Interviewee Name: Margaret Miller

Project/Collection Title: Decades of Change in the Florida Reef Tract: An Oral History Project

Interviewer(s) Name(s) and affiliations: Zachary Mason, NOAA Heritage Program

Interview Location: Key Biscayne, Florida

Date of Interview: July 24, 2020

Interview Description:
Margaret Miller
Key Biscayne, FL
Coral Reef Restoration Research Director Interviewed by Zachary Mason

Margaret Miller is the Research Director for SECORE International, a conservation nonprofit dedicated to creating and sharing the tools and technologies to sustainably restore coral reefs worldwide. She leads SECORE's research strategy and fosters research collaborations with scientific partners. Margaret serves on the US-Acropora Recovery Implementation Team (ARIT) and as a Councilor-At-Large for the International Coral Reef Society. Previously, she spent 19 years as a Research Ecologist with NOAA Fisheries' Southeast Science Center. She led an active field research program in the Florida Keys focused on coral early life history, coral restoration, population studies of threatened elkhorn and staghorn corals and their threats as well as playing instrumental roles in shaping NOAAs coral reef monitoring program and the listing and recovery planning process for corals under the Endangered Species Act.
Margaret grew up and learned to SCUBA dive in southern Indiana. She has an undergraduate degree from Indiana University and a doctorate in marine ecology from UNC-Chapel Hill. She currently resides in Miami with her husband and 17-year-old son and is an active member of Crossbridge Key Biscayne church.

Collection Description:
Florida is home to the only barrier reef in the continental United States. This project uses oral history interviews of coral reef stakeholders in Florida to showcase major changes in the reef tract over the past few decades. The stakeholders interviewed include scientists, fishermen, and SCUBA divers

Citation:
Margaret Miller, Decades of Change in the Florida Reef Tract: An Oral History Project Interview, July 24, 2020, by Zachary Mason, **37 pages, NOAA Voices from the Fisheries. Online: Insert URL (Last Accessed: Insert Date).**

Transcription by: Edith Mari, NOAA Voices Oral History Project

Start of MILLER_MARGARET_7_24_20.mp3
[02:01:49.0]
ZM: Zachary Mason (Interviewer)
MM: Margaret Miller (Interviewee)

[00:00:00.00]

[00:03:00.0]

ZM: This is Zack Mason on July 24, 2020. I am interviewing Dr. Margaret Miller of SECORE [Foundation]. SECORE, if I am not mistaken, stands for SExual COral REproduction International. Is that right?

MM: It does indeed. We get to have "sex" in our name.

ZM: Funny enough, I was looking through the website and I could not find what the acronym represented, so I resorted to Wikipedia. My first instinct was, "There's no way that's right". But...

[00:00:48.0]

MM: Indeed, indeed it is. Which is why you generally only find the acronym name there. But it is an accurate name that was chosen some years ago. I think there might be some done differently if we did it again, but that's us, and it's accurate. Related to what we do. I'm sure we'll talk about that a little bit more later.

[00:01:13.0]

ZM: With the acronym out of the way for now - there are so many acronyms that I have come across so far that I think it is always good to define them immediately.

[00:01:25.0]

ZM: Let's start at the very beginning. Actually, before we do that, I watched a YouTube talk that you gave at a convention for -- what is the proper term for people that have home aquariums? Is it aquarists?

[00:01:48.0]

MM: Right. Yes. Probably the Macna Convention in ...

ZM: Yes, that is the one. I think you explained it really well. I think a lot of people are very confused about what a coral or a coral reef actually is. And they always ask, “Is it an animal, a plant, a mineral?” It's a very good 20 Questions topic. Could you explain very briefly, what is a coral reef?

[00:02:16.0]

MM: Yes. The answer, as the way you phrased it, is yes. Corals are animals.The primary organism that builds coral reefs is an animal, but it builds rock. That's what the reef is, that’s part of its skeleton. And those skeletons build up over time to build reefs as we know them. That's the mineral part that the animal creates, mineral skeleton that it leaves behind and builds reefs. But the really cool thing about corals is that they actually have plants that live inside their tissues. They're different. They're unicellular plants that live inside their tissues. When I talk to school kids, I always ask them, “Wouldn't it be cool if at lunchtime, you just go out and sit in the sun and make your lunch, just sitting out there?” Because that's essentially what corals do. They're able to get their energy through photosynthesis through the photosynthesis of their symbionts. That's really what makes corals special. There are various other types of organisms that live on coral reefs that have a similar symbiosis with small plants that enable them to make their living from the sun, even though they're animals. They have all three of those bases covered, which is one of the cool things about corals, I think.

[00:03:31.0]

ZM: I think the photosynthesis aspect is really interesting. I am not sure if we will have time to get into it later, or if we will even get into it later, because there is so much to talk about, but a lot of people do not even realize that when there is all kinds of other particulate matter in the water, that could actually inhibit corals from getting the nutrients that they need.

[00: 03:56.0]

MM: It can be. This is something that the biologists have been studying and trying to figure out over many decades in terms of how it is, really, that corals best make their living. We know that they use the sunlight. There are different environments, and different species of coral have a range of dependency in terms of what they have to eat as well. Certainly they do eat organic matter and prey from the water column as well, but they're not real good at it, most of them. Some species are better than others; they're just not really good at catching prey, because they just sit there.They have little tiny tentacles. But there is definitely a balance there and they're able to get a lot of their nutrients from that prey. Whereas they get their energy from the sun, from the photosynthesis of their symbionts for the most part. There's certainly a range of biology. There's a lot of biology going on there in terms of how corals balance those different sources of nutrition and how they can compensate in different environments and different conditions. We'll probably talk about coral bleaching, maybe some later, but that's one of the neat things that we've learned recently is that some species of coral - not all of them, but some of them - can actually compensate. During coral bleaching, those plants are lost and corals lose that source of energy when it gets too warm. We call that coral bleaching. Some species are actually able to compensate a little bit so they can eat more prey during periods of time when they're bleached, and be able to survive better during those periods of stress. That’s an example, as I said, of different environments or different conditions, how corals are quite flexible, and how they can make their living.

[00:05:46.0]

ZM: That is really interesting. Yes, I actually did not know that about eating more in response to a bleaching event. We will definitely talk more about coral bleaching in a little bit. It is so easy to jump into all the cool coral science stuff, but I really want to know more about your experiences and development as a scientist. Let's start at the beginning. Can you tell me where you were born and a little bit about your life growing up?

[00:06:20.0]

MM: Yeah, so I was born in Seattle, Washington, but I moved to Indiana when I was a child. I grew up in Indiana, in Southern Indiana. That's where I learned to scuba dive, believe it or not. The story - this classic story, origin story - is when I was a young child, in elementary school, there was a coal strike in the Midwest. Much of the town where I lived - well, it was the university town, but the university closed down for three weeks during the coal strike to save coal because they ran on a coal electric plant. We had three weeks for Spring Break instead of one week and my family decided it was their patriotic duty to go south so that we weren't running our furnace and all this thing. We took a family trip to the U.S. Virgin Islands. On that trip, I was actually too young to enjoy snorkeling, but my intrepid parents, being from Indiana, read how you're supposed to go snorkeling when you go. That was one of the cool things to do. Of course, this was February in Indiana in the late ‘70s, so a little hard to come by snorkelling gear in this situation, but there was a department store. They were able to get masks and snorkels, for them anyway. But there was a little kiddie bathtub mask and snorkel is what I had, which was not a good experience. That first trip, I actually managed to get diadema spines in my feet, the whole thing. I had not a good experience, my first encounter with a coral reef. However, my parents were hooked. My dad learned to scuba dive thereafter. I was able to take subsequent visits and do more snorkeling in different [??], largely the Florida Keys. We took several trips to the Florida Keys when I was young and I was certified to dive when I was 12. We took several trips to the Florida Keys thereafter. That was really some of my first diving experiences in the Florida Keys. I subsequently got to study those reefs quite a lot. It wasn't a pleasant experience the first time I was in a coral reef, but I definitely learned to love them thereafter. I also learned that diving in Southern Indiana is not that much fun. It's much nicer diving in the Virgin Islands or the Florida Keys. I learned that early on.

[00:08:48.0]

ZM: That is really interesting that you grew up in Indiana. I feel like the more scientists that I speak to who specialize in any ocean-related science -

MM: Lots of us are from the Midwest.

ZM: - are from the Midwest. You're all landlocked. It's like a hotbed of marine science.

MM: It's true. It's true. A lot of us come from the Midwest.

ZM: That is really interesting. You said your father was hooked on scuba diving after his first try. Did he persuade you to get into it after the initial bad experience?

[00:09:33.0]

MM: Yeah, more or less. Once I was big enough, and I got a regular mask that would actually seal against my face and I didn't have a faceful of seawater, it was much easier to enjoy. I didn't take a lot of convincing later on, once I could get the hang of it a little bit. I definitely benefited from being able to hang off of his coattails. , he had to convince the instructor to take me on at 12 because that wasn't very typical back then. It's a lot more common to have kids in dive classes now, but back then it was pretty unusual. He went through the class with me with the instructor and things like that. It was definitely beneficial.

[00:10:12.0]

ZM: Yes. That is actually pretty young to be starting scuba diving. Not unheard of, but definitely on the young side. I am wondering, was it your interest in scuba diving that propelled you towards this career? Do you remember, or do you have one realization?

[00:10:37.0]

MM: I would say it's an affinity for coral reefs that made me want to learn to dive. I think that's definitely the way that it played out. I had done snorkeling on the reefs several times before I learned to dive. Being stuck at the surface and watching the divers down there, it's like, “No, that's where I want to be”. I'd say that was definitely the order of things.

