Genome Insider Episode 5: Corals in Hot Water Get Help From Their Microbes

One of the reef study sites in Puerto Morelos, Mexico (Caribbean Sea), where the team collected the shallow water starlet coral (Siderastrea radians). (Sergio Guendulain-García)

ALISON: Hey! I'm Alison Takemura, and this is Genome Insider, a podcast of the US Department of Energy Joint Genome Institute or JGI.

OK, so I want you to imagine going to a tropical beach on the Caribbean coast of Mexico. White sand, hot sun, smell of the ocean spray coming off the clear, turquoise waters. You've got your bathing suit, your life vest, your goggles, your flippers – you're ready to snorkel in the coral reef. So, you splash into the water. Small fish dart around you, flashes of orange and yellow, darting amid the tans, greens, magenta, and golds of the coral terrain. But amidst all the color, there's also white – coral that has bleached to the color of bone.

Coral is bleaching because of climate change. Warming oceans are stressing corals, which can cause them to lose the colorful part of themselves: their photosynthetic microalgae.

Corals have a symbiosis with these algae. Corals give them a home and in return the microalgae gives them food.

So, the algae is kind of like the personal chef of the coral.

And losing the chef isn't good. Corals can survive a while if that happens — they still get some nourishment from the zooplankton and food particles that they catch in the seawater.

But if they're without their photosynthetic microalgae for too long, then they die.

Today, we'll hear from scientists trying to figure out why some corals are better able to keep their microalgae.

But first, let's answer: Why do corals matter?

ROBERTO: Coral reefs actually provide huge services to a humongous human population

ALISON: That's Roberto Iglesias-Prieto, a marine biologist at Penn State.

ROBERTO: Just to give you some examples, more than 500 million people receive most of their proteins from fish collected from the reefs.

ALISON: Roberto says coral reefs are often bigger than people think. He likens them to underwater mountains that are big enough to protect coastlines, like the barrier reefs of the Yucatán. Corals' size is another reason they're so valuable.

ROBERTO: These mountains, these reefs can dissipate the energy of storms and hurricanes into noise. So, this energy that can be equivalent to several atomic bombs, is released as noise and protects life and property on the other side of the barrier reef.

ALISON: Coral reefs are also bastions of biological diversity, which Roberto says could harbor unfathomed biotechnological solutions. So not only are corals beautiful, they have untapped potential and provide all kinds of ecosystem services. Now, what exactly is a coral?

ROBERTO: A coral is basically a cnidarian, which is an invertebrate.

ALISON: A familiar cnidarian example is the jellyfish. Cnidarians have a floppy, Jello-like texture, but reef-building corals can have a stony skeleton underneath. A coral is actually a colonial animal, so one colony has many individuals, called polyps, each about a centimeter or two across. Polyps are basically little soft mouths with a circle of small tentacles around them. Many polyps make up a coral, so a coral is basically a living mound of mouths.

But that's not all.

Jellyfish, an example cnidarian. (Joshua Reddekopp on Unsplash)

ROBERTO: Now a coral establishes a symbiosis with microalgae that keeps inside the tissues.

ALISON: And because they establish this symbiosis with a microalgae, Roberto has given corals a nickname.

ROBERTO: I, I normally call them a monster, because monster in mythologies in different cultures are combinations of two or more real things. So you have combination of snakes and lions and that's part of a... this zoological garden mythology. But in real life —

ALISON: In real corals

ROBERTO: you have a carnivore,

ALISON: That's the coral. It eats zooplankton.

ROBERTO: — living with a primary producer, like a tree. So I think this is even more monstrous than the most monstrous animal monster in, in mythology, no?

MÓNICA: I think one of the things that is most fascinating about corals, about this monster, is that there is these tiny little critters that are responsible for building the reef ecosystem.

ALISON: That’s Mónica Medina, a biologist at Penn State.

MÓNICA: And this is exceptional in that the ecosystem can be so large that you can see it from space, like the Great Barrier Reef. So you have a symbiosis between an animal and an alga that builds an entire ecosystem, the most biodiverse marine ecosystem in the planet.

