the 1980s, and I should say every individual except for Elizabeth Ann.

0:02:22.9 SC: Okay, we'll get to that in a second.

0:02:24.8 RF: They've seen some decline in what they call reproductive fitness. They are just getting a little bit worse at making babies, and then the babies that are born still mostly, I think, coming out healthy, normal black-footed ferrets but some problems have started to crop up, like their tails will have a little pink in them, or their sternums will be a little bit deformed, mutations that are cropping up because all of the ferrets are basically as related at this point as siblings or first cousins.

0:03:01.1 SC: Okay, here is a question. So they're very kind of uniform, they're cousins, they're siblings to each other, how can cloning help increase diversity in a population like this?

0:03:11.4 RF: There were 18 ferrets that were initially captured for the captive breeding program, and just seven were able to reproduce and pass on their genes. So there were actually two individuals who were captured who did not breed, but their DNA was cryo-preserved somewhere called the San Diego Frozen Zoo. Cloning is a way to unlock the biodiversity that's been frozen in time at the Frozen Zoo.

0:03:46.1 SC: We've had this type of cloning since the 1990s, think Dolly, the sheep.

0:03:51.4 RF: Yes.

0:03:51.7 SC: And it's been used for sheep, for pets, for more kinds of livestock, why is it just now being applied to conservation?

0:04:00.4 RF: Several wild animals have been cloned, even a few endangered species have been cloned, the first... Right at the turn of the 21st century, but in all of those instances, it's just been one or two individuals cloned as a proof of concept. One of the challenges with endangered species is they don't necessarily have the infrastructure, the facility, the resources that, for instance, agriculture does to try a sort of a riskier form of breeding.

0:04:37.3 SC: We're pretty good at keeping sheep alive and breeding sheep.

0:04:40.6 RF: Yes. [laughter]]

0:04:41.6 SC: Maybe it's a little bit easier than some rare animal that people have almost never bred in captivity.

0:04:47.4 RF: Right, we have so much more practice with sheep.

0:04:50.1 SC: Well, why are black-footed ferrets a good early test for this?

0:04:53.0 RF: They actually have a lot of things going for them that make them kind of perfect to be pioneering this as a potential option for other endangered species down the road. One thing was just that they happen to be lucky and have these two individuals that happened to be able to make a really big difference for black-footed ferrets genetic diversity. Part of it is that black-footed ferrets were very unlucky. They have this genetic basis that is so slim that even help from one extra individual can make a ton of difference for them.

0:05:35.4 SC: They also have close relatives that can support the cloning process.

0:05:39.8 RF: Yes, so one of the things that makes cloning endangered species challenging is because each individual is so important. Another animal is usually used as the surrogate mom. So in the case of black-footed ferrets, that's actually the domestic ferret, so any cloned black-footed ferrets will be born from a domestic ferret mom and luckily black-footed ferrets and domestic ferrets are very closely related, and because domestic ferrets are used in, for instance, biomedical research and bred as pets, we have a lot of experience breeding them as well.

0:06:23.2 SC: When you say the domestic ferret is the surrogate mom, it's not just that the fertilized embryos are put into the mom, but the embryo itself comes from the domestic ferret, right?

0:06:34.0 RF: Basically, when I say cloning, I'm talking about something called somatic cell nuclear transfer, that's just a fancy way for saying, you take an egg cell and you suck out the nucleus that contains that egg cell's DNA. And then you take a cell from the individual that you want to clone, and you put its nucleus in that egg cell, and then you kind of give them a little jolt of electricity. If everything has gone well, they start to reproduce, divide and form an embryo.

0:07:10.9 SC: The tricky bit there is that there's mitochondrial DNA hanging around that's inherited from the domestic ferret mom.

0:07:16.3 RF: Yes, that's an added complication of using this form of cloning where you're using a surrogate mom from a different species. The mitochondrial DNA always comes from the mother, so if you use a surrogate from a different species you're going to have the mitochondrial DNA from that species but there is actually a way to deal with that.

0:07:40.9 SC: This is when we finally get to mention Elizabeth Ann, the ferret that was recently cloned.

