Podcast Interview: Juliana Vianna and Rauri Bowie

PNAS: Welcome to *Science Sessions*, the podcast of the Proceedings of the National Academy of Sciences, where we connect you with Academy members, researchers, and policymakers. Join us as we explore the stories behind the science. I'm Paul Gabrielsen, and I'm speaking with Juliana Vianna of the Pontifical Catholic University of Chile and Rauri Bowie of the University of California, Berkeley. In a recent PNAS article, they and their colleagues examined genomes of 18 species of penguins to learn more about their origins. Penguins are often associated with Antarctica, but according to the authors, that's not where they started out.

Have either of you had the opportunity to observe penguins in the field? Juliana?

Vianna: Yes. So we have been capturing penguins for several years in different parts; Humboldt and Magellanic in the coast of Chile; in Patagonia, rockhopper penguins, macaroni penguins. And we also have been working in Antarctica for several years with gentoo, chinstrap, adélie. And I have been to South Africa as well. I could see the African penguin in the wild, and also in New Zealand the very endangered yellow-eyed penguin and the little penguin. So yeah, I am lucky to have seen 11 species of penguins already.

Bowie: I've seen only two species of penguin, both more associated with human habitats. I've spent quite a bit of time with African penguins, rehabilitating them after an oil spill. And then I've been to New Zealand to see the smallest species, the little penguin. But I hope to see many more.

PNAS: Tell me about the diversity of penguin species across the Southern Hemisphere.

Vianna: Only two species of penguins are distributed around Antarctica, the entire continent. This is the emperor and adélie. You can find several other species in the Antarctic peninsula, like gentoo, adélie, chinstrap, and the macaroni penguin. And there [are] several other species that are sub-Antarctic: king, macaroni, rockhopper penguins. So they are found north and south of the Antarctic polar front and also have species that are north of subtropical front, like the northern rockhopper penguins. You can find species associated with the cold waters of Benguela Current in South Africa. And you can find species in Australia and New Zealand. And also there [are] several species in South America: Magellanic, rockhopper, Humboldt, macaroni, king. Humboldt, for example, can go up to the coast of Chile, to Peru, associated with the cold waters of Humboldt current. And the one that is the lowest latitude is the Galápagos penguin that you can find in the Galápagos islands. So this is about a general distribution.

Bowie: I think it's just fascinating that penguins managed to occupy some of the most remote landmasses on Earth; on these really tiny little islands you can find a penguin colony. So they've been a remarkably successful seabird group from that perspective.

PNAS: Before your study, what was known about the origin and diversification of penguins? Rauri?

Bowie: So there's been an interesting debate in the literature with exactly where the two largest species—the very charismatic king and emperor penguins—where they fitted in the family tree for penguins. And one of the ideas was that they were closer to some of the other living penguins, some of the smallest species nested inside the family tree. And then the other idea was that they were most distantly related to all of the other ingroup—we say they were sister to the rest of the penguins. Penguins also have a rich fossil history. So although modern penguins only date back to about 20 million years, penguins go all the way back to 60 million years. So given this debate, one of the things that we wanted to try and resolve with our study was where exactly do king and emperor penguins go in the family tree. And that would then help us understand how penguins originated and where exactly their origination occurred and when. And so you know, our main conclusions resolve one of these longstanding questions. And we were able to determine that penguins originated along the coast of Australia and New Zealand and the nearby South Pacific islands, and that this occurred about 22 million years ago.

PNAS: How do you determine where and when penguins may have originated?

Vianna: So we use 22 genomes of 18 species, and we could reconstruct the phylogeny; and we use the recent distribution of all of these species, and we modeled the best distribution of the species. And we could find the region of New Zealand and Australia. But we also used ecological data. We obtained satellite information of sea surface temperature, chlorophyll, and also a salinity for each of the 18 species. And we model the best historical niche distribution. And we could also find that the historical maximum temperature was nine degrees Celsius, which match with the geographical region that we found. So both data, ecological and genomic, support the same timing. Rauri, maybe you want to add something?

Bowie: No, I think that's good. So one of the things that we were able to do by reconstructing where penguins originated and using the phylogeny, as well as this large amount of ecological data that's available, is we were able to show how penguins have been able to diversify, to occupy the incredibly different thermal niches that they live in today. And so, by mapping this environmental data back across the family tree of penguins, we could show that penguins originated in temperate waters, probably around nine degrees Celsius—or about 48 degrees Fahrenheit—which is roughly the water temperatures around Australia and New Zealand today. And then from there, we see this really remarkable twin axes of radiation, one which is down into the really frigid water of Antarctica and the sub-Antarctic, which you can get down to negative degrees. And then the other is, as this Drake's passage between the tip of South America and Antarctica opened and changed how the currents flowed around the bottom of the world allowing this circular current to form, penguins were able to move up the coast of South America, eventually reaching the Galápagos islands, which of course are right on the equator.

And so as a consequence of that, they can occur in temperatures right up to 26 degrees or even slightly warmer. So you see penguins being able to span from their ancestral conditions of around 48 degrees Fahrenheit to being able to then colonize freezing temperatures, as well as up to about 80 degrees Fahrenheit on the equator. So really occupying a broad diversity of thermal environments.

PNAS: What did genetic adaptations allow them to do that they couldn't before?

Bowie: So one of the advantages of using the whole genomes is that it provides a record of how genes have changed through time and allows us to estimate different levels of selection across different genes. And so we were able to take all the coding genes from the genome and look at how selection had operated. And from that, we could identify certain parts of the genome that have been what we call enriched or overemphasized in different penguin lineages. And some of the genes that came out were related to pathways, for example, that relate to how blood vessels constrict and expand. And if you think about it, that makes a lot of sense because penguins that live in really cold temperatures, if they can reduce the circulation of blood to their extremities, they can maintain a warmer core body temperature, much as many marine mammals do in the same vein. Similarly, penguins have really interesting adaptations for binding oxygen in the same way that many species that live at high altitudes do. And this fits in with some penguins being able to dive to relatively deep depths where really efficient oxygen metabolism is really important.

