Hey to all you fish enthusiasts out there. Whether you're an avid angler or just curious about fish, we'd like to welcome you to Fish of the Week!, your audio almanac of all the fish. It's Monday, February 13, 2023. And we're on a week-by-week tour of fish across the country with guests from all walks of life. I'm Katrina Liebich with the US Fish and Wildlife Service in Alaska.

And I'm Guy Eroh. And if you listen to our recap-looking forward episode, you might recall my lamentation about how we've completely disrespected the Fundulidae family and the genius Fundulus. And today is our first step and rectifying that. We're talking about the California killifish.

And when you say disrespect, we just haven't covered them as much as should've

They're very speciose. And we haven't even scratched the surface. It's very important that we balance species representation with what we talk about. That's how I feel.

We've got a great guest today. We've got Drew Talley, who's a professor in the Environmental and Ocean Sciences Department at the University of San Diego. I've never met someone so excited to raise awareness about the California killifish. So welcome to the show. We're happy to have you.

Well, thanks, you guys. It's a delight to be here and to get to talk about what is my favorite fish out there.

Okay, so I think killifish in general are a beautiful fish. It seems like some of the species are really colorful, they have a pleasing fish shape, at least in my opinion. I was hoping you could kind of put us in the waders of maybe one of your students that you work with. You haven't seen this fish before you happen to be at a salt marsh in California. What's the scene like? And what might they notice about this fish? What's gonna stand out to them?

Wow. So for *Fundulus parvipinnis*, California Killifish. I think one of the things is it really will depend on time of year whether they're in spawning mode, and whether it's a male or a female, because there's some pretty strong sexual dimorphism as far as how they look. They occur in shallow wetland habitats in California. And what they would see and notice is, first of all, they're small fish they you know, a monster California killifish is maybe 10 centimeters long. So pretty tiny little guys.

So a few inches? Can we convert that quick cause people are frustrated when we talk in centimeters?

Yeah, sorry. So yeah, maybe a three-inch fish is pretty huge. And the males overall color is a sort of olive green with some bars on them. But during the breeding season, the males get pretty yellowish, so not bright yellow, but a distinctive yellow color. And they actually develop these little bumps that are called nuptial tubercles on their scales that they use for stimulating the female when they're spawning. So you could actually hand someone a male or female killifish during spawning season. And without looking, you could just feel it and know whether you were holding a male or a female. The females are a little less colorful, so they tend to be more silvery with those little hints of olive on them. But of course, during the breeding season, they get really huge and so they're these plump little things just waiting to lay their eggs.

Awesome. Is the California killifish California's only killifish?

Yeah, it is. Well, it should be. Recently we have had the *Lucania parva*, the rainwater killifish, which is not native, but somehow has gotten introduced into some of the wetlands up in the LA area. And I think it showed up in the Tijuana estuary down here in San Diego.

Like a bait bucket or an aquarium type introduction. I'm surprised that people are moving around rainwater killifish all the way from the east.

Yeah, I think, I suspect it has to