0:07:45.4 RF: For the most important ferret in this story, Elizabeth Ann, who was born last year, actually has most of her mitochondrial DNA from a domestic ferret but the hope is that when she has her own kids, she will have some male kids who will also have her mitochondrial DNA, but then when they breed with a female black-footed ferret, the kids that they create should be 100% black-footed ferret with all of their genetics, mitochondrial and otherwise.

0:08:24.3 SC: That's great, really interesting. And so that's kind of the big step here is that not only has Elizabeth Ann been cloned, born, survived and maybe even to breeding age, then breeding her will kinda be the big step.

0:08:36.5 RF: Yeah, so if she gives birth this year, she's going to be the first clone who's really integrated into a conservation program, and that's the thing that's really never been done before, breeding a clone of an endangered species, especially breeding with this eye towards, "Well, how can it help the conservation effort and really taking care to make sure that it packs as big as a kind of bio-diversity punch as possible."

0:09:10.1 SC: So you mentioned that this one ferret, one Elizabeth Ann black-footed ferret will introduce a lot of diversity into the black-footed ferret population. Is there a way to quantify that?

0:09:20.5 RF: Yes, so they've actually done genomic analysis of the current captive bred population and of Willa, which is the ferret that died in the 1980s that Elizabeth Ann was cloned from, and they found that Willa's DNA actually has 10 times more unique alleles than DNA from the captive bred ferrets. What that means is that her chromosomes just have more traits and more combinations that can be introduced to the population much, much more than any ferret alive today.

0:09:57.8 SC: Is this something they can do again? Are there other black-footed ferrets in the freezer somewhere?

0:10:02.2 RF: There is one other black-footed ferret in the freezer somewhere.

0:10:05.0 SC: What's his name?

0:10:06.8 RF: Oh, it's Studbook Number Two. [laughter] That one actually died of a disease called canine distemper, so right now they're working on trying to figure out how to get that out of any samples that they use, but they do have high hopes that they will eventually be able to use that sample as well. There are two things to kind of look for down the line, which is more cloned siblings from the same founder ferret as Elizabeth Ann and a clone from this male individual as well.

0:10:41.6 SC: There's some great names in this story, Elizabeth Ann and Studbook Number Two, maybe could be introducing some serious diversity into this population. So what other species might be eligible for this approach of introducing new diversity?

0:10:58.3 RF: Yeah, so another species to watch for, I guess, is the Przewalski's horse, and there actually... Was the Przewalski's horse clone born the same year that Elizabeth Ann was born.

0:11:12.9 SC: His name is Kurt.

0:11:14.4 RF: His name is Kurt. Kurt is named after Kurt Benirschke who was actually the researcher who founded the San Diego Frozen zoo, where the DNA of the horse that Kurt is cloned from was preserved.

0:11:31.4 SC: That's great. So these special horses and then also maybe rhinos could be eligible for this?

0:11:38.2 RF: Northern White rhinos were obviously incredibly endangered. There are only two living individuals left, neither are capable of giving birth at this point, I think several groups around the world who are looking at options to make sure that that rhino subspecies does not go extinct. Luckily, there has been DNA from several Northern White rhinos that has been cryopreserved in a way that could allow for future clones, but the process is not nearly as far along as it is in the Przewalski's horse and the black-footed ferret. Obviously, rhinos don't have something like the domestic horse or the domestic ferret to act as a surrogate, which makes things a little bit trickier. And I think rhinos are also a bit notorious for being more challenging to breed, I think in captivity.

0:12:34.6 SC: I'm curious about this Frozen Zoo. Do they have a really big collection at this point and really wide-ranging selection of animals?

0:12:41.9 RF: Yeah, it's crazy. So the entire Frozen zoo is basically in a room the size of a master bedroom, [chuckle] and it's just this really unassuming looking room full of these sort of big deep freezers, but those freezers contain cell lines from over 10,000 individual animals from...

0:13:07.9 SC: Wow.

0:13:08.8 RF: More than 1200 different species.