Roberto calls corals 'monsters' due to their chimeric nature: an animal and plant. The original chimera was a combination of lion, snake, and goat pictured here in this statue, the Chimera of Arezzo, c. 400 BC (Carole Raddato)

ALISON: Mónica and Roberto are studying corals, because they’re vulnerable. Corals can lose their plant symbiont, the photosynthetic microalgae.

MÓNICA: This symbiosis is highly dependent on having a certain temperature for it to function properly. And with global warming and climate change, especially tropical waters have been getting warmer and warmer. And this symbiosis is disrupted, and that leads to coral bleaching.

ALISON: But corals don’t all behave the same. There are hundreds of species of corals, and they have different adaptations and physiological responses. Some of them are more resilient. And not only that but each coral species has its own species of photosynthetic microalgae. I used to think they all had the same one as if there was one model of microalgae that they all bought at the same store. But, actually, life is way more diverse, and each coral species has its own particular partner. When it comes to bleaching or preventing bleaching, Mónica and Roberto think that those partnerships matter — that a coral’s resilience could also depend on its microalgae partner.

And maybe something else.

VIRIDIANA: We're also starting to understand that no animal lives without microbes, right?

Mónica Medina (the principal investigator), Viridiana Avila-Magaña, and Roberto Iglesias-Prieto (left to right) in their marine lab, filled with UV lamps, where they grow corals at Penn State. (Alison F. Takemura)

ALISON: That’s Viridiana Avila-Magaña. She’s a PhD student working with Mónica and Roberto. She says the corals live with a microbial community — a microbiome — and that could be an important part of coral resilience. In an earlier project, JGI helped sequence some coral microbiomes to figure out who’s there.

MÓNICA: One of the things that we started to observe initially is that there is high endemicity in the coral in the sense that there is a large microbial community that is rare in the water column. But it's very abundant in a coral. And then when you compare from one coral species to the next, these microbiome changes.

ALISON: So corals live with their microalgae symbiont and their broader microbial community. And the microbiome could be helping out, too, by providing some nutrients to the coral. Or even to the algal symbiont. Scientists don't quite know who's providing what nutrients to whom. But it seems like everyone — all the organisms associated with the coral, or the coral "holobiont" — contribute to a well-functioning, stable system.

MÓNICA: So, there is a big movement today to try to understand local adaptation and these combinations of hosts, algal genotypes and now hosts-algal-microbial genotypes that are acting in concert to respond to a particular environmental condition.

ALISON: One environmental condition is when the waters get too warm. Mónica is saying that the goal is to really be able to link the physiological responses of everyone in the coral holobiont to their genes.

MÓNICA: We want to kind of understand the genetic stock, to understand the potential to confront the future. And the, the very strong selections that we're putting them under, so that we can strategize better, to repopulate — if possible — to restock, or to manage the current standing genetic variation in the reef.

ALISON: So Mónica, Roberto, and Viridiana — who goes by Viri — and their team undertook an ambitious experiment. Working in the Caribbean, they gathered up three different species of coral: the mountainous star coral, which looks like a tan-carpeted rocky hill, the knobby brain coral, which has an uncanny resemblance to the brain with all its undulating folds) , and the shallow water starlet coral, which has these beautiful star-like patterns all over it. Each coral has its own microalgal symbiont, and of course, its own microbiome. So the scientists took these coral samples, and heated the sea water that they were incubating these coral samples in up to 34˚C, which is 90˚F, and they kept it at that temperature for 9 days. They wanted to see how each coral species, its algae symbiont, and its microbiome would respond to that heat spike at the genetic level. JGI helped them do that by sequencing the expressed gene transcripts, or the transcriptomes. Viri and her collaborators found that when the coral starts getting stressed, the algal symbiont and the microbiome can help keep the coral host from bleaching.

Mountainous star coral (Orbicella faveolata). (NOAA)

VIRI: We saw that people may think that thermo-tolerance is given by the host. But we start to characterize that the thermo-tolerance is at the level of all the members — like all of them are engaged.