[00:11:00.0]

ZM: Got you. Okay, that makes sense. Do you remember the first time you saw a coral reef? I guess that first experience was bad, but the first time you had a good experience on a coral reef?

[00:11:14.0]

MM: I don't know if it was the first time you. My early impressions of snorkeling, as I said, it was a couple trips that we took to the Florida Keys, it was at Christmas time, so it was cold also. But I remember seeing just those schools of barracuda on the reef, like out there at Molasses [Reef] and stuff like that. And that was one of the coolest things that I think I'd ever seen. That's probably one of my earlier memories of being enthralled with the reef and the beauty of the fish. I wasn't necessarily oriented towards corals back then. Coral is the background for the cool looking fish, for most people when they first visit a coral reef. I think that was true of me as well, that the fish were probably a little bit more enticing than recognizing what a coral is. I definitely didn't like the urchins, those diadema I thought were pretty nasty. I was not pleased with those at all. But those schools of Barracuda that you see when you're snorkeling sometimes, and just the beautiful fish, I think are my earlier memories from when I was early on and snorkeling in the Keys.

[00:12:24.0]

ZM: Barracuda are obviously very charismatic. I remember the first time I saw a school of Barracuda hanging out under a buoy, and they are just sinister looking, but so cool. You almost can't resist getting closer.

[00:12:43.0]

MM: That's part of it, I think. They're a little bit scary. Especially when they watch you with those eyeballs, it’s always like, “oh, they're watching you”. But it's just enthralling.

[00:12:57.0]

ZM: Did you have a favorite subject in high school growing up? When did you realize that you were interested in the science aspect of everything?

[00:13:08.0]

MM: It's hard to say I had a favorite subject in high school. I can't say that my science experience in high school was particularly enthralling, but certainly when I went to undergrad, I had an interest and a desire to study field ecology, to be a field scientist. At that stage, it wasn't clear. I knew I love coral reefs, but again, I was going to college in Indiana. A lot of my earlier science and ecology and field work experience was in streams and forests in the Midwest. That was my perspective at that stage. I knew I wanted to be a field scientist, because I love nature. We did a lot of hiking and stuff when I was a child as well, so I knew I wanted to study nature. I hoped I could study coral reefs, but if I hadn't ended up supporting coral reefs, I probably would have been a forest or a stream ecologist instead, I would expect.

[00:14:15.0]

ZM: Where did you do your undergrad?

MM: At Indiana University, in my hometown. [Laughter]

ZM: What was your major study?

[00:14:29.0]

MM: I was a biology major. And math, I also had a math major as well. I had a double major as an undergrad.

[00:14:38.0]

ZM: Do you find that that math major has helped you out later on, when you are doing statistical analysis?

[00:14:47.0]

MM: Yes, definitely. To be honest, I always worried that it should have helped me more. I never actually became a quantitative ecologist, and certainly there's a range of use for that. It's certainly helped me in terms of …. a lot of the other work that's crucial to ecology and management, too, is modeling. I was able to take a mathematical modeling class as an undergrad. As you say, it was the first math class where you got the textbook Hello. And it was all prose like paragraphs, you're like, “Um, this might have been a mistake”. [Laughter] I think having that math background - it isn't something that I ever used as a primary tool in my work, but I definitely think it helped me have perspective that those quantitative aspects of ecology are really important and useful. And modeling. And that there are at least things that I wasn't scared off by; that I had some basic understanding of how those things worked. If I really had to read one of those papers, I could sit down and work through it and make sense of it. I think it definitely helped me, as I said. Sometimes I wonder if I should have leveraged that background more in terms of doing more quantitative work in my research career, but you can't do everything.

[00:16:13.0]

ZM: After that double major was completed, did you move on directly to your PhD?

[00:16:23.0]

MM: I did, actually. At that stage, when I was finishing my undergraduate degree, was when I saw a possibility then of studying marine biology. That was at the point when I was looking for PhD programs. I was looking for opportunities, hopefully, to study coral reefs, to study marine biology, something like that. I ended up at UNC [University of North Carolina] Chapel Hill. I wasn't for sure I was going the coral reef route when I started there, but I was able to. The reason I went to Chapel Hill is they had an interdisciplinary ecology program, which is what I was enrolled in and what my PhD is from, which I found very appealing in that it incorporated both biological science and social science as well. And policy, across the range of what ecology is, and I was really attracted by that. In the end, I was able to do marine work. I did study corals for my PhD, however, they were weird corals that grew up in North Carolina. That’s where it started. I had a fabulous experience during my graduate career and I was able to start scientific diving in North Carolina. I was able to participate on several research projects in the tropics, dabbling in real coral reef, as I called it at that stage, as opposed to the weird little corals that grew up in North Carolina, which was the focus of my dissertation.

[00:18:05.0]

ZM: That's also really interesting. I find there's another weird nexus in North Carolina for these kinds of things. I actually did my scientific diving in North Carolina as well. I went to East Carolina University. Less corals and more shipwrecks. Can you elaborate a little bit more on the social science aspect of all that? What classes?

[00:18:41.0]

MM: It was an interdisciplinary graduate program, so it essentially meant you had a lot of leeway to pick and choose some of those aspects that you wanted to incorporate. Because I had the opportunity to really focus on corals for my dissertation, I didn't end up doing as interdisciplinary a research project as some of my cohort did, but I was able to take classes in environmental policy, for example, and sociology and some of the biostatistics classes over in the public health school in Chapel Hill [UNC Gillings School of Public Health] and things like that. In my case, it really related more to the classes that I was able to take, to get that broader background. That background definitely helped me when I went to work for NOAA. I had had some of that grounding in environmental policy, for example. It didn't end up being heavy on the Endangered Species Act, which is what I ended up working much more with when I was in NOAA. When I first started at NOAA, actually some of the work that I was involved with was related to the Everglades and the South Florida ecosystem restoration work. That's when I first started out as a NOAA postdoc. I was thrown into some of this broad scale, interagency Everglades restoration stuff and I think that that would have been incredibly intimidating if I hadn't had some of that more interdisciplinary graduate education that I'd had under my belt. I was thankful that I'd had that preparation.

[00:20:14.0]

ZM: That brings up a couple of different things, but you mentioned that you were a postdoc working for NOAA. After your -- the chronology...

[00:20:31.0]

MM: Ican take up the chronology. I was in North Carolina for five years. I got my PhD and then I got a postdoc at the University of Miami. I moved to Miami in 1994 and I was at University of Miami for about three years, three or four years. I was hired as a postdoc on a project, actually, that was actually doing coral reef ecology. This was a very cool - this was pretty thrilling to me. The project I was working on as a postdoc that brought me to Miami was a follow up of monitoring and baseline and some other research-related post-Hurricane Andrew effects in Biscayne National Park; the very northern end of the Florida reef tract here in Florida. We did a lot of monitoring and some experimental work on the reefs there. Biscayne National Park was my initial direct research in coral reefs that I started when I moved to Miami.

ZM: What year did you move to Miami?

MM: 1994, and then I started working for NOAA in this postdoc position in 1999.

[00:21:45.0]

ZM: Okay, so ‘94. The [Florida] Keys [National] Marine Sanctuary was ‘90 or ‘91. So things are still new. I have heard some interesting stories from people around that time. Can you describe the attitudes of people in Florida about the Sanctuary around that time?

[00:22:17.0]

MM: I was thinking about that, because in some of the questions you asked me to think about ahead of time - certainly when I started at NOAA and when I started working in the Keys was just around the time that they were beginning the zoning process, the implementation of the first no-take zones, and the zone management plan that applied to the Florida Keys National Marine Sanctuary. I think that plan was implemented in 1997. And I think I misspoke. I started the postdoc position at NOAA in ‘97 and in ‘99, I actually became a NOAA employee. I got that timeline slightly wrong. But yeah, it's right around that time. So there was, of course, a lot of controversy related to the implementation of the zoning, particularly. There were other aspects of the management plan that I think were less controversial. The Florida Keys is an interesting place culturally; there are different attitudes. There certainly was some degree of antagonism to the Sanctuary itself, but especially to the idea, the concept, of creating different zones within the Sanctuary that would be partitioned for different uses. The intent of many people is that they should be able to do whatever they want, wherever they want. That attitude is certainly still present. I think in most places where zoning plans have been implemented and managed well, over time as the impacts of that management and the benefits of that management are able to be experienced, I think those attitudes tend to diminish over time. We had quite a repeat of that same antagonism just a couple years ago, when there was a proposed zoning scheme for the Southeast Florida coral reef. In state waters, the State of Florida had gone through a very extensive planning process to set up a zoning program for the reefs that are north of the Sanctuary and north of Biscayne National Park, where there's no current management scheme really at all. Unfortunately, it was this similar way that it played out where there were, it's hard to know, but certainly a contingent of folks that were extremely vocal and extremely opposed to the concept of zoning. They have the ear of certain politicians and the manager, such that that plan has not been carried forth, which is really unfortunate because especially the reefs here in the northern section of the reef tract, which are even closer proximity to high densities of human populations, the fisheries and some of the other impacts on those reefs are quite substantial. It really would benefit from some degree of zone management. But yeah, it's been a journey. We heard - and I wasn't directly involved in those management planning processes, but my boss at NOAA was. When I first started at NOAA, he described himself as a “combat boot biologist”, as largely a result of that zoning planning process. I certainly was aware of that aspect of what NOAA was doing. I was also equally thankful that I was not directly involved in those undertakings. But yeah, it was interesting times. [Laughter]

[00:25:58.0]

ZM: Did people generally respect the rules and regulations? Do you think even if they were vocal in their opposition, do you think people....