0:13:11.9 SC: That's really cool. But this gets to the next point, which is, cloning is not the solution for all endangered species. Is there a concern that this will become the go-to technique approach instead of habitat preservation, for example.

0:13:26.1 RF: I think that while cloning, for instance, for black-footed ferrets can have these huge benefits, right now, there's probably a small handful of species that can really be applied to and it's never, never going to be a replacement for keeping species abundant in the wild, protecting their habitat. Protecting the diversity of ecosystems that already exist, it's much, much harder to build things from scratch, as black-footed ferrets themselves are evidence for. Cloning isn't something that means, "Oh, it's fine if the species gets super rare or goes extinct because we can just clone them back into existence." So it's really more something that will be helpful in the case that species do become extremely rare as a kind of last resort, and as the thing that keeps them from going completely extinct.

0:14:30.1 SC: Thanks Rachel.

0:14:31.1 RF: Thank you, thanks so much for having me.

0:14:33.1 SC: Sure. Rachel Fritts was the news intern for Science. Today is her last day, this day that we're recording, and I hope you'll join me in wishing her well.

0:14:42.4 RF: Thank you.

0:14:43.0 SC: You can find a link to the article we discussed at science.org/podcast. Stay tuned, up next, we have researcher Rick Kraus. We talk about dynamos and magnetospheres on rocky exoplanets.

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0:15:04.1 SC: We've gotten pretty good at finding exoplanets, and if all goes as planned with the James Webb Space Telescope, many new and interesting finds are probably coming soon, but how many of them will have signs that we think of as related to life, oxygen, water or maybe something you don't always think about for habitability, a magnetosphere driven by a dynamo. This is basically a shield that protects the planet surface from ionizing radiation. Rick Kraus and colleagues wrote about the possibility of dynamos and magnetospheres on exoplanets in this week's Science. Hi Rick.

0:15:39.4 Rick Kraus: Hi Sarah, how are you?

0:15:40.9 SC: I'm good, I'm excited to talk about Earth's little magnetic umbrella that basically protects all life on this planet from a lot of scary stuff.

0:15:49.7 RK: Absolutely.

0:15:50.8 SC: And it's driven by liquid iron in our planet's core. How exactly does it work?

0:15:56.5 RK: From basic fundamental physics, if you have a moving metallic material, you can create a magnetic field, and so n Earth's core... We have a solid inner core and a liquid outer core, and because Earth is cooling, that liquid iron is convecting, and so you have material that's moving up towards the surface, and then as that material cools, it descends and then motion in the liquid metal, it creates a magnetic field which extends to far beyond Earth's surface, and that magnetic field then protects the Earth's atmosphere from charged particles from the sun.

0:16:33.9 SC: Most of the rocky exoplanets that have compositions that we think are similar to Earth are bigger, and we don't know that they're all bigger, maybe that's just what we can see with the equipment that we have now, but so far, we've mostly seen Super Earths that have the same composition as us, and that's raised a debate about whether something that big would have a dynamo similar to ours. Why might they be different?

0:16:57.8 RK: So for planets larger than ours, the pressures and temperatures and their interior get to conditions that are way beyond what we have in the Earth, also much further beyond what we can measure in the laboratory. At the center of the Earth, the pressures are 360 gigapascals, which maybe in a more comparable unit, that's 3.6 million atmospheres of pressure.

0:17:19.4 SC: I don't think either one is very understandable for us, [chuckle] but it's a lot, a lot, a lot, right?

0:17:24.8 RK: It's a lot, it's a tremendous amount of pressure, temperatures of 5000 degrees, just conditions that are very, very difficult to reach in the lab. And so if you go to what are called Super Earths, Earths that are one to 10 times the mass of the Earth, those pressures can get to be thousands and thousands of gigapascals, so pressures way beyond those in the Earth. They're so far beyond what we've previously been able to study in the laboratory. Our understanding of materials is generally an extrapolation of what we know, and so those extrapolations can vary depending upon what assumptions you make. And so sometimes based upon certain models, you could say, "Well, those planets will always have a solid iron core, and therefore they wouldn't have a dynamo, or maybe they always have a completely liquid core, and so you would never get solidification which would drive a dynamo." And so we really needed experimental data to constrain what would be happening just at a fundamental level.