Partially bleached mountainous star coral (Orbicella faveolata). (Ryan McMinds)

Knobby brain coral (Diplora clivosa). (Phil's 1stPix, CC BY-NC-SA 2.0)

ALISON: What does that mean? Imagine for a minute that you're a happy coral. You're bathed in nice Caribbean water, not too cold, not too hot, but just right. But then an underwater heat wave hits. And some of your algal symbiont cells, which are your photosynthetic powerhouse, start feeling it.

Shallow water starlet coral (Siderastrea radians) with retracted polyps in Flower Garden Banks National Marine Sanctuary. (NOAA)

VIRI: Probably here the symbiont already says. Hey, bye, you know.

ALISON: Now, it’s not necessarily all of the cells that are saying bye, but some of your symbiont cells pack up and leave! You, the coral, have a problem: The algal cells were absorbing light. That’s their thing; they make food out of it. But now there are fewer symbiont cells in your body, with the same amount of light is falling on you. That means that there’s more light per symbiont cell.

VIRI: So the organism is like, Oh, this is so much light.

ALISON: More light makes the algal cells uncomfortable. Thanks to the light, they’re photosynthesizing at a faster rate, producing more of photosynthesis’ byproduct: oxygen. Oxygen can be harsh on a cell’s interior, because oxygen creates free radicals that can damage the cell’s membrane, proteins, and DNA. This state is called oxidative stress.

VIRI: So now this oxidative stress is going to be used as a signal like to say 'Hey, something is happening — like, there is a damage in our molecules and DNA etc, like, what we going to be doing?'

ALISON: The symbiont starts activating genes in response. And a lot of these genes weren’t what Mónica, Roberto, and Viri were expecting.

VIRI: You think like, just a family of genes or ultimately proteins that are going to be important and it's always like oh the Heat Shock proteins and all of those, like people think about them.

ALISON: Heat shock proteins are these proteins that biologists often hear about bacteria making when their environment gets too hot. The heat shock proteins are really canonical; they’re conserved in almost every organism, from bacteria to humans. And I think biologists typically learn about them in their introductory classes. That’s where I heard about 'em.

VIRI: And yes, we have some of them of course, but we start to realize that actually, there are many more others that are related specifically to photosynthesis. The photosynthesis is key for the thermotolerance because if you can keep it up, then you can, you know, perform, and get all of these metabolic pathways.

ALISON: Let me repeat that: Photosynthesis is key for dealing with heat. How does that work? It works because the coral's symbiont, when it keeps photosynthesis going, can invest more energy into repairing systems and putting out the fire of oxygen radicals, so that it can actually help prevent the coral from bleaching. But corals and their symbionts don't all react the same way. And here's where Viri could see that the corals that were heat-tolerant acted really differently from the corals that were heat-sensitive. So, first, which coral was the most resilient to the heat and the least likely to bleach? It turned out to be the starlet coral. The most sensitive coral, on the other hand, was the knobby brain coral. And for both corals, their resilience, or lack thereof, was strongly dependent on their algal symbionts. Both of the coral's symbionts activated photosynthesis genes under heat stress. But in different ways. The starlet coral's symbiont activates genes that help maintain its photosynthetic machinery.

VIRI: They have a way better ability to repair the photosystem to like keep performing tasks that are essential for the holobiont's health.

ALISON: By contrast, the heat-sensitive knobby brain coral symbiont tries to fix damage after it's already been done: it activates genes related to degrading broken photosynthesis parts and replacing them. So I think of these two different coral symbionts — the more resilient one in the starlet coral and the less resilient one in the knobby brain coral — as being like different bike owners. And maybe this is because I bike, but one owner is conscientious and invests in the upkeep of their bike, keeping it indoors, protected from the elements. The other owner leaves their bike outside and doesn't notice gears are rusted until the parts need to be replaced. The knobby brain coral's symbiont is like that negligent bike owner, and has to invest more energy into replacing pieces of its falling-apart photosynthetic machinery. Viri also says that the knobby brain coral hosts…

VIRI: They don't communicate that well with their symbiont. And we also see all of these metabolic pathways that are already disengaged.