[00:26:09.0]

MM: I'm sure most people did. There are always some that you observe that don't. [Laughter] It's actually something that we experienced a fair amount in the subsequent years, because I was out on the water a lot doing field research. We would periodically encounter someone who was fishing, pulled up on one of the mooring balls in one of the no-take zones, and had two or three fishing lines in the water. It was always a dilemma for us; we were researchers, but it was very - it was generally difficult to engage those people in conversation, especially from one boat to another, it's hard to yell across and communicate well - but it was often a dilemma in terms of when you would observe that happening. It wasn't something that we were really well equipped to deal with. We would generally call the law enforcement folks that were around. We never really had too much idea if that ever helped or not. There's always a few people that are not going to follow the rules. That's true with any type of rules. I think regardless, most people will. As I said, I think generally the Sanctuary did a lot of work in terms of engaging the community. That was effective over time. There's a lot of advocates as well as a lot fewer folks that were not following the rules. Probably a lot of them, too, were folks from far away. That’s part of it, just that people weren't aware. It's hard out in the middle of the ocean. Okay, there are some yellow buoys around, but if you don't know what that means, and maybe the yellow buoy is pretty far away, and you got two foot chop [small waves that make the surface of the ocean rough] in the way, maybe you can't even see the yellow buoy over there. To some extent, especially early on, it was challenging because there's a lot of people that don't know, or even if they vaguely understand, there's a lot of people boating in the Keys that don't know their way around very well. Which is a different type of problem. It isn't that they were necessarily fishing where they shouldn't have been because they wanted to fish there. They just didn't have enough local knowledge to be able to be very effective in following the rules.

[00:28:27.0]

ZM: Yes, exactly. It might not always be malicious, as opposed to ignorance. I did speak to a recreational diver who used to work for Horizon Divers. He said when they would see someone doing something they are not supposed to within the Sanctuary, they would try and talk to them and see if they knew what was going on. He said sometimes that was very effective. People had no idea and they were like, “Oh, thank you so much for telling me”.

[00:29:05.0]

MM: And they pull off and they move on. Yeah, absolutely. That definitely happened a lot.

[00:29:09.0]

ZM: Do you think some groups of reef stakeholders were more supportive of these kinds of restrictions?

[00:29:23.0]

MM: There's certainly components of the local population in the Keys, as well as visitors and stakeholders from other places in the country, that very much appreciated having at least small areas of the reef protected from extractive uses. There definitely were and I think they were probably in the majority overall. It's not something we ever have a referendum on, so the numbers are a little hard to parse out, but there is a lot of support for that type of management and conservation. [??] small areas to enable the reef to persist without extractive uses. That’s important.

[00:30:07.0]

ZM: Yes. I guess at least from what I'm hearing, I do not know if it is different with you, and I think you actually already touched on it, but people now are starting to get more used to the idea and more supportive of it. In some cases, they are not, like you said, but at least the Florida Keys Sanctuary that's already there, I think people are seeing as a good thing. Right?

[00:30:37.0]

MM: I think so. I think yes, the recognition that the Sanctuary provides benefit to the community and having a sanctuary there is a beneficial thing. They've just redone that original management plan here in the past year or so and there's proposals now on the table to expand some of those management areas and some of those zoned areas. There was a lot of opposition that was voiced to that. But I think they're in the process now, working through all the comments and the feedback that they got from the community, and we will see how that process plays out. Generally, I think that the vast majority of the Keys community recognizes that the Sanctuary is a positive presence in their community.

[00:31:27.0]

ZM: Let’s move on a little bit from the Sanctuary side of things. We are chronologically in the late ‘90s right now. I have a couple of questions about a project you were doing in the late ‘90s. The title is a long one. There is a specific publication that I am talking about. It’s The Status of Candidate Coral Acropora Palmata and Its Snail Predator in the Upper Florida Keys National Marine Sanctuary. That was from ‘98 to 2001. I thought this was really interesting. I probably should have put this on the list of things in advance. I had that thought earlier, but it is too interesting not to throw it in. I am not sure how well you remember it. The basic hypothesis originally was that the no-take sanctuary would increase the fish population that preyed on the snail population that in turn would eat the coral population, and then there would be less damage from the snails on the corals. A couple of things went wrong, or sideways at least, during this. There are all these twists in this paper that really kept me interested.

MM: [Laughter] That's funny.

MM: You think you are reading about snails and then all of a sudden, there is a bleaching event and a hurricane. And it takes on a whole other life. Yeah.

[00:33:19.0]

MM: [Laughter] It tends to be the way field ecology works. You start out to study one thing and then nature happens and then you end up studying at least that thing and a few other things together. I guess I'll back up a little bit. In the late '90s, as you point out, when we were beginning to - I became involved in some of the monitoring work that was going on as these no take zones were implemented, so it was one of the projects I was working on early on. But also the general status of the Acropora coral. These branching corals that were the ones that had really built the main structure of the reefs in the Keys and throughout the Caribbean, folks had started to notice they were going down fast. There was a recognized disease phenomenon that swept through much of the Caribbean. It would have probably affected many of the sites in the Keys in the early '80s, like '82 through '85 or so is when a lot of the elkhorn - so this is elkhorn and staghorn coral that we're talking about - the elkhorn coral tanked at a lot of different sites in the Keys. This was noticeable because it's that iconic species that people were aware of and was ubiquitous on reefs prior to that. So this was a specific aspect of research that I and some of the folks I was working with became concerned about. There wasn't a lot of data from the Keys about this species from Florida, but it was recognized that it had declined a lot. We didn't exactly know how much and we knew that there was this disease going on but there were other things going on as well. Predation by the snail is one of things that we had noticed. You think, "Oh, snails shouldn't do too much damage. They're probably pretty small and slow moving". But if you're a coral, you're even slower moving than the snails, so you're pretty much a sitting duck to predators essentially. We observed snails that were four or five inches long on some of these elkhorn coral colonies, like at Elbow Reef, for example. A five inch long snail can eat a lot of coral. You could see individual colonies where those snails maybe had eaten half of the colony in a relatively short period of time. So I became interested in the snails. There wasn't a lot of literature, a lot of study that had been done on this aspect of coral predation at all, but specifically for this snail that preyed on the elkhorn and staghorn coral. So it's something I became interested in, and in the process of thinking about the no take zones as well, thinking about essentially prior to that there had been fishing everywhere. So whatever we observed, or whatever we had learned about the structure of Keys/Florida reefs previously, was based on a fished system; a system that had had a lot of biomass taken out and a lot of predators taken out. That was the only knowledge that we had, because that was the only system that we were able to observe because there had been fishing everywhere. And so as these no take zones were going into effect, it presented the opportunity to begin to understand better if fishing had caused basic changes in the way reefs function. We call that the food web and the food webb of the trophic cascade of coral reefs. So that was how those two pieces of study fit together. As I said, we had noticed these snails on Elkhorn coral in the Keys, and it wasn't something that people had apparently noticed too much before or in other locations. Then you need to know, why are they so noticeable here? They're really noticeable. I think if this much coral had been eaten by snails in other places, people would have noticed. That's where we have this hypothesis related to what we call a trophic cascade, where you have altering trophic levels in a system. Obviously, if you remove a bunch from one trophic level, the trophic level they eat is probably going to explode. Then if that explodes, that's probably going to drive down the trophic level below them. That's the concept that we had hypothesized maybe could be a reason why these coral reef snails seemed to be overrunning the Elkhorn corals in some of the places that we were watching.

[00:37:57.0]

MM: To be honest, it's the same hypothesis we could expect with regard to the diadema, those urchins that I mentioned earlier. They also have a very important functional role in coral reefs. They had also had a disease event that had wiped most of them out in the early '80s, in the same timeframe that all the Acropora had been dying. There was a lot of bad stuff going on, on reefs in the early '80s. The same idea about a trophic cascade, we thought might apply to making it difficult for diadema to recover. If you had predators or that might be an alternative scenario that might be going on, if we had no-take management, where if the predatory fish expanded, maybe that would not be the best thing for diadema recovery. That was an alternative hypothesis that we had in mind. That was the idea. Both predatory fishes and also lobsters, we expected were probably predators on those snails; octopus as well. This was just a hypothesis that we'd come up with early on when we were beginning to think about what we were going to expect in these no take zones. And also just to try to get a handle on what was killing this palmata, because it was noticeable. We did a lot more work on those snails over the years, and indeed, they kill a lot of coral.They're actually able to transmit disease from one coral colony to another; they can act as a disease vector. That's an even more add-on effect that they can have, causing damage to coral. Those snails are pretty nasty, actually. We did a lot more work on those over the years. We could never really tell that the trophic cascade thing was going on, so that was not a hypothesis that was borne out in the studies that we were able to do. After years of study, the hypothesis that makes more sense is simply that because those Acropora corals had declined, the snails - the Acropora, those staghorn and elkhorn corals are like their favorite snack, they'll eat other corals when they have to - when the Acroporas declined, probably more of those snails were able to live on other species of coral that remained more abundant. But then whenever you had an Acropora pop up, and later on even when we started out-planting Acropora that we were culturing for restoration and farming - we put those out there. If you transplant just a few, or if you had just one or two colonies recruit, or if you had one of these disturbance events where there was maybe only two or three colonies left and all their neighbors had died, all the snails would come running to these poor little remnant staghorn and elkhorn coral. That actually was more the process that, over the years, they came to understand was more influential in terms of there being an outsize effect of those predators on those elkhorn and staghorn coral. Over the years we looked at, okay, so maybe if we go and remove those snails, how much can we help preserve? Is that a very targeted management action that makes sense to think about? Earlier on, those types of interventions were definitely frowned upon from a management point of view, because the goal of management was to remove the anthropogenic stressors and let the natural system recover. Over the time that I've been working, unfortunately, I'm afraid the paradigm has changed quite a lot. To understand that we've pushed coral reef systems a little bit beyond their brink and they have lost the capacity to recover naturally. Over the past five to ten years, we have been trying to discern more active interventions that we can have to help bolster corals. Removing snails is one of those. Now, when most of the restoration work is done, when Acropora colonies are out-planted to a reef, there's a fairly deliberate process of removing snails from those over time, as there is an opportunity to monitor those and get rid of them. Because they're pretty damaging.