0:18:21.6 SC: To get a sense for what's going on in the cores of a Super Earth, to get to these extreme pressures that might be found in the cores of larger rocky planets, you used a laser to put pressure on iron here on Earth, a lot more than has been done before. How much pressure were you able to exert on the iron in these experiments?

0:18:40.4 RK: So we use the National Ignition Facility, which is the world's most energetic laser. The extreme amount of energy in that laser allows us to get to pressures of nearly a thousand gigapascals, which is about three times more than the pressure at the very center of the Earth, and about four times greater pressure than has been achieved in previous experiments to measure the melting curve.

0:19:00.8 SC: You didn't just put a bunch of pressure on iron and say, "That's what the inside of a bigger planet is like," instead you kind of re-created a scenario, the experience of iron inside of an exoplanet. Can you walk us through that?

0:19:15.6 RK: We tried to perform an experiment where we took our small sample of iron and tried to mimic the conditions that a parcel of iron would achieve and would see when it's descending within say a Super Earth, so we would tune the laser pulse very precisely to first heat it and then we would slowly, on a relative scale, slowly compress the iron such that it would be compressed like the conditions of cheese in a planet.

0:19:44.1 SC: As the iron sinks towards the center of the planet, the pressure changes traveling that distance.

0:19:50.6 RK: Yes, as it cools and transfers its heat to the mantle, that becomes now more dense and so it sinks. And so what we try to do is emulate those conditions of, "Let's try to compress the material along the same type of pressure temperature path that you would see in that convective Super Earth, but just do it in the laboratory," and then we would use a diagnostic called X-ray diffraction to evaluate if that iron has solidified or if it stays liquid, and so that allows us to sort of test if you would observe solidification or if you'd never see solidification in one of these Super Earths.

0:20:31.1 SC: Why do you have to use X-ray diffraction to see whether iron is liquid or solid?

0:20:36.3 RK: This is actually a complex question in the community, is what is the best way to evaluate if something is molten or if it's solidified. And actually, some of the recent research has shown that probably the most robust method is to use X-ray diffraction, 'cause what X-ray diffraction does is it tells you if there's any long range order in the system, and so for a liquid, the atoms are moving around at random and so it doesn't have a lot of long range order, whereas a solid, a crystalline solid is by definition has long range order. So X-ray diffraction is somewhat the optimal diagnostic to tell you the difference between this randomly moving liquid and highly ordered solid.

0:21:18.5 SC: The set-up of these experiments is in imitating or recreating one exoplanet in particular, but instead it's more of a generalized Super Earth?

0:21:28.2 RK: Because there's so many planets out there, what we really wanted to say was improve our model for what happens in pure iron, and so what we did was we performed a series of experiments to map out the conditions at which iron solidifies. And so what we were able to do was show that four different initial temperatures in the iron sample, which represents different say temperature profiles in a planet. We then map out the pressures at which that iron would solidify. So we were able to show that if a planet has this temperature profile, it will solidify at this depth, and that's actually a really powerful statement because it allows us to say, "Well, for planets hotter than this, they will never be solid or planets cooler than this they'll be all solid and also sort of give us an idea of the dynamics at which a planet solidifies, because we have ideas for how quickly planets will cool, and then with this experimental measurement, we can also then say how quickly they'll solidify.

0:22:32.3 SC: So they're now kind of a defined set of characteristics that you can say, "Well, these planets, if they fit into those parameters will have a magnetosphere or will likely have a dynamo."

0:22:43.2 RK: There are other controlling factors, but it certainly helps us say, "Yes, we will have a solidifying core, which will drive a convection and that's sort of the key parameters for helping to drive a dynamo.

0:22:58.4 SC: Now, if you put Earth on this curve that you've generated, does it match up with what we see here?

0:23:03.8 RK: Yes, it does.

0:23:04.9 SC: Did you look at a handful or a sampling of exoplanets and try to determine which ones were likely to fit this profile and have a dynamo?

