BONNIE WILLISON: Hey, introduced listeners. We'd Love to learn more about you. So we're asking you to fill out our listener survey in the description below. It will take you only about five minutes and it will help shape the future of what Wisconsin Sea Grant makes. So click pause, fill out the survey, then enjoy the show.

I'm Bonnie.

SYDNEY WIDELL: And I'm Sydney.

BONNIE WILLISON: And this is Introduced, from Wisconsin Sea Grant.

SYDNEY WIDELL: If Jake Walsh was a daphnia in Lake Mendota or one of the tiny little organisms that floats around in the water eating even tinier pieces of algae, the scariest thing to him about the spiny water flea invasion would be watching his friends get eaten.

JAKE WALSH: Oh, my gosh. So spiny water flea are just, they are violent when they eat zooplankton. It's like, they will get a hold of a daphnia and they just shred it to pieces. And so to watch that as a daphnia would be horrific. Yeah. I don't want to assign judgment to how something eats. It's just eating.

But like if I were a daphnia, I would judge that as pretty awful.

SYDNEY WIDELL: Jake's not a daphnia though. He's a program coordinator with the Minnesota Department of Natural Resources. He can't really speak for these tiny aquatic animals but he did study them and their relationship with introduced spiny water flea during a PhD and later a postdoc at UW Madison. And he wrapped that up in 2018.

BONNIE WILLISON: You were able to speak to a lot of daphnia for this episode, right?

SYDNEY WIDELL: Only if you wanted to go on the record with it.

BONNIE WILLISON: They're being targeted. I understand.

SYDNEY WIDELL: They're really shy, Bonnie. They're so shy.

BONNIE WILLISON: Well, you mentioned spiny water flea. What are spiny water flea?

SYDNEY WIDELL: Spiny water flea we are an invasive zooplankton. They're from lakes in Eurasia area. They thrive in cold water environments. They're predators. So they are zooplankton but they eat other zooplankton, specifically daphnia. They were brought over in ballast water into the Great Lakes and then they've kind of like, people are slowly spreading them to other lakes inland from the Great Lakes.

BONNIE WILLISON: Are they actually spiny?

SYDNEY WIDELL: Yeah. They have this long barbed tail, like half their body is this tail. They're bigger than native zooplankton. They're like half an inch big. You can pretty much see them with your naked eye. Jake said that spiny was actually a really spiny like at all scales.

JAKE WALSH: It's got this big tail spin coming off the spiner spines and then if you look very closely on these barbs right on the spine, there's like even there's sort of like two ridges, almost like shark skin. So it is, spiny water flea is very spiny.

BONNIE WILLISON: Oh, my gosh.

SYDNEY WIDELL: Yeah, so that tail makes it really hard for other fish to eat them.

BONNIE WILLISON: Yeah, and don't they cling to people's fishing lines? Like as you're reeling the line in through the water or pulling it behind the boat while trolling, if the line goes through swarms the spiny water flea get attached and when you look at a picture of this they look like little lumps of like gel on the fishing line.

And then when you reel that in, those clumps like catch on the islets of the fishing rod they can even break a fishing line. That's so strange.

SYDNEY WIDELL: And all of this means that a spiny water flea introduction into a lake can have cascading impacts on the fishery and water quality in general. So I want you to think like more algae blooms, less food for fish, and then that means less fish for people.

JAKE WALSH: And so in I think the majority of lakes that it invades, it just upends that bottom part of the food. Zooplankton are really important food sources for fish and so when spiny water flea comes in, they're eating that food source. They're not a great food source themselves because they have that really long tail spine. And that can really changed how much prey are available to fish.

So another really important thing that some zooplankton do, daphnia in particular, is eat algae in lakes. And so when spiny water flea preys on those daphnia that used to be eating algae, algae are allowed to grow a little bit more unchecked and we actually lost a fair amount of water clarity in Lake Mendota. And part of the reason that we see more algae blooms in the lake is because we don't have daphnia because spiny water flea ate the vast majority of them in Lake Mendota.

BONNIE WILLISON: Spiny water flea were first noticed in Madison's Lake Mendota in 2009, which was there just before Jake Walsh arrived.