And then another category that we see is related to osmoregulation. And that again, when penguins are limited with how much fresh water they may have access to, and as a consequence need to be able to drink seawater, being really efficient in your osmoregulatory pathway allows you to, for example, excrete salts and it facilitates them being able to colonize these really diverse habitats.

PNAS: How does this finding help us better understand the penguin species we have today?

Vianna: We have answered lots of questions about the evolution of the group. And we could understand that like big times of decrease of temperature, like the middle Miocene, was associated with the diversification of penguins as well, the intensification of the Antarctic circumpolar current and other more recent decrease of temperatures as well was associated with a great diversification in penguins. But right now, climate change is occurring too fast for some species to adapt. And so we can already see some species decreasing population sizes, like adélie and chinstrap in the Antarctic peninsula. And on the other hand, gentoo penguin, we know that came from sub-Antarctic region, it's increasing in Antarctica and expanding farther south.

So we know that this species could adapt in the past with a large geological time scale to climate changes. But right now it's too fast for them to adapt. And we know that in South America in Chile and Galápagos, Humboldt and Galápagos penguins have been impacted by the El Niño Southern Oscillations; and with increase in temperature is associated with high mortality for both species. And El Niño is becoming more intense

and more frequent with climate changes. So we expect now to use our ecological data and our genomic data to see how each one of those species were going to adapt in the future. So this is our next step in our research. And also, our data gave lots of answers about the taxonomy of the group. So, how many species there are; we could see that we didn't find many genetic differentiation, genomic differentiation between the macaroni and royal penguin, for example; but [o]n another hand, there was a debate about how many species of rockhopper penguins, and our data supports three species as well. And right now, two of them are considered by the IUCN as only one and vulnerable and decreasing. But we know that one of those—the eastern rockhopper—it has much more strong decreases in population sizes. And it's more affected by climate changes and also other impacts like fisheries and predation in the nest, also invasive species, cats, dogs, rats, and many other impacts.

Bowie: I think I can really think of three interesting ways that our data leads to a better understanding of penguins that can influence their conservation. I think the first thing that's really important to realize is that the genetic variation that we identify and the mutations that may have facilitated penguins expanding across the Southern Hemisphere occurred over a period of millions and millions of years. And the rate at which climate's changing today is so fast that it's unforeseeable that penguins will be able to change rapidly enough to be able to adapt to these changing environments. And this is as a consequence of why we're seeing certain colonies starting to disappear, and other penguins having to redistribute their distributions or having to redistribute themselves because of changes in food resources. And then the other thing that Juliana mentioned as well is that our data gives interesting insight into actually the diversity of penguins.

And we find one instance where perhaps what we think of as two current penguin species, macaroni and royal, should actually be considered one with a really interesting polymorphism in coloration. But in other cases, with rockhopper and gentoo penguins where the diversity has been underestimated and where we may have one species today, maybe three or four different species that are very different evolutionary histories, and have responded very differently through time to changes in environments. And there seems little doubt that, whether we want to call them species or not, they should be managed as separate entities, and so as a consequence should have much greater conservation attention placed upon them because they each represent isolated little units rather than one unit broadly distributed across the Southern hemisphere. And then the last point I think that's worth making is one of the really fantastic things that we can do with genomes is, because we have so much data, we can look back in time as far as a million years of how population sizes have changed.

And so by doing that, we could very conclusively show that most penguins had the largest bump in population size somewhere between 40 and 70,000 years ago, so, when the world was much cooler. And the world has continuously warmed since the last glacial maximum and penguin colonies have been declining for a long time, and it's only been accelerated by these human-induced changes. So they really are in dire need of conservation attention.

PNAS: One last question. Do you have a favorite penguin species?

Vianna: It's difficult. The little one is very cute, but I have been working for a long time with gentoo penguin[s], and I'm really impressed how this species has adapt[ed] and have diversified in Southern Ocean and Antarctica. So gentoo penguin has taken my attention, just because of the results and the work I have done with gentoo, but I really like most of the species and it's very beautiful. And when I was in New Zealand and I could see the yellow-eyed that is very threatened and the little penguin I was fascinated, but I was very happy to see them. Rauri, do you have a favorite penguin?

Bowie: Now you're asking me! Um, it's always so hard. I think my favorite is the emperor penguin. They're such majestic looking animals and so charismatic, but also they have, you know, a most fascinating life history being secluded on the ice, looking after a single egg for such long periods of time and how the male and female need to cooperate to raise their young, and so I've always found them fascinating. But penguins as a whole are a really, truly remarkable group of birds as well as an adorable group of birds.

Vianna: So yes I think emperor and Galápagos are the two extremes in terms of adaptation to the different temperature and environmental conditions, and it's very interesting that both of them take attentions to the public. Like most of the people now talk to me and said*, I didn't know there was, like, penguins in Galápagos or in the coast of Chile and Peru*.

Bowie: For me, I think one of the great results of this paper, one of the things I most enjoyed the most, is that this is a nice example of work that could never have been completed without international collaboration with people and scientists from all over the world, contributing material, contributing their expertise—Juliana in Chile, bringing her extensive knowledge of penguins and genomics, and then my lab being able to help. And so I think that's a really great example of how NSF and other funding agencies have facilitated bringing together different groups of scientists to really do science that has real implications for conservation of charismatic organisms but could never be done by one individual or one organization on their own.

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