0:23:13.6 RK: You know what, actually, we didn't do that. Our main goal was to really improve our understanding of pure iron and then allow future planetary scientists and astronomers to take this data and evaluate the specific applications for different planets they observe.

0:23:30.3 SC: Right, a bigger planet might actually have longer lasting dynamo according to this calculation.

0:23:36.2 RK: Yeah, that was unexpected and really interesting. Planets larger than the Earth, it will take their cores longer to solidify than smaller planets. But what we believe is that the solidification of the cores drives the dynamo and therefore it sets the time scale for which the surfaces will have a protective magnetosphere which protects the surface from charged particles from the star.

0:24:00.6 SC: And therefore habitable?

0:24:02.2 RK: And therefore have one more component that would make them more likely to be habitable or more time for life to evolve.

0:24:11.4 SC: Very cool. Is there a way to measure the magnetosphere of an exoplanet directly?

0:24:18.3 RK: Yes, there are some methods out there through spectroscopic techniques, by looking at the light that is absorbed in the atmospheres of planets, astronomers can help gain information about the strength and whether or not these planets will have magnetic fields. And so they come at it from an observational way, and we're coming at it from, this is what we predict to happen based on our understanding of material properties.

0:24:45.5 SC: I really thought the fact that the planet was spinning, was what was shaking that metallic liquid around and making the dynamo.

0:24:52.9 RK: It's actually all involved, the fact that the planet's spinning as well as the fact that you're having this convective flow creates the complex motion of that metallic fluid. The field of generating dynamos is something that's incredibly difficult to study, and it actually is a very thriving area of research.

0:25:12.7 SC: Is it possible that the composition of exoplanets insides or maybe their atmospheres or their distance from the stars or other planets, basically other factors could interfere with a working magnetosphere, even though we have the correct proportion of size and pressure and iron and all that stuff.

0:25:32.3 RK: Absolutely. This is not the end all study of whether planets will have magnetospheres. There's a lot of questions about what is happening in the mantle, for example, if the mantle cannot remove heat, if the mantle is completely solid layer and it's not convecting, it doesn't have plate tectonics, you're not gonna remove heat and so the core won't cool very quickly. And so that's gonna have a lot of implications for what's happening in the interior. One key item I wanna make sure is caveat is that we studied pure iron, but we know that the core of the Earth is not pure iron. There's some nickel and there's some light elements, maybe oxygen and carbon and silicon, and those compositions are gonna change depending upon the composition of the star and the specific composition of the planets.

0:26:19.7 SC: Was habitability, the main driver of this research, or were you also interested in iron and pressure and those kinds of things?

0:26:27.1 RK: When we oftentimes looked about what makes a habitable planet, there's a lot out there, but sort of the first order question people asked was, "Is that planet in a habitable zone? Is the surface temperature in a region that would support liquid water?" As we know, liquid water is a requirement, we believe for prebiotic chemistry to evolve. And so what we're looking to do here was to provide another relatively simple observational metric that would help us understand, is this planet more likely to be habitable or less likely to be habitable? And that was how big is the planet, and therefore is it likely or less likely to have a protective magnetic field? Beyond habitability, another really important benefit of this work is that this work paves the way for experimental techniques to measure the melting curves of materials at such extreme conditions, and which is a really sensitive test for our understanding of materials in general.

0:27:26.9 SC: Thanks, Rick.

0:27:27.8 RK: Hey, thank you, Sarah.

0:27:29.0 SC: Rick Kraus is a research scientist at Lawrence Livermore National Laboratory. You can read more about the work we discussed and a related commentary piece at science.org/podcasts.

0:27:39.4 SC: And that concludes this edition of the Science Podcast. If you have any comments or suggestions write to us at sciencepodcast@aaas.org. You can listen to the show on the Science website at science.org/podcasts. You can subscribe there or anywhere you get your podcasts. This show was edited and produced by Sarah Crespi with production help from Podigy, Meagan Cantwell and Joel Goldberg. Transcripts are by Scribie, Jeffrey Cook composed the music. On behalf of Science Magazine and its publisher AAAS, thanks for joining us.