ALISON: Viri also investigated what the coral microbiomes were doing. And the microbiome's role is definitely fuzzier. But it seems like the coral microbiome might be able to help coral holobionts be more resilient. For example, the microbiome had more metabolic capabilities that could help cover the needs of the coral and its microalgae symbiont when they were stressed.

Viridiana Avila-Magaña processing fragments from the coral colonies before putting them in an -80ºC shipping container (right) to prevent nucleic acid degradation as they're transported back to the United States. Avila-Magaña is now a postdoctoral fellow at the University of Colorado Boulder. (Ana María González)

VIRI: It's really important because what we see also is when you have the thermal stress, well, the symbiont is, sometimes the photosynthesis is compromised.

ALISON: And one example of how the microbiome appears to help out is by providing more nitrogen.

VIRI: The photosynthetic machinery needs a lot of nitrogen so they can take it from all of these microbes, presumably.

ALISON: And in the analysis of all the RNA transcripts, the meta-transcriptome, the team could see that a more diverse population of microbes made for a more resilient coral holobiont.

VIRI: We starting to unveil thermo-tolerance like more, how you say like, like a response or it's all together, you know, and all the members have to be communicating and have to be like performing at certain level to have this robustness.

ALISON: One of the real strengths of the analysis, Monica says, is that her team looked at different species of coral simultaneously. And that was important for looking at adaptations. The team worked with Rori Rohlfs, who's a computational biologist at San Francisco State University. Together, they developed a general statistical technique for looking at how life responds to different conditions — whether that's heat or a change in pH or low oxygen levels. It could be anything. The method is based on a phylogenetic ANOVA (or analysis of variance), and the algorithm they developed is called EVErESt, for short. With this technique:

MÓNICA: You can pinpoint the genes that may have had an adaptive role in thermal stress response.

ALISON: With corals, the technique allowed the team to go beyond just a description of coral gene responses to being able to compare them across lineages and infer which responses might've been inherited from a common ancestor — i.e. who got the genes that help deal with heat?

MÓNICA: So before we could say, it bleached, it didn't bleach. And it seems like these are the pathways doing it.

Here, Viri was able to say: This is how the host is responding. And these are the pathways responsible in this lineage. And these are the genes responsible in this lineage, and this is conserved across these two lineages.

ALISON: They can do the exact same thing with the microalgae symbiont, too. They can ask: What gene responses are conserved? And which aren't? This analysis approach let them open a window into what kinds of responses have evolved in corals and their symbionts. And that allows scientists to make hypotheses about corals that have never been tested.

So, where does that leave corals? They're still threatened. Climate change is still warming and acidifying ocean waters, which can lead to coral bleaching. But not all corals behave the same, and neither do their microalgae symbionts. Some can take a little heat. Now we better understand how.

ALISON: This episode was directed and produced by me, Alison Takemura, with editorial and technical assistance from Massie Ballon, David Gilbert, and JGI's intern, Ashleigh Papp. Ashleigh also collaborated with me on sound design of this episode. Genome Insider is a production of the Joint Genome Institute, a user facility of the US Department of Energy Office of Science. JGI is located at Lawrence Berkeley National Lab in beautiful Berkeley, California.

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And if you're interested in hearing about cutting edge research in secondary metabolites , also known as natural products, then check out JGI's other podcast, Natural Prodcast. It's hosted by Dan Udwary and me. That's it for now. See you next time!

Additional information related to the episode

Check out a recap of Medina's original Community Sequencing Proposal submitted in 2007.
More information on coral-algal symbiosis at JGI's GenomePortal.
Publication: Avila-Magaña, V. et al. Elucidating gene expression adaptation of phylogenetically divergent coral holobionts under heat stress. Nature Communications. 2021 Sep 30 doi: 10.1038/s41467-021-25950-4
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