JAKE WALSH: It was an exciting time, I guess. They're not fun to have in your lake but for its scientists, it's an opportunity to really understand how your lake works. And also to understand an invasive species that does have some pretty detrimental impacts in the Midwest.

SYDNEY WIDELL: So since then, Jake's tried to figure out what makes a lake like Mendota vulnerable to aquatic invasive species like spiny water flea, and then also if it's possible to predict where invasion's will happen next. There are a lot of reasons an invasive species could get into a lake and take off.

Like there are a lot of actions we can do to prevent them from spreading. But there's just so much movements, like of people and things.

BONNIE WILLISON: You know there's a lot of huge factors like global trade between continents that we don't have much control over as individuals but at the same time it's like something has to be in the exact right place at the exact right time in a way to be established because for something to become invasive here in Wisconsin, it's got to be able to survive our winters. It's got to be able to survive in our kind of like rainy-ish climate, a humid place.

So not every species that could be introduced is going to be able to thrive here.

SYDNEY WIDELL: Right and I know that like we don't want things to wind up here but part of me is just like blown away and thinks it's like a miracle that this could happen. There's something like almost awe inspiring about just like how everything can align to be just right.

But then again, with so many people using lakes or living near lakes, the odds of a species being introduced start to increase a lot. So maybe it's not surprising at all that some species eventually are introduced and succeed. Basically, there are a lot of reasons and invasive species can get into a lake and then take off.

BONNIE WILLISON: Yeah, like you have to consider how does a lake get used? Are there a lot of tourist, is it used for trade, how connected is it to other lake?

SYDNEY WIDELL: But in the end, Jake told me that temperature is like the most influential factor in determining whether or not an introduced species or really any species, is going to be successful in a lake. Temperature is kind of like the master thing that controls all the other things. If you know how warm a lake is, you have a better idea of how likely it would be for that lake to become a foothold for any new species.

And if scientists want to predict how warm the lake is going to get as climate changes, they can also predict like which species are going to be successful there in the future and which species won't be as successful.

BONNIE WILLISON: So how do spiny water flea fit in? Is the temperature in Lake Mendota particularly suited to them?

SYDNEY WIDELL: Actually, no it isn't, like at all. So spiny prefer cold water. Temperatures above 70 degrees are just like really stressful for them. They spend a lot of energy just trying to stay alive and don't have as much energy for like mating or finding food. So if you have a cold lake, there are a lot of spiny water flea. In a hot lake, the spiny start to die off.

And if you look at temperature alone, in Wisconsin there are more lakes in the north part of the state that would be vulnerable to spiny than there are lakes in the south, like on paper. And a lot of times air temperature is really all people look at if they want to make estimates about the temperature of a lake.

But Jake suspected that it wasn't that simple.

JAKE WALSH: In Wisconsin we have very similar climates across the state where it's like southern lakes are generally warmer the northern lakes, but when you really dig into it, lakes that are right next to each other can actually be really different in terms of temperature and that's because lakes respond to air temperature in really different ways. Their size, their depth, their shape, their clarity, all sort of it determines how a lake warms throughout a year.

And so what it means is that you can have two lakes that are right next to each other in Wisconsin but one can be cooler and one can be warmer, just because of how they manage heat, essentially.

SYDNEY WIDELL: So lake size, shape, clarity, depth, all of those things play a role in determining how a lake warms. And no two lakes are exactly alike. At first glance, Mendota might seem like an unlikely place for spiny water flea to thrive because it's located in southern Wisconsin, which tends to have that warmer climate and the warmer lakes. But Mendota is not always warm and that's one of the reasons spiny water flea could get established there.

Jake said it's sometimes cool temp, despite the fact that it's in the southern part of the state, that makes it a foothold for cold water aquatic invaders like spiny water flea, whose ideal habitat you'd expect to find like way further north in Wisconsin. So the summer of 2009 was way colder than normal and that is perfect weather for spiny water flea.

JAKE WALSH: Spiny water flea really loves those cool water temperatures and it just was allowed to grow sort of unchecked through the summer, which is the time it usually struggles in Lake Mendota, and established this really big, impactful population.

SYDNEY WIDELL: So I have this picture of what spiny water flea look like when they're just clouding in the water. Do you see that?

BONNIE WILLISON: Yeah. I can't see the individual water fleas. Obviously, it's a picture of a lake but it looks like there's kind of milky white water at the top kind of clouding over.

SYDNEY WIDELL: Yeah, those are just like clouds of spiny water flea. And that's kind of like what Mendota looked like at times after they appeared in the lake. So the population really took off after 2009 after that cold spell.

JAKE WALSH: We actually had one year in Lake Mendota where they were super abundant and then we had this really intense storm that was pushing waves sort of from the north into our boat slip at the Center For Limnology and we just got these massive swarms of spiny water flea in the lake.

It was really cool and we have these videos of just spiny water flea swarming in our boat slip and we were like pulling them out of the boat slip and watching how they move and how they swim. But one thing that's about all zooplankton is they kind of go wherever the water pushes them.

SYDNEY WIDELL: For a really long time, people believed that spiny water flea had shown up in 2009, that cold summer. But then a group of researchers discovered the remains of spiny water flea in lake sediment that dated back to the mid 90s, so they'd been here longer than anyone knew.

And what's so bizarre about that is Lake Mendota is right next to UW Madison and it had been studied very intensely over that time.

BONNIE WILLISON: Researchers have been gathering data on it for more than 100 years, more than so many other lakes. So I'm really surprised that they're just seeing the remains of spiny water flea in sediment and they didn't even know they were there for like 15 years or more.

SYDNEY WIDELL: Right, yeah. Jake thinks that that cold snap gave the spiny a foothold. In Mendota, he sees the potential for random and brief moments of climate variabilty, for example, like a really cold summer, to drive sudden long term changes in the lake like the emergence of a new species like spiny water flea.

I wanted to know what happened before the cold snap in 2009 that allowed spiny to get a foothold and what that foothold will look like in a warmer future. No one knows exactly when in the 90s spiny water flea showed up.

BONNIE WILLISON: Yeah, that's something that always is kind of frustrating to me about aquatic invasive species because it's really rare to ever know how exactly something was introduced. Like it's this mystery. You want to know like how did it get here, but it's really hard to tell.

SYDNEY WIDELL: Yeah. So around the time that we think spiny water flea got established based on like that sediment core, Mendota is in the middle of a huge makeover. Jake called it one of the greatest success stories in fresh water management.

BONNIE WILLISON: Wow. So what did the lake look like before this lake makeover? Like why did we want to give it a makeover?

SYDNEY WIDELL: I'll set the stage for you, Bonnie. So water quality in the lake had not been great. For a lot of reasons water quality today is not great and Mendota and other lakes surrounded by intense agriculture. Nutrient rich runoff is always flowing into the lake and there are even more nutrients, researchers call these legacy nutrients, those are stored in the soils of the watershed and they've been accumulating as the use of fertilizers and land spreading of manure has gotten more intense.

All of these nutrients can help fuel algae growth. A team of scientists and managers wanted to change that though. One is Dick Lathrop, who you might remember from the Lake Wingra carp exclosure we talked about in season one episode six.

BONNIE WILLISON: Yeah. I remember that Dick told me about trying to change water quality in Lake Wingra, which is actually kind of close to Lake Mendota. And they were trying to do this by taking out an entire species of introduced common carp, in this case. This is back in the early 2000s and he called this kind of experiment bio manipulation.

SYDNEY WIDELL: Bio manipulation is also how Dec described to me like what was going on with this Lake Mendota project, which began in 1987. Dick was working for the DNR as a research scientist at this point. Dick has this wild ability to remember details about the weather going back so many summers.

DICK LATHROP: We had an early spring and we had a really warm summer and early spring in '87. I lived on the lake myself back in those years so I know exactly what was going on.

SYDNEY WIDELL: So around this time, there is a series of really, really influential studies underway about this thing called a trophic cascade.

BONNIE WILLISON: What's a trophic cascade?

SYDNEY WIDELL: Let's say you start with a lake with a lot of algae and then if you go up the food web, so plankton eat the algae, small fish that eat the zooplankton, and then big fish eat the small fish. There is this question, could you change water quality in a lake by changing the lake's food web?

So to get rid of the algae, you would need more zooplankton, which means you need fewer small fish because they're eating the zooplankton and that means more big fish. So if you stack big fish in the lake, will that change ripple all the way down to the point where you don't see as much algae? And a team of limnologists, some of them are from UW Madison, they were trying this out on a few tiny lakes on the Wisconsin, Michigan border.

DICK LATHROP: So the cascade as you work at the top, and it cascades all the way down through to the level of the algae.

SYDNEY WIDELL: So in theory this would work and those pond sized lakes on the Wisconsin, Michigan border, the results were looking promising. But what about Lake Mendota, which is a way bigger lake? People thought that manipulating the food web might be worth a shot.

DICK LATHROP: Quite frankly, the algae problems had been going on for decades at that time and without any real ability to curtail them.

BONNIE WILLISON: So they have an algae problem in Lake Mendota did they try to fix that by putting more of those big fish eating fish into the lake?

SYDNEY WIDELL: During that hot and dry summer, Wisconsin DNR fishery scientists and managers began to heavily stock walleye and pike in Mendota. The most intense stocking happened during the first five years of the project but over the next decade, they stocked about 2,800,000 fish in total. That's about as many fish as there are people in Chicago.

The vast majority of those fish were very young walleye and of those walleye, not too many survived. They also stocked smaller numbers of somewhat older and larger young northern pike and those survived better. For context though, the DNR stocked about five times as many young walleye in Mendota in the year 1990 as it did in 2020. All of this was really an attempt to expand that top part of the food web ultimately, to create a lake with lots of daphnia and far less algae.

But they didn't account for one key detail.

DICK LATHROP: You know, it's a trophic cascade but they forgot that there's one more trophic level above the sports fish and that's the humans.

SYDNEY WIDELL: So in addition to stocking, they also had to create these really restrictive fishing regulations in order to keep those high density fish in the lake faster than humans could take them out.

DICK LATHROP: So you may have more fish but if you've got 10 times as many people fishing even though you have regulations, you cannot maintain a really high density of sport fish because everybody loves to catch walleye and northern pink.

BONNIE WILLISON: That's just really funny to me to imagine scientists dumping fish into the lake and then hordes of people just coming to fish them right out.

SYDNEY WIDELL: I know. Yeah. So this really intensive stocking went on from 1987 to 1999. And despite like all of the new fishing pressure and also the climate and land use, lots of changes happening, and those were kind of like out of the researchers control, but water clarity did improve and populations of the large algae eating daphnia began to surge in the lake. Dick wrote about all of this in a 2002 paper where he basically said that this project was successful.

BONNIE WILLISON: Yeah, it sounds like it's working.

SYDNEY WIDELL: Right, yeah. But I also can't stop thinking about the story Dick told me about how as word traveled about the stocking project, more and more people just came to Lake Mendota. Newspapers all over the Midwest were talking about this project and Dick said even when they tried to tighten up catch regulations, it was still really hard to keep up with like this huge demand for all the fish and people coming from all over the place.

And that's just kind of like a fact about Mendota. It is like a central hub for fishing. It's in the state's capital. It's a big, beautiful lake. It has this lake very well maintained sport fishery. So not only does that make Lake Mendota susceptible to introductions, it also makes the lake a foothold for invasive species.

People come in, they put their boats in the water and then they leave, and no one is guaranteed to leave with exactly what they started with. And at some point during this period a handful of spiny water flea got introduced into the lake and maybe they feasted on the abundant daphnia that this terrific cascade project had created or they might have also been really stressed out by how warm the lake was and maybe it was like some combination of both.

Eventually, those original spiny water flea had children and then they died and their bodies drifted down to the bottom of the lake and they stayed there buried in lake sediment for years. And either those water flea or their children were the ones that Jake saw when you open up that sediment core so many years later. And by that point, Mendota had the highest spiny water flea population densities anywhere in the world.

So like how did no one noticed that? It took until fall 2009 when a group of undergrad students at Madison were learning how to sample for zelle plankton. So what they do is they take like this long net and they drag it to the water and they pull it back up and then dump it out and like it was just full of spiny water flea and they're like, what is this? And how could something like this just go undetected for so long.

BONNIE WILLISON: So when you think about all the other lakes in Wisconsin or in places you care about and then all the other potential species, is that like--

MIKE SPEAR: The thing that keeps me up at night? Yeah. As an invasive species ecologist I think this example is fascinating. So when you think about spiny water flea, Lake Mendota is probably not the only lake where they're sitting at low densities sort of waiting for an anomalously cold summer like happened in Mendota, or some other environmental change to happen and trigger them to be this sort of explosive invasive population.

SYDNEY WIDELL: That was Mike Spear. He finished a PhD at UW Madison in the fall of 2020 and he spent a lot of time thinking about how spiny water flea could have gone unnoticed for so long. He said that no one picked up on spiny water flea because no one was really looking for it, which stresses me out, like a lot.

MIKE SPEAR: And that's weird to say because the lake is so well studied. They're looking for everything. But spiny water flea is sort of a cool water species and everything we knew about its biology said that it couldn't live in Lake Mendota. Lake Mendota was too hot.

And that was sort of true. It never did very well in Lake Mendota. Too often we think about invasive species in sort of binary terms. A non-native species shows up somewhere and if the environment is good for it, it sort of grows uncontrollably and becomes invasive, or the environment is not so good for it and it dies.

But what we're starting to realize is there's this whole middle ground where they show up and it's not ideal conditions but it's just good enough where it can sort of eke out this sort of low density existence. And that's exactly what happened in Lake Mendota. And the fact that Lake Mendota is a warm water lake and spiny water flea are a cool water species, we weren't really on the lookout for it.

Where even at low densities we might have found it if we knew what we were looking for.

SYDNEY WIDELL: That middle ground that Mike's looking for, it might be a new way to think about aquatic invasive species but ecologists have thought about it for a really long time.

MIKE SPEAR: A lot of sort of foundational ecology tells us that most species and most places are not super abundant. They're at very low densities and that that probably holds true for non-native species as well. Not this binary thing where a species shows up and it explodes or it shows up and it dies.

BONNIE WILLISON: That makes a lot of sense. So if species are kind of just hanging out at low levels naturally, what makes something like suddenly pop up and become like a nuisance?

SYDNEY WIDELL: Mike said this comes down to triggers in the environment.

BONNIE WILLISON: So like if there's a summer that's really cold for some reason?

SYDNEY WIDELL: Yeah, or just like, if suddenly you change like the ratio of nutrients in the lake or you set off some kind of change in the food web. Like all of these things could create a condition where something would suddenly see a drastic shift in its abundance in the lake. And if that could happen in Lake Mendota with spiny water flea, I mean, it could happen anywhere with any species and the scariest thing is like you don't know it until it's too late.

Preventing new species from entering lakes is obviously like a really important part of managing AIS but like what if they're already there? Like at that point the most important thing you can do is like not manage the species. It's like, manage the triggers.

BONNIE WILLISON: But you never know what's going to trigger them.

SYDNEY WIDELL: Yeah, exactly. We know some triggers but like maybe there are triggers we can't anticipate. So some triggers are easy to manage. Like for example, like changing a food web is like a lever that people actively use, like stocking more fish.

BONNIE WILLISON: Still not super easy though to manage that.

SYDNEY WIDELL: LIke, not cheap. Some are a little harder and like managing nutrient pollution and triggers that we don't know about yet. But nearly all of these things really are, like we need to reflect pretty deeply about how human activities have impacted fresh water now and in the past, and how the legacy of our activities like continues to impact the condition of our lakes.

MIKE SPEAR: The lake is connected to the land and we can't pull one species' edition out of this story and make sense of it all. Everything's connected back through time and it all leads back to how humans have impacted the system, mostly through land use around the lake, not even our activities and or on the lake.

SYDNEY WIDELL: And then of course there's climate change.

MIKE SPEAR: When you add on to that the fact that we're living in an era defined by environmental change, between global climate change sort of shifting things directionally warmer and wetter, but also increasing the sort of frequency and intensity of these extreme events that we have, that sort of is a recipe for disaster. You have all of these low lying, non-native populations waiting for environmental change and we're living in this era defined by environmental change.

SYDNEY WIDELL: The stars need to align for spiny water flea to be successful, and in 2009 they kind of did.

BONNIE WILLISON: Mendota is a foothold in a few senses. It's centrally located it's a hub for travel, and introduction is more likely. Despite being in the southern part of Wisconsin, it's really big and deep.

SYDNEY WIDELL: Yeah, so it kind of sits on like that middle ground Mike was talking about. Like Jake said, it is influenced by like these very random climate patterns whereas other lakes might be more stable. And then in 2009 it was cold, it was cold, it was cold, and this spiny finally exploded.

After the break, where is the lake heading next and what does it mean for the people who depend on it?

SPEAKER 1: Teach Me About The Great Lakes as a twice monthly podcast in which I, a Great Lakes novice, get people who are smarter and hardworking than I am to teach me all about the Great Lakes. And it serves a really important purpose within my job because I do need to learn a lot about the Great Lakes.

But I think what's really great is that also, the audience can learn at the same time. And so it's really become like a one stop shop for everything you could want to learn about the Great Lakes. Things from biology to ecology, to geology, natural history, political history, the arts, whether. Anything that you might want we probably have an episode about or if we don't, we'll probably have one soon.

And then because this is every two weeks, we might have another one shortly thereafter, maybe even a two-parter. I don't know. And it's a friendly format, which is good. But I think what's key to our success is that we're unafraid to ask the important and difficult questions. Questions like, so if you could have a great donut for breakfast or a great sandwich for lunch, which would you choose?

SPEAKER 2: I would definitely have a sandwich.

SPEAKER 2: I would go with the sandwich.

SPEAKER 4: I think I'd have to go with the donut.

BONNIE WILLISON: Find Teach Me About The Great Lakes at TeachMeAboutTheGreatLakes.com.

So a lot of things can trigger changes in a lake. One is when a new species is introduced. Mike, that PhD student from UW Madison who did all the work on triggers explains.

MIKE SPEAR: We're assembling these ecosystems that have never existed before. We've got all of these North American fish and Wisconsin specific algae, mixed with these invaders from overseas. We don't have a lot of context to build expectations on.

SYDNEY WIDELL: By 2010, it was clear that spiny water flea had a pretty good foothold.

DICK LATHROP: So then you got 2010 11, 12, 13.

SYDNEY WIDELL: In some ways, Lake Mendota responded to spiny water flea the way many scientists expected it would. There are fewer daphnia, there is more algae. In some ways, it was a lot like traveling back to 1987, like right before that stocking project started. Only instead of those fish eating most of the m it was spiny water flea and that was disastrous for all the fish that came next in the food web.

BONNIE WILLISON: Yeah, so spiny water flea. They kind of took the fish's spot. They like cut the middle out of the food chain so the fish didn't have enough to eat, right?

SYDNEY WIDELL: Yeah, pretty much.

DICK LATHROP: Nobody likes to see invasive species come in and changing everything. Nothing good can come out of that in the long run.

SYDNEY WIDELL: So that takes us up to 2015 and then zebra mussels show up and then everything gets way more complicated.

BONNIE WILLISON: Uh-oh.

SYDNEY WIDELL: There's some weird parallels to spiny water flea with this. Like zebra mussels were also spotted by an undergrad limnology class, just like the spiny water flea, they were also like in pretty high densities by the time they were discovered which kind of leads you to suspect that they'd been there like much longer than people thought.

So zebra mussels if you haven't seen them before, they're like an inch big. They're this mollusk so they have the shell, the stripey shell. Kind of looks like a zebra. They grow on hard surfaces, mostly around m and they filter floating algae out of the lake and they're really powerful at doing this.

Like it could take them two to three weeks to filter out all of Lake Mendota. It's like a huge amount of water passing through these small animals. Dick said that zebra mussels are fundamentally altering the way nutrients moved through Lake Mendota. They start by pulling water and nutrients out of the middle of the lake to the shore. So that strengthens the shoreline food web, which is really good for carp and bottom feeders.

But in the open water, which Dick refers to is the pelagic area, that's terrible news for wildlife and other sport fish that people have been working really, really hard to keep stocked in Lake Mendota. And the other thing that all the zebra mussel filtering is going to do, is it's going to make the water ultra clear. So that extra sunlight is great for aquatic plants. Those take off, and that provides habitat for long stringy cotton candy like algae to start growing.

Dick give me a quick forecast for where Mendota might be headed.

DICK LATHROP: The game changer is zebra mussels. They're changing the whole food web, shunting it from a pelagic kind of system and we're getting a more benthification process where the nutrients are taken from the middle and moved into the shore, either as the clear water aquatic plants, fulminous algae cotton candy like galopin and stuff that grows on rocks and things on the shoreline, and the type of blue green algae that aren't eaten that take up the nutrients, and then they float in the blow downwind along the shore too.

But yeah, you go to the middle of lake and it might look pretty clear and be pretty nice, but if you're doing the lake from the shoreline like most people do, you're going to think things look pretty bad. So that's what we're going through now we don't have quite enough years yet to fully understand how this will play out in Mendota. But this condition that I've just described, this is well as all the other lakes where zebra mussels have been in there for 20 years or so.

BONNIE WILLISON: So how do spiny water fleas fit now when there is a really big zebra mussel population problem?

SYDNEY WIDELL: Dick says it's too early to know what the relationship between spiny water flea and zebra mussels looks like and Lake Mendota and what that means for the rest of the lake.

DICK LATHROP: So we've got a lot of interesting things going on here and I don't think we would want to- I would not want to say that zebra mussels will cause the demise of spiny water flea. But I think the effect of spiny water flea is not the same as when it was basically by itself controlling the daphnia population.

SYDNEY WIDELL: Zebra mussel might not mean the end for spiny water flea, but a warming lake might. There are ways to prevent the spread of new species, just like there are ways to prevent catastrophic climate change. But at this point, a small degree of warming is already underway and the big question is how our lakes are going to respond to that?

Jake built a tool that could help answer that question. He created models of the way hundreds of lakes across the region are going to warm in the decades to come. It's this really scaled down way of looking at climate change impacts that gives people who care for those lakes, a way better understanding of exactly what changes could play out under different climate warming scenarios and also what species are going to do well in those lakes in the future.

JAKE WALSH: The really key thing is that we need to be looking, at least at the state level, at this sort of lake to lake variation. And we need to be thinking specifically about each individual lake to actually get an accurate picture of vulnerability in our state. I think what this does for us with aquatic invasive species is it gives us a way to pinpoint foothold lakes for warmer water species that might expand their range to northern lakes, so into our region.

So some lakes are going to be warmer than others, just because of how they deal with heat. And so we can identify those foothold lakes for a given species. But we can also think about it like for spiny water flea where it's like what lakes are going to be sort of those refuge lakes that give spiny water flea habitat in our region even though the region is warming generally.

And you can think about this in the same way for like species, native species that we're trying to manage in a positive way where we're trying to keep them in our states and are trying to help them maintain populations even though climate change is happening. So for a lot of our cool water fish, this could be a way to identify those refuge lakes that we really need to protect and we really need to manage carefully in order to keep walleye fishing going in this stage or something like that.

SYDNEY WIDELL: One thing climate change is going to do is it's going to constantly reshuffle the species that are going to do well here, like in the upper Great Lakes. Jake says that focusing on large scale prevention like ballast water sterilization, is one thing that's really important to focus on because that's going to keep our local pool of species from changing. Because at the same time species from the south of us are already on the move north.

Introduced species, climate change, and other human impacts all work together to alter lakes. In Mendota you really see this playing out with spiny water flea. Spiny water flea have really eliminated people's ability to control algae but at the same time there's more rain, which is part of climate change here, and that means more nutrient runoff and also more algae. So spiny water flea and rain are going to interact together to create outcomes that nobody really wants.

JAKE WALSH: The biggest thing that I have taken from this is thinking about how all of these different stressors work together to sort of impact the ecosystems that we care about or the lakes that we care about where we have climate change impacts that are going to be impacting lakes in certain ways, oftentimes adverse ways, if we're thinking about how things change. And we have invasive species that are doing the same thing, impacting lakes in certain ways.

And so thinking about that all in terms of sort of risk and risk factors that are all working together to create the management problems that we'll have now and into the future. I think so for me it's more conceptual where it's just, it's another factor and it's another thing that's going to lead to changes in our lakes that we don't necessarily want.

SYDNEY WIDELL: In general, climate change is not going to favor the spiny water flee, at least in this region. But that doesn't mean we should let our guard down just yet. Mendota is right on that temperature threshold. Sometimes the lake is too warm and sometimes it's just right.

JAKE WALSH: And so the key finding there is like climate change is going to be bad for spiny water flea but we saw a lot of vulnerable lakes and we need to keep trying to prevent and manage spiny water flea or manage against spiny water flea.

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