[00:42:38.0]

ZM: Yes. That is interesting. Underwater pest removal. Actually, that is really cool. I do not think a lot of people even realize that that is a strategy that is being employed. I really want to get into restoration and more active, happy things in a second. But before we do that, there is actually one specific paragraph in this report that really hit me. It said two of nine patches of reef that were being surveyed were completely wiped out by the end of 1999. It also said that that is a loss of about 220 colonies in one year, and no meaningful recovery and abundance was evident at the end of the study there. What hit me was how objective that sounded. Then probably the disconnect between how you were feeling at that point. I am wondering if you could tell me a little bit about how you felt when you jumped in and saw that devastation after the hurricane and the bleaching.

[00:44:18.0]

MM: Yeah, well, as you point out, there is an emotional experience of having been a coral field ecologist over the past couple of decades. I'll tell you, part of that experience when there is a disturbance like that - in 1998, as you referred to, there was a tropical storm. It wasn't a storm that anybody's ever heard of; it was Tropical Storm George in 1998. It's not even one anybody's ever heard of, but it caused a lot of damage in the Upper Keys. Several of these patches that we had carefully mapped out earlier, and we had tagged a bunch of colonies, and counted all the snails on each colony and each patch and everything. When you go back after a situation like that and you can't find things, it takes you a while to scratch your head and say, “Am I in the wrong place? Like, am I really lost? Is it me? Am I missing something? Because surely, it can't be this bad.” There are various events that have happened in the Keys that that has certainly been the response. Much more recently, the bleaching event that happened in 2014 had a similarly devastating effect on palmata and many other corals. In ‘14 and ‘15 both, we had bleaching two years in a row, very severe bleaching two years in a row. The same phenomenon, entire patches of palmata, dead. I mean, they were stark white for a few weeks, which was also a heartbreaking vision, to watch that happen. And then within a few weeks, completely dead. Myself and several other colleagues at NOAA, over the years, have continued to follow these elkhorn corals in the Upper Keys over many years now. I started that study in ‘98. The more colony-based study, we started in 2004. That's been going on for many, many years now. Especially for Elkhorn coral, the story has continued to be that punctuated disaster. There's one of these disturbance events, we lose maybe half of the Elkhorn colonies that we had been following, and then maybe it's stable for a couple years. And maybe it starts to grow a little bit, and we think maybe there's a little bit more. Then another disturbance comes and you lose half of what was left. Then a few years later, you lose half of what is left. That has really left the situation - In Florida, the situation with Elkhorn coral is extremely dire because those types of disasters have continued to recur. Sometimes it's a hurricane. We had those bleaching events in 2014 and ‘15 that I mentioned. In 2017, we had devastating hurricanes. Whatever survived the bleaching in ‘14 - ‘15 got nailed by Irma two years later. A few years before that, in 2005 was the previous really bad disaster, where we had several hurricanes in one year and this disease interaction with the hurricane. Many times after we have a physical disturbance like that, these disease events just wreak havoc. Every few years, there's one of these devastating events. Each of them has been slightly different. It's not always the same thing. But the result is that we have lost virtually all of the elkhorn coral in the Keys. In the past year or so, it   even snuck up on us. I didn't realize how bad the loss in 2017 had been. Even since then, we continue to lose a few each year; maybe not half of them in a year, but a few each year. The water’s warming up a lot already here now and there's concerns about having another really bad bleaching here in the Keys coming up this summer.

[00:48:34.0]

MM: So it   snuck up on us, this bad situation to palmata. There is a lot more direct attention now to wondering and figuring out what   extreme measures do we need to think about now, if we don't want to lose the elkhorn coral from the Keys completely. If you look at the data, the trend line over these punctuated disasters over the past 15 years, that line hits zero in about eight more years. That means we might be facing local extinction without some pretty serious action.

If we want to talk a bit more about restoration, there is a lot of effort now going towards staghorn and Elkhorn coral, particularly staghorn coral but growing effort towards elkhorn coral, as we recognize how much more important it is and how great the needs are. There is a very large and comprehensive restoration plan for the Keys that has been put together over the past year or year and a half that is very much dependent on having and propagating a lot of Elkhorn coral because that's the iconic species that grows fast and it builds the crest of the reef. The functions that we get from reefs for protecting the coastline from storms and things like that, the Elkhorn coral is the most important coral for helping us restore that function. Our restoration plan calls for a huge number of elkhorn corals to be propagated and restored. Honestly, at this point, I don't think we have enough to responsibly carry out that plan. We don't have enough genetic individuals left to be able to even propagate that many. It's a very serious concern. That is definitely a process that I have watched firsthand, since the late ‘90s. And yes, the story is either mediocre or disastrous, and we haven't really had any good bits in between. It's just been a punctuated decline. Each each time that that happens, as it happens repeatedly and we have less to lose, it feels a little bit more desperate each time.

[00:50:53.0]

ZM: Yes, definitely. It is one reason I try not to bring this part up at the end of the interview, because I do not want to end on that note. I have some pictures from the 2014 bleaching event pulled up. Wow. It is horrible, absolutely eerie. The color contrast between the bone white coral and the deep blue of the ocean backdrop. It is just really sad to look at.

[00:51:32.0]

MM: It's heartbreaking. I'm worried that we're going to have another one of those cases this year. We'll see. I was out diving last week. My temperature gauge on my dive computer said 89 degrees in the ocean in a coral reef. That is not where we want it in mid-July, because it's got another couple months to get hotter.

[00:51:59.0]

ZM: Can you talk a little bit about that? A lot of people are thinking mid-July to August is probably the hottest months. When is bleaching season? And how does that heat energy work? What is bleaching, too?

[00:52:24.0]

MM: It is something that’s interesting. Even as somebody who has dived as much as I have over time, you still tend to forget because, yes, in terms of our normal experience, August is usually the peak of the summer. Then starting in September, it starts cooling off. The ocean temperature actually lags that by a month or two. The warmest ocean temperatures are actually in September and October. That's also the reason why that's the peak of hurricane season, because it's the same phenomenon. That heat in the ocean is what drives the stronger hurricanes as well. That is the situation in the Fall. When you think about diving, it's really comfortable diving through October, November usually. The water doesn't really start getting uncomfortably cold until like December, January. On the other hand, the coldest diving is in March. [Laughter] Because the water's still really cold in March, and mentally you think, "Oh, it's Spring, it should be warming up by now." and it's totally not warming up in the water. The ocean temperature lags a little bit, like a month or so behind what we experience in the air in the atmosphere. That is one point. The peak of bleaching coincides with that peak of the hurricane season in late September, even into early October. Early-late September is really the peak of when we expect the bleaching to be the worst. So we've got a couple of months for it to get worse, for the heat stress. Essentially what coral bleaching is, is it's a breakdown in that symbiosis between the animal part of the coral and those tiny algae that live inside it and help give it its energy, feed it energy from the sun. When the environment gets a little bit too warm, or other types of stress, any type of physiological stress that the animal experiences often will trigger this breakdown in the symbiosis. You can imagine that an organism is very finely tuned - all those organisms are very finely tuned to enable one to live inside another. Different types of physiological stress will cause that to break down. Heat or warm temperatures is one of those factors that most commonly causes massive and damaging bleaching events. The phenomenon then is as the water warms just a little bit - and the other thing to know about coral bleaching and corals - although humans, probably our optimum temperature is probably like seventy-eight, when we're perfectly happy and comfortable and we can sit there forever. We don't die till you get up to one hundred twenty, one hundred thirty. So we have a good thirty degrees buffer, between our thermal optimum (where we're best off) and our thermal lethal level (when we die because we cook). Corals, those two numbers are very close together. Although coral's optimum is twenty-nine degrees Celsius, I don't know exactly what that is in Fahrenheit, twenty-nine degrees Celsius, by the time you get to thirty-one, they're hurting and they're bleaching and they're at risk of death. Whereas for humans, you might have fifteen or twenty degrees leeway before you really have serious damage, for corals you get that damage within just a couple of degrees. For this reason, they're the canary in the coal mine. We think of them when we think about climate change and global warming because the ocean has already absorbed a lot of new heat that our alteration of the atmosphere has trapped around the Earth. A lot of that heat has already been absorbed into the ocean. The average reef temperatures in the Keys - the coastal waters along the reef track - are already about a degree warmer than they were a century ago. So the corals are already experiencing one degree hotter than they used to on an average year. When we have a warm year, as we did both in '14 and '15, I'm pretty concerned that's going to occur again this year in 2020, they don't have much buffer there before they experience that really serious stress, the symbiosis breaks down, the corals bleach. If the stress is relieved within a couple of weeks, they can recover. They can get that symbiosis back.

[00:57:09.0]

MM: However, if it doesn't, they die. This is something that we learned about the elkhorn and staghorn coral in those events in ‘14 and ‘15. The elkhorn and staghorn coral actually, after they bleach, they die a lot quicker than the mounding corals. It has to get a little bit warmer before they bleach, so they have a little bit more resistance, a little bit more dosage of warm temperature that they can tolerate before they bleach, but once they bleach, they're much more likely to die. And that's where we saw all of that mortality in the ‘14 and ‘15 bleaching. So they can recover. But often they don't if the warm temperature persists for more than a few weeks. The other thing that we know - because we've seen it too many times in some of those devastating occurrences - is that even in corals that have recovered from a bad bleaching event, many times subsequently, maybe a month or two subsequent to that, they succumb to disease. So they still die, but they die not directly from the bleaching, but indirectly from the bleaching because their biological reserves have just been depleted. So it's like if you've been without - as a human, if you're not eating right and you're not sleeping well, a lot of times you might get sick just because your immune system and your body systems aren't at top notch. That same phenomenon we see in corals where, even if they can recover from a bleaching event, often there is a serious disease event that comes on its heels and still causes devastating mortality. Those are the double whammies - a hurricane, a physical disturbance can have the same effect. Usually in a hurricane, even if a coral survives from the hurricane, it often gets broken up or bashed or has sand that scours and this thing. There's a lot of stress that the coral colony experiences, even if it survives, and probably that stress makes it more susceptible to disease following. In several cases, we have seen corals just up and die within weeks following a hurricane, following a physical disturbance event as well.

[00:59:25.0]

ZM: It is always tough when people say, “What's killing the corals?” And you are like, “Well, where should I start?” It always seems like it is so much more than just one thing. It is a combination, oftentimes, and it is like one after the other. That is what does it. Even as they are trying to recover, they get hit with the second thing.

[00:59:49.0]

MM: Yep, it is. And it is a combination of things. Scientifically speaking, it’s often because it's a combination of things that tend to happen at the same time. It's often difficult for us to parse that out very carefully. However, I do think that there is ample evidence at this point that warming is the base driver for several of these other follow-on stressors. We know that warming directly causes these mass bleaching events. Warming is associated also with the disease that's devastating to many coral types, and this linkage between bleaching and disease that I mentioned. Warming is also a root driver of more severe and more hurricanes. So we know that warming is a base driver for several of these other complicated and interacting stressors.

[1:00:40.0]

ZM: That is a really important note that there is one driver for a lot of these things. Let's take one step back real quick. In the late ‘90s, early 2000s, you started looking at the snails that were eating the corals, and then there was also a major bleaching event happening. Corals are being damaged by a tropical storm at this point, but increasing severity of storms due to warming and climate change are really on the way. You have just started working for NOAA and you said you were starting to be involved in monitoring projects. Was most of this bleaching or was it disease related? Can you describe it?

[1:01:43.0]

MM: Most of them, not. Early on, there were two avenues of monitoring that I was involved in. One was with regard to the zones, the no take zones. I was involved for five years or so with some of the coral and macroalgae monitoring related to the zoning plan. We also began, at that point, because we were becoming concerned about the Elkhorn and staghorn coral, we developed and initiated focal monitoring on Elkhorn coral, specifically. That report was started in ‘98. We solidified that monitoring plan in 2004, where we tagged a bunch of individual corals across six or eight sites across the Upper Keys. Those are the ones that we've been following ever since 2004. That's the main monitoring effort that I've been involved in over time is this effort that was focused on Elkhorn coral.

[1:02:47.0]

ZM: You wrote the monitoring protocol, or at least were heavily involved. Can you explain? How did you identify certain colonies for long term monitoring or certain sites? What are the criteria? Also, how do you make sure that you can find the site when you come back?

[1:03:20.0]

MM: [Laughter] That's always a tricky one. Starting in 2004, we took more of an individual colony approach. The project we started in ‘98, we were trying to map larger areas. This is a dilemma particularly when you’re interested either in staghorn and Elkhorn coral, because the normal way they're supposed to grow is in these big thickets. Along the reef crest or along the fore reef, these colonies grow together and they can form huge, vast thickets in these areas. That's where we had started trying to monitor an area and have an understanding of how much coral was in this area. If we swam around it and we had different transects, we were trying to measure density and things like that in a specific area. That was the approach we started '98. It was hard to be quantitative that way and that's the report you referred to and then we had all this stuff that died and they were like, "Wait, is this where the transect was before? Surely not because there's nothing left?" In 2004, we switched monitoring tactics to try to follow individual colonies, because it was a little bit more tractable. With staghorn and Elkhorn coral, it's still tricky, especially for staghorn coral. We did much more with Elkhorn coral. They're a little bit more stable. Staghorn corals actually, believe it or not, are a lot more like tumbleweeds. They do not stay put as much as you expect. They will break up and travel around. So they're actually much harder to track by colony. Some subsequent researchers and some of the folks that have been doing some of the outplanting for the restoration work had further developed some of the monitoring methods for staghorn coral for that reason (they're a little bit harder to track individually). For the Elkhorn coral in 2004, and this is work that I've done over the years with Dr. Dana Williams who's still with University of Miami and Southeast Fisheries Science Center, we chose to focus on individual colonies so that we can hopefully track them a little bit better. How do we choose a site initially? Where there were some colonies that we either knew about or could find that weren't in a thicket is what we were looking for. We were looking for sites where there was a decent number of colonies, we looked for patches with at least a dozen to twenty colonies, so that we had a good sample for that site, but that were growing as individual colonies and not as a big thicket where we couldn't tell where one colony ended and the next colony began. That's what we started with is looking for sites like that. We put individual numbers - we gave each colony a serial number that we've tracked it with ever since 2004. It's tough finding things. About that time, handheld GPS units became much more available. That was a huge boon to any marine scientist trying to run around and find individual coral colonies and sites and stakes, or whatever we had marking things out on the reef. Before that, it was a whole lot harder. We had a bunch of plots that we just used a piece of rebar, like a stake that was in the middle of a circular plot is how we set those up. Then we could map each individual colony from that center point by taking a heading on our compass and having a measuring tape that we can measure the distance, and then the bearing in terms of what direction that individual colony was. They each then had a little tag. The tags come and go, the tags go away. Eventually, after years, you learn and you know each colony. You say, "Oh, he's lost his tag, but that's actually number three hundred and twenty-one. I recognize him." We would use a lot of photographs as well. Underwater photography was becoming much more tractable by 2004. It was much easier just to take photographs of everything and then print those photographs out. We had a little cheat sheet that we could take with us in the water, so that we could say, "Oh, yeah, well, that's the same colony, but, oh, look, a whole branch has broken off since we were here the last time." Those are the type of changes that we could then track over time.

[1:07:38.0]

ZM: You say that you wrote this procedure? What was the procedure for monitoring before this? Was there a procedure?

[1:08:15.0]

MM: Nobody had done it much. That was part of where we were looking towards getting more quantitative information. Otherwise, most of the monitoring had been either in areas with these thickets, where we tend to use percent cover as a standard coral monitoring tool. I guess back in the old days, when there was a lot of it, you could use percent cover and learn a lot. You can see changes happen that way, but once you don't have very much anymore, percent cover doesn't tell you very much. That was really where we felt like moving to a colony based approach was going to be much more important. The other thing that enabled us to do is around that time frame in the early 2000s, we were also just gaining the genetic tools to be able to identify individuals in these clonal species. Elkhorn and staghorn coral, because they have these nice, beautiful branches, those branches can break off and make new colonies. That's a lot of times where you get the thickets forming, because one colony will break off and you got three colonies, and then they'll break off and so you get a thicket pretty quick. Because we knew that that happened, we didn't know how much it happens. As we became concerned about the status of the species, understanding if we went out and we could count 100 colonies, we have a very different understanding of the endangerment of that species if those 100 colonies represent 100 different individuals versus they represent the same individual, which case maybe you have 100 colonies but you may only really have one coral in one sense, only one genetic individual coral. So these questions about clonal structure became much more important as we became concerned about the species status and evaluating its endangerment. We were just gaining the tools. A graduate student that I worked with, Dr. Iliana Baums, developed the first tools to be able to distinguish between clones in Elkhorn coral. Right about that time, early 2000s. As we began setting up these monitoring colonies, we were then also able to take a very tiny biopsy sample of tissue from each one and then understand how many represented clones of each other and how many represented new genetic individuals. That was the point that we learned that the Elkhorn coral in the Florida Keys that was left, what we were starting to look at in 2004, had not a lot of diversity. There were a lot more clones than there were genetic individuals in most of the plots. Many of the plots that we were looking at, where I said we had maybe twelve to twenty colonies that we were following, maybe were only one genetic individual, or two. This was qualitatively different than other areas in the Caribbean, where there tended to be many more genetic individuals within a population or within a patch. This became an important aspect of the biology in the Keys that relates to their reproductive potential and many other aspects. As we thought about judging the endangerment of these species, those bits of knowledge were very important in understanding the status of the species and to what extent it might be at risk of extinction.

ZM: That makes a lot of sense. It is also terrifying, because you look and you see what to the eye looks like a bunch of different colonies, but if they are all just clones, then reproduction is…

MM: You kinda got a big ghost.

[1:12:02.0]

ZM: t could be functionally extinct, even though…

MM: Exactly. Even if it looks good now, it is going nowhere. Yes, that was part of the more slow motion realization - when we had those big disturbances, you have this emotional response with all this coral dying at once. It was a much slower realization that we had with regard to the clonal structure to say, “Oh wow, actually, this species is - at least in Florida - is in worse shape than it looks. And we're losing.” Then, by having the individual colonies that we had genotyped and then we followed over time, we can also see when genotypes were lost, in addition to when individual colonies were lost. As we started realizing that genotypes were being lost from the population, that also was a big wake up. Like, “Oh, this is a worse situation than we were hoping.”

[1:13:00.0]

ZM: Yes. I am kicking myself, because I am going to ask this question, but I know it might open up a whole can of worms that I was not prepared to get into at this moment. But I am going to do it anyway, because we are talking about genotypes. This new technology allows for the identification of certain genotypes that may be resistant to environmental factors, right?

[1:13:32.0]

MM: Potentially, and that leads to one of those ideas, like more intensive interventions that we're now thinking about to help rescue this species that's gone a little bit farther down the pipe than we were hoping. Yes, by being able to identify individual genotypes, we can then also observe how those corals perform - what we call the phenotype, how they actually perform and behave in different conditions. We can identify - through our monitoring project, we've been able to do that, to say, “Okay, we have certain genotypes of elkhorn coral that don't bleach as badly as others or that maybe bleached and did recover more effectively.” We can identify that. Now, it's more challenging to understand prudent ways to use that knowledge in enhancing the resilience of populations when we're going about restoring them. That's really the major challenge that we have, and have been dealing with very actively over the past five to ten years. Even since we've talked about farming corals and out planting them, from the beginning, there was a concern that we're then changing the wild population, because whatever genotypes that we're propagating and outplanting, we’re skewing the wild population with those genotypes. Maybe that's not good for the wild population. As we think even more about perhaps selecting particular genotypes that we have observation of being resistant, same way with disease, we're able to do exposure experiments and identify that certain genotypes are somewhat more resistant to some of the disease damage as well. We would like to leverage those characteristics to build more resilient, restored populations. There's just a lot of fear and trepidation that goes with that. I mean, it represents risk when we're going about manipulating a wild population that we're trying to help. There is a lot of concern. There's a lot of scientific work and management concern and a lot of deliberations currently ongoing now. The State of Florida is revising the genetic management policy that they've used in the past, to begin thinking about more of these genetic approaches. If it's breeding or if it's selecting individual traits, or if it's - one of the other things that we're considering now very carefully, is trying to bring genotypes in from other locations where they seem like they're doing better, to infuse - especially because the Florida population is so low now, we think they need some genetic rescue from some outside infusion of new genetic individuals. Those are things that are being thought about extremely carefully, and planned very carefully in terms of genetic management, to try to leverage those advantages that certain of those genotypes have, but doing it in a wise way that you don't have unintended consequences as well. That's a big challenge.

[1:17:00.0]

ZM: Yes, a lot of that sounds like some radical intervention ideas that maybe would not have been considered decades ago.

[1:17:10.0]

MM: Not in a million years. It's shocking. I mean, it's a testament to how fast things have declined, is to what extent those types of more dicier interventions are now being very seriously considered. And it's not just in Florida and Caribbean. It’s true now throughout the world. In Australia, they also have a very large research and restoration project that they are similarly working on discerning wise ways for these types of genetic interventions and things like this. It's true with corals throughout the world at this stage, but even five years ago, would not have been. Essentially prior to the 2015 bleaching event, none of those types of actions would have been contemplated.

[1:17:59.0]

ZM: I really want to get to restoration, because it is super exciting. But I am trying to work my way there slowly. Did any of your restoration work happen while you were still with NOAA? Or was that afterwards?

[1:18:22.0]

MM: I was working in coral restoration when I was at NOAA. And it's two different aspects that I was involved in with NOAA. As the coral propagation and gardening approach began kicking off in the Florida Keys due to the amazing work of Ken Nedimyer and some of his partners, we were able to come alongside Ken and some of the other nursery operators and help - well "help" maybe not the right word - but to be involved in some of the scientific aspects as that activity was ramping up. Some of that was designing out-plants with different types of genotypes and doing some of that evaluation of "do different genotypes perform differently in different habitats?", doing some of the monitoring and the scientific support for the ramping up of the nursery and the coral gardening work in Florida. I was quite closely involved with several of the nurseries in that regard. The other piece of - coral restoration related - is that I also, during all the time that I was at NOAA, was also involved in Coral larval propagation, coral spawning, and color reproduction. It's from my postdoc experience in the lab of Dr. Alina Szmant, who had worked out much of what was known early on in terms of coral reproduction in the Caribbean. I had mentored with her. During all the time that I was at NOAA, every year but one, we did coral spawning in the Keys. We were involved in the slow, painful process, learning when corals spawn, and how to raise babies. Doing studies and research also, that early life history and that sort of thing. That was a major area of research that I was involved with my entire time at NOAA. That is the aspect of research then that led me to my current position. Because SECORE, that is the focus of what SECORE does, is really targeting larval propagation. Before, we mentioned the coral gardening and propagation uses fragmentation, so there we're making more clones of an individual coral, like we were talking about before. When we collect eggs and sperm, and we make larvae, we get gajillions of new genotypes. That's where the new individuals come from. It's important and that's an important and a growing aspect of coral restoration now is incorporating sexual propagation as well. SECORE is really at the forefront of that type of coral restoration and has been for a long time. I'm involved with that part of that side of restoration full time now. Whereas at NOAA, I was involved with a lot of different aspects of monitoring, and endangered species recovery and general reef monitoring, now I get to focus entirely on coral reproduction and larval propagation.

[1:21:33.0]

ZM: [Banter] You have done so many different things… It seems like every time we get to mentioning restoration, you light up. You can tell that you are really passionate about it. When did you realize that you wanted to focus on that?

[1:22:37.0]

MM: I think it was a gradual process. We haven't talked a lot about the Endangered Species Act listings. I don't know if we have time to get into that really closely.

ZM: We can talk about it a little bit.

MM: I was involved in the agency process for Endangered Species Act listing for all the corals. Elkhorn and staghorn coral were listed first. Then seven or eight other species here in Florida were listed, eight or so years later, and I was involved in all of those evaluations and processes. After the elkhorn and staghorn coral were listed, there was then an up-step, there was a qualitative emphasis that the agency and many other partners here in Florida and throughout the US territories, on restoration for these species that were endangered. Once we recognized that they were endangered, then there was a lot more motivation to help do repopulation and population enhancement. It was an action that got written into the recovery plan for those species. There was an agency mandate that said this is something that's necessary to recover these and that's mandated by law, at that stage. So there was a gradual uptick in this gardening approach. I was involved in that, not directly as running and helping with the gardener, but in scientific support as we first started thinking about adding corals that we had farmed to a wild population. That's a big deal. There was a lot of scientific and management thought, and evaluation and consultation and genetic evaluation that went into that process. I was involved in a lot of that. That was between say 2005 or ‘06 and 2010 when that process was really ramping up. I certainly thought about restoration a lot more. That was a fundamental paradigm shift to this point, saying, “Okay, we're going to propagate corals and we're going to add them to a wild population.” We hadn't done that before. Management would not have thought that was a good idea before that, right? We had to get to a situation where it was bad enough that we thought the risks of doing that were outweighed by the benefits of doing it in terms of helping those corals get repopulated and getting those populations to be a little bit larger. That process of being involved in recognizing these species as endangered, and then really being involved in recognizing and saying, “Okay, yes, we need to bite the bullet and we need to be actively engaged in propagation and population enhancement for these species, if we don't want them to go extinct if we want them to recover.” That was a several-year process, but it's certainly focused my work much more on restoration and its necessity, and this uncomfortable territory between proactive meddling in wild populations that we feel is really needed at this point because things have gone down the tubes so far.

[1:25:56.0]

MM: That was an ongoing process that was accelerated, I'd say, after the 2015 bleaching event. Then there were several other scientists that came out and published papers that said, not just not just fragment propagation and out planting; we need to think about selective breeding and tweaking, like manipulating the zosenfelli?? that are in a particular coral so that we can make them more temperature -- these much more interventionist and meddling types of approaches that other researchers were bringing to the table and saying, “These are scary things to think about, but we need to start thinking about them and researching them now, because we're probably going to need them sooner than we want to need them. We don't want to need them at all. But we're gonna, and we need to start working on that now.” There was a paper that was published in 2015, Madeleine Van Oppen was the lead author on that paper, that was very influential. It uses the term “assisted evolution”. That really got me thinking more that we need to - partly as NOAA, as an agency that's responsible for this stuff - we need to start thinking about this a lot harder. We also need to think about how ramping up restoration and how we incorporate some of these other procedures into restoration. That led me directly to conclude, and then as the opportunity in SECORE presented itself, that if we can develop some of these other more interventionist strategies that involve selective breeding and other types of manipulations, that coral breeding is a fundamental aspect to being able to implement any of those types of actions that we deem to be appropriate, and likely to have a positive cost-benefit ratio in the future. And SECORE was the only organization that was really focused on larval propagation, but also we are focused now on developing tools and technologies to upscale larval restoration and propagation in an efficient way, so that it can be implemented in an island community where you don't have a marine lab and you don't have a microscope. We're really focused on upscaling and upscaling with tractable tools that can be implemented where the coral reefs are, because I think it's clear that those tools are going to be needed. Whenever and if some of these more serious radical things, were like, “Okay, get a green light” and say, “Okay, if we can feed all the babies a particular type of symbiant when they're just newly settled and start them out with that, it's going to help them, it's going to help those corals be more resilient in the wild.” We don't generally want to manipulate things that much and we're not doing those types of things yet, except in a research scale. That's the evolution that brought me to being focused entirely on larval propagation or restoration, because that's what we're going to need. We're going to need to be able to do that at large scale, if some of those interventions are going to help us in the future.

[1:29:48.0]

ZM: Are there people that disagree with that?

[1:29:53.0]

MM: Of course. This is what I've observed: the people that will come back and say, “You can't possibly think about picking winners.” That's one of the critiques. “You can't possibly pick the winners for this, because you don't know what's gonna happen in the future.” My understanding, and in talking to some of those people, I think they have not observed and experienced and understand how far down the pipe things have gone. Because it's happened really fast. It's understandable that people don't have - even even scientists and coral reef scientists, if they're not involved in the field, or they haven't been in the water much in the past several years - it's hard to believe how fast things have changed. It's understandable. Nobody would have contemplated any of this stuff five years ago. There certainly are a contingent of folks that would say, “You gotta be crazy for thinking about this sort of stuff.” But the management community has really had to come around very quickly. That has happened from observing the decline and the resources that they're responsible for managing. The articulation by the scientists that it's not going to get better anytime, it's only going to get worse, it's not going to get better. The other critique, though, which is appropriate at one level, says that we shouldn't be investing all this resource and brain juice on restoration, because it won't matter; we really just need to solve climate change. We shouldn't be wasting all of this effort on restoration and growing corals and stuff like that, because it's never going to do any good if we don't solve climate change. It is true that it will not do any good in the long term unless we solve climate change, we have to solve climate change. But for most of the coral populations and the reefs that I've worked on for all of my career, they're not going to last that long for us to get it fixed. We have to prop them up. I expect that that's going to be an active process of propping them up for the next twenty or thirty years until we can get climate change fixed. A lot of people say, “Well why would you plant a bunch of baby corals?” My old advisor was actually like, “You wouldn't take baby humans and just lay them out by the side of the road.” [Laughter] There is a critique there in terms of it isn't that probably where we are out planting corals is necessarily where we're going to get those self-sustaining populations anytime soon. I think we're going to have to prop those populations up over a long term. However, I'm not willing to give up on them yet. I'm willing to be invested in propping those populations up over the next ten or twenty years. Yes, we've got to fix climate change at the same time, but if we wait to do restoration until we have climate change fixed, there won't be any corals left. I'm quite confident of that.

[1:33:28.0]

ZM: Wow. That is very interesting, the differences in thought there and how rapidly things are evolving. There are a few different methods of restoration that we have touched on. One is when a piece of coral breaks off, you can either affix it with a zip tie or some epoxy. What I am really interested in is how do you collect the eggs and sperm for the propagation to create new individuals? That is what seems to be the more long term solution, right?

[1:34:22.0]

MM: I think both methods of propagation need to be incorporated. We can get biomass that will build a lot faster using fragmentation. But we don't get any new genetic individuals, so we need larval propagation. To get new genetic individuals, it's a little more complicated, the process. It is indeed. We utilize the natural reproductive cycle of the corals, which generally involves a natural spawning event, sometimes one or a couple times a year. There are limited opportunities. Oftentimes, those corals are somewhat inconvenient in their spawning. It tends to be in the middle of the night, it tends to be often when there's raging either hurricanes or tropical storms or just normal thunderstorms going on. The corals as part of their natural reproductive process release eggs and sperm into the water column. Many species do. There are different reproductive modes, but most of the ones that we're looking at are important rebuilding species, or we call "spawning species". Their eggs and sperm are released into the water column on a somewhat predictable basis. It's predictable based on a lunar cycle; not perfectly predictable, but within a week or so. We can go out and watch those corals during those nightly vigils. We use little homemade collectors. They're like little tents that we place over the colony as it's preparing to spawn. Because the eggs have a lot of lipid in them, they will float. So as they're released from the colony, they'll float up this little tent that we put over them. We can collect them in a little cotton container at the top of the tent. Then we have the eggs and sperm that we can bring back to shore. We do in-vitro, or in-plastic fertilization usually, either on the beach or the boat deck or wherever we are diving from. We can perform the fertilization in an hour or two. Then we have baby corals, we have larvae. They go through their full developmental phase, usually as we watch them, either in a laboratory setting or - as I mentioned, SECORE is really has developed and is really using, with a lot of our partners in a lot of locations, in-situ mesocosms; essentially like like big floating pools that we can keep in the coastal water. We can raise large numbers of larvae in these in-situ pools. We provide the larvae - at a certain point, usually five to eight days or so of age to actually start swimming. This is when you can tell that they're animals. When they're little tiny, they will start swimming. You can watch them swim around in a petri dish. They're really cool. They will begin a behavior to find the bottom, to find a reef surface where they will undergo metamorphosis, and become a polyp and then grow into a coral colony on the bottom. That's the process. In doing propagation for restoration, we're in the business of predicting, collecting large numbers of larvae. The other cool thing about using larval propagation, corals can produce a lot of eggs. We have the potential to produce lots of propagules from a single spawning event. We're just working on ways to do that more efficiently. The larvae are very tiny, so naturally, they don't survive well. Most of them die, they get washed to sea…

I am getting a low battery on my phone, I've got 10% here. Excuse me, I will, um, I may have to run and get my plug in just a minute.

[1:38:20.0]

ZM: Okay, no problem.

MM: Let me finish that story. Naturally, most coral larvae don't make it to be corals. Sort of none of them do now. That's the problem that we're trying to solve. So we utilize these in-situ large scale pools that the larvae can do their own thing. We don't have to take care of them a lot, that way. We provide them also with designed substrate; little pieces of ceramic that we can convince them are a bit of reef so that they will settle and metamorphose. Then we can take those designed substrates and then place them back on the reef, or in a nursery or wherever. The other major challenge with larval restoration - so that's a lot of steps. As I said, this has been where research has really come a long way. When I started working with coral spawning back in the mid ‘90s, it's a lot easier than it was then. There are a lot more people involved. It's something that's tractable, that a lot of teams are working with now. It used to be not very many people at all. The other major bottleneck is after we have corals settled and placed out on the reef, we're placing them back into that environment that we know is not really great for corals. It's maybe not surprising that we don't have great survivorship even when we raise lots and lots and lots of baby corals. This is where maybe making those baby corals more resilient by some of these manipulations we're talking about earlier might help with a lot of different things; grazing regimes, keeping predators away from them, and keeping big fish from eating them, providing micro habitats where they can grow a little bit before they're exposed to things, or simply providing a grow-out phase and a nursery or land-based facility to let them grow a little bit bigger. When they settle, they're microscopic. [Laughter] You cannot see them. They're really tiny. Getting them a chance to grow a little bit bigger before we place them out on the reef, there are a lot of different things to try. There's a lot of room for improvement in that aspect of larval propagation for restoration that we're working on a lot. The challenge is our coral reef environment is highly degraded. That's the challenge with getting the babies to do better. The babies tend to be a little bit more sensitive than the adults that you're out planting with fragmentation. It is challenging to get them to join the population.

[1:41:12.0]

ZM: Got you. So it is almost like you create as many new corals as possible and then see what sticks when you put it back out there. Right.

[1:41:23.0]

MM: Yeah, and actually, that is part of the strategy. We're creating lots and lots of new genetic individuals. By placing them into the current reef environment, there's an opportunity for selection to do its thing. That’s where we’re working with natural selection in that regard. By using larval propagation and putting lots of babies out there, we have a chance that those resilient genotypes are created de novo, and that they're the ones that can be successful in our culture efforts.

ZM: Yes. Have you found that to be the case at all?

MM: I don't know that we're far enough along that - we've had a chance to do a lot of genetics on the survivors that we have, that we have survivors in different locations, that are adults now and spawning on their own, but we haven't got to the stage where there's enough of them to really look at genetics. When they're little, you don't want to sample them. You want them to get bigger. We're not far enough along, I'd say, to have an answer to that question.

[1:42:33.0]

ZM: You mentioned that the technology since the ‘90s has changed, or at least the techniques used. How were people doing this back in the ‘90s?

[1:42:48.0]

MM: I don't know that the techniques were all that different. We just refined it. Here's an example: the tents that we used to use, we had like a rigid hoop around the bottom that would fit over the colony and we had drawstrings. We’d go around and we'd tie. Before it got dark, we go and dive, and we tie all these collectors over individual colonies that we thought might spawn that night. It was like a whole dive and lots of trying to tie these collectors down over the individual colonies. Then maybe they spawn later that night and maybe they didn’t. Then we had to go around and untie them all at the end of the dive and go back the next day and do the same thing over again. Now we made collectors with lead line in the bottom so you don't have to tie them off. You just go “bloop”, and it sits right over the colony. You can actually wait and watch which colonies are going to spawn first, then just put the collector on when you can see the colony spawning. Because it's really quick, you just go “ploop”. That's just a really simple example. It's stupid stuff like that; it isn't technology. I would say the other factor that we've learned - this is partly a psychological thing, because you work really hard to get these larvae and you don't want to sacrifice any of them - but the culture is much easier if you keep all of the cultures at low density. That's the key to keeping the larvae happy through their early phase. If you can be disciplined and keep only enough larvae that you can keep it low density, life is much easier. [Laughter] Although we know that, it's psychologically still hard to practice that. But if you're disciplined that way, it's much simpler and much easier and the process can go much more smoothly. If you have too many larvae, once you get a few that die, then that makes more die and you're constantly trying to change the water and the culture is just really gunky. It's just a mess. That's another example where you just have to have a little bit of discipline.

[1:45:00.0]

ZM: Got you. Yes, that almost seems counterintuitive. You want as many coral babies as possible.

MM: Exactly. With many years of experience, your discipline improves.

ZM: Can you talk a little bit about what it is like to be in the water during a spawning event?

[1:45:20.0]

MM: It's amazing. It's amazing. I've done a lot of spawning events. I guess I've been doing this for, wow, 16 years. No, ‘94 is when I did my first spawning event. How many years is that? It's a long time. But it's always amazing. First of all, I don't know if anyone has been night diving before, the reef is just such a different place at nighttime. There's that background where you're in a reef and, even if it's a familiar place and a familiar site that you dive a lot, it's just a totally different world at night. You see different creatures. We often see octopus at night when we're diving, which you rarely see during the day, and they're just super cool. You get to watch those in the meantime. Part of this is background of spending time on the reef at night, and it ends up being a lot of time by the time you've been out there five or six nights in a row, and you do get tired by the end of the week, but when you have a corresponding event, it's - I don't know, people describe it as like an upside down snowstorm. Because you have these little bundles and they're just rising off the corals and into the water column. Partly also because there is a lot of work and preparation and stress that goes into being prepared for doing a spawning and a larval propagation event, when it actually happens, it's like, “This is it, it's happening.” There's both this amazement and awe that corals work this way, and that this is the way that corals do their thing and how reefs have propagated over the millennia. The privilege to be involved and to have a midwife role in that process is pretty thrilling. There's a little bit of panic that's always going on, at least for us scientists. If you were going just as an observer, I think it obviously wouldn't have the panic, but it's like, “Oh no, it's really happening now. I need to make sure this, this, this, this, this, this, and I don't forget that and I hope they fertilize and oh no, what if this goes wrong or whatever.” It's always a mixture for me, but it's amazing. It's an amazing experience. We never get never get tired of it. It's a thing you can never quit doing. For many of my colleagues as well, it's like, I don't know what I'd do in August, if I wasn't doing coral spawning. [Laughter] What do you do otherwise?

[1:48:00.0]

ZM: You are talking about remembering all these other things that are going on and all the preparation that goes into the coral spawning. It is not just putting that tent over the colony. Can you talk about the prep work for that?

[1:48:17.0]

MM: Part of it is often you're going places that are remote. Oftentimes, you're having to go and set up there. All the years that I worked in the Keys, we actually freelanced our own little field lab and set up plumbing. We would actually haul water from the reef, because the larvae are sensitive. We would actually haul water back to a land based little lab that we set up. The way that we do it now, one of the processes you have to do, I mentioned these substrates that you're asking the corals to settle on, you have to trick them into thinking that this is a piece of the reef. There's a process, we call it “conditioning”, but essentially it's taking these substrates and putting them in the ocean for a little while to get this biofilm and some of these other microorganisms that enable the larvae to recognize that substrate as a little piece of reef. That means hauling a bunch of heavy stuff around, we usually end up scrubbing it all. Getting everything set up to be ready for the corals. Oftentimes you're doing lab work, you're filtering a lot of water. It’s a lot of lab setup and then a lot of field setup as well...

I'm sorry, I'm still worried about my plug - but it's a lot of lab setup and field setup for things depending on which. Then the other aspect is because you only get one or two chances a year, you usually have like five times as many experiments lined up as you can possibly do because if you get a chance to do this, you really want to do X, Y, Z, A, B, and C. So you always are prepared for about twice as much work as you probably are ever going to be able to do, just because you don't want to miss an opportunity.

[1:50:14.0]

ZM: That makes sense. After the spawning event, you mentioned nurseries and having a place for the coral to grow up before you put it out on the reef. You also mentioned that the juvenile corals don't do as well in the tougher conditions. Can you describe the nurseries that you use at SECORE?

[1:50:43.0]

MM: That's something we're still working out in terms of what is going to be most effective. Our team in Mexico, they have a pretty extensive wet lab facility. They're able to keep and keep track of corals. Several of the facilities here in Florida as well now are being very successful in raising these larvae, the settlers, in land base tanks and in husbandry, and they've learned ways to feed them. We were talking about feeding earlier, but feeding them in ways that they can grow faster, and cleaning the substrate for them to make sure they don't overgrow and things like that. There's certainly a lot been learned in the last few years about being successful in growing coral babies in captivity. Ultimately, we'd like to get away from that, because there's a huge amount of work. It can be successful, but it is a huge amount of work. Figuring out tricky ways to get habitats and conditions that those babies can survive on the reef is still our goal. In different contexts, too, people have placed the settlers in some of the same nurseries that they use for the fragmentation propagation. More mixed success, as I understand it, in those situations. A lot of times there's still just a lot of fuzz that grows on surfaces. A lot of times the babies just get out-competed. That's certainly something that we are still actively engaged in testing. It's probably maybe a little while on land and then a little while in a field based nursery and then transferring to the field, but what the trade offs are in terms of how much work you have to put in, and how much improvement of survivorship you get, are all questions that are still definitely in active stages of research. It's probably different for different species, and it's different for different locations. So it's a big question.

[1:52:39.0]

ZM: I really liked the almost absurd metaphor that your advisor used, that you would not throw human babies out on the side of the road to see if they grew up. But this is actually working, though, right? I read that there was a study done to see if we could actually see a difference in the amount of coral colonies over a large area and the result was yes, we can.

[1:53:21.0]

MM: Yeah, absolutely. That was based more on the coral gardening and fragmentation work here in Florida. But yes, I do think that. One of the things that we've learned from the monitoring and monitoring other areas with these species - here in Florida, I mentioned the palmata has tanked and it's doing terrible. The server cornice is doing not so bad. Everywhere else in the Caribbean, it's the opposite. The palmata is doing okay, and the server cornice is doing terrible. I attribute this to the restoration effort in Florida which has really focused on server cornice for the past ten years and has out-planted a lot of server cornice. That has made a difference in the population in Florida. They don't live forever. Most of them probably live and grow for seven to ten years, but the amount of coral that you can see out on a reef, you can see server cornice and you can see staghorn coral growing on many fore reefs in the Florida Keys. That's because they've been restored. It can definitely have a landscape effect. The larval propagation and outplanting, we have a ways to go to that level, for sure. The goal is to integrate these two approaches in a way where the fragmentation is always going to get you more biomass quicker. The larval propagation complements that by creating new genotypes and you really want to use both of those together.

[1:54:46.0]

ZM: Got you. Okay, that makes a lot of sense. So, let's see, wrapping up a little bit and...

MM: I'm working with my plug for 10 seconds. I can hear you. Go on.

ZM: No problem. How does it make you feel to be on the proactive side of reef science? You used the phrase “proactive meddling” earlier, which I really liked. There is a difference in the outlook from somebody who is focused on restoration, as opposed to someone who is more focused on something like disease monitoring.

[1:55:45.0]

MM: Oh, yeah. A lot less psychological problems. [Laughter] It gives you a different perspective. Not that there aren't still plenty of discouraging things. You still see plenty of things that you see how big the need is, and how little that we're actually able to accomplish. But it at least puts us in a position of doing something besides just watching the corals die. That's a huge difference. We've got a long way to go, there's still a lot of challenges to solve. I'm not ready to give up on them. Being engaged in active - being part of the solution. As humans, we're all still a little part of the problem. Being part of the solution is very gratifying. Still have a lot to do. I'm naturally a pessimist, so I tend to dwell in that space myself. Being able to work with corals in a positive way is a real blessing.

[1:56:57.0]

ZM: I would not have pegged you for a pessimist.

MM: It's the key to a happy life.

ZM: Expect the worst and then when it is a little bit better..

MM: Exactly.

[1:57:08.0]

MM: You're often pleasantly surprised and you're rarely disappointed. So it works out well.

[1:57:13.0]

ZM: Do you think that's what we should do with corals?

[1:57:18.0]

MM: [Laughter] I don't know. I mean if you were truly pessimistic, you would give up, obviously. I'm not I'm not quite that pessimistic. I think we can limp corals along, so to speak. I think that's what we're engaged in. It's maybe the wrong word to call it "restoration". We're not going to get them back to what they were. I think a realistic goal is, as I said, gonna limp them through the next couple of decades as the climate needs to get stabilized. I think we can do that. I think we can limp them through. And hopefully, within those decades, if we can get the climate system stabilized, then we will figure out what that new normal looks like with the corals that we've limped through. That's a heck of a lot better than letting them go completely, which I think is the alternative.

[1:58:16.0]

ZM: If you were able to give advice to a new generation of people that are thinking about getting into marine science or marine biology or any related field, what would you tell them?

[1:58:40.0]

MM: Don't believe people that tell you, you can't have a career in marine science. And honestly, there are a lot. Coral restoration is a growth endeavor, there are a lot more people involved in coral restoration than there were five years ago, and many, many more than there were ten years ago. It is possible to have a career that way. I had a lot of people tell me, "Yeah, everybody wants to work on coral reefs, what do you really gonna do?" You don't have to believe that. It is possible for a girl from Indiana to manage and have a very rewarding career. So it is possible. There is a lot going on in the field of coral restoration in a lot of different realms. I think there will be many, many more opportunities than there have been in the past. There's going to be room for people to make their careers as restoration practitioners, not necessarily as scientists, and I think that's such a direction that we're moving. That was never a thing before. A coral farmer, that was never a career but I think we are approaching a point where it can be. That's something that some of the management and some of the ideas about how do we get core restoration to be supported and pay for itself. I mean, there's these types of opportunities that may grow in the future. Even if you're not a scientist, I think there'll be more opportunities in the future.

[2:00:11.0]

ZM: Coral farmer sounds pretty good. There are definitely worse jobs out there. You said you have a lot more work that needs to be done. At this point in your career, I know it takes a lot to go through all those years of schooling, then all that diving and setting up labs and stuff is not easy work. How do you feel about your decision to go into this field?

[2:00:52.0]

MM: Oh. I can't imagine doing anything else. What I would have imagined doing if I wasn't studying corals and doing coral restoration would be studying streams or mayflies or something else. I would have been involved in field science in some sense, or fisheries. I think that's the only thing I can imagine doing. So it might not have been corals, but it might have been something else. Definitely field science is what I've always wanted to do. I haven't ever been dissuaded from that. It gets a little harder as you get old. I'll say that. [Laughter] But it's definitely still what I enjoy.

[2:01:35.0]

ZM: Awesome. Well, thank you, Margaret. I really appreciate it. I know it's a long interview. But I had fun. Learned a lot. I really appreciate your time.

[02:01:49.0]

END OF RECORDING