Reindeer lichens are having more sex than expected

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Reindeer lichen. Credit: Marta Alonso-García

In northern Canada, the forest floor is carpeted with reindeer lichens. They look like a moss made of tiny gray branches, but they're stranger than that: they're composite organisms, a fungus and algae living

together as one. They're a major part of reindeer diets, hence the name, and the forest depends on them to move nutrients through the ecosystem. They also, at least in parts of Quebec, are having a lot more sex than scientists expected. In a new study in the *American Journal of Botany,* researchers found that the reindeer lichens they examined have unexpected levels of genetic diversity, indicating that the lichens have been doing more gene-mixing with each other than the scientists would have guessed.

"We were surprised because this species of reindeer lichen had always been considered mainly a clonal species that reproduces asexually," says Marta Alonso-García, the paper's lead author and a postdoctoral fellow at Quebec's Université-Laval. "It doesn't follow the expected pattern."

Reindeer lichens swing both ways: they can reproduce sexually via spores, or they can asexually clone themselves. When fungi reproduce sexually, they send out root-like structures toward a neighboring fungus and exchange genetic information when they touch. They then release spores, single cells containing genetic material, which travel on the wind and disperse. When they land, they start growing and produce a new baby fungus that's genetically distinct from its parents. In asexual clonal reproduction, on the other hand, a piece of the entire lichen (fungus and alga), called the thallus, is pinched off and regrows into a whole organism that's genetically identical to its parent.

The two reproductive methods have different advantages. "Sexual reproduction is very costly," says Felix Grewe, the co-director of the Field Museum's Grainger Bioinformatics Center and a co-author of the study. "You have to find your partner, it's more difficult than reproducing asexually. But many organisms do it because when you have this combining and mixing of genetic traits, it enables you to weed out negative mutations long-term among other benefits."

Microscopic view of reproductive organs of reindeer lichens. Credit: Kim Daloise

The researchers were examining reindeer lichens (Cladonia stellaris) to learn about their genetic patterns. "We used DNA sequences to tease apart the genetic relationships between populations of this lichen," says Alonso-García. "We tested whether individuals from northern Quebec (Hudson Bay) were genetically different from those from the South (Parc National des Grands-Jardins, two hours from Québec City). At the same time, due to its important role in the colonization process after a fire, we evaluated lichen genetic diversity along a post-fire succession."

Lichens can reveal a lot about how wildfires affect ecosystems.

"Wildfire is the most significant disturbance in the world's northernmost forests, and it plays a major role in determining the distribution and composition of plant communities," says Alonso-García. "In Eastern North America, four successional vegetation stages are generally identified after a fire. During the first stage, crustose lichens and mosses colonize the burned surface. Subsequently, the soil is covered by cup and horn lichens. The landscape remains mostly uniform for around 20 years until the arrival of fruticose lichens which replace the previous vegetation. Cladonia stellaris arrives the last one, usually three or four decades after fire." By studying genetic variations in reindeer lichens, the researchers hoped to learn how lichens recolonize an area after a fire.

To study the lichens' DNA, the researchers ground up samples of lichens and extracted their DNA. But lichens present an extra challenge in this process, since they're made up of a fungus and an alga (or a kind of bacteria that performs photosynthesis) living together. "That means that all the DNA is mixed up together, we get one pool that contains fungal DNA and algal DNA," says Grewe. "We have to carefully filter and sort the sequence reads bioinformatically." The main body of a lichen is made up of the fungus, so the researchers wanted to focus on the fungal component's DNA. By comparing the pool of DNA to existing genomes, the researchers were able to pick out the DNA belonging to the fungus, and they could then compare the fungal DNA from reindeer lichens from different areas of Quebec.

What they found was surprising: in general, there was a lot more genetic variation in the lichens than the researchers expected, and that indicates hanky-panky. "It's a general assumption was that these reindeer lichens mainly reproduce asexually because there's little evidence for them producing spores, but now the genetic data shows all this diversity, and that leads to the assumption that might be some form of sex," says Grewe.

A Canadian forest carpeted with reindeer lichen. Credit: Marta Alonso-García

"We were expecting that lichens from North Quebec would be more similar to each other than to those from Parc National des Grands-Jardins. However, our results suggest constant migration of C. stellaris between populations throughout Eastern North America," says Alonso-García. "In fact, contrary to the widespread belief, we found many reproductive structures in the species and these structures are formed after sexual reproduction."

But while the lichens are apparently doing more genetic intermingling than expected, the researchers also found that after a forest fire, the new

lichens that crop up are genetically similar to the ones that were there before. That was counterintuitive— the thought had been that the little cloned lichen bits would be destroyed in a fire, and that the repopulation of lichens would be growing from spores that arrived on the wind from other areas. "Regarding the genetic diversity of the species after fires, we found no differences along four stages of the succession. This was also astonishing because time since the last fire increases the probability that clonal fragments successfully reached the sites, enhancing genetic diversity," says Alonso-García.

In addition to revealing the hidden sex lives of reindeer lichen, the study could have implications for forest conservation. "We have learned that time since the last fire does not necessarily mean more genetic diversity, so conservation strategies in boreal forests should take this into account," says Alonso-García. "Prioritizing the protection of an area should not be based exclusively on its age. This is quite important because funding is usually limited, so we cannot carry out conservation activities in the entire forest." In short: if conservation scientists want to protect areas of forest with genetically diverse lichen populations, the forest's age isn't the only indicator of diversity.

Grewe adds the importance of bioinformatics in learning about how organisms are related to each other. "It is astonishing that today we can have such a detailed view of the evolution of populations using bioinformatics," says Grewe. "This is another good example of how advancement in sequencing technology allows us to learn about the evolution of an organism in more detail than ever before."

Provided by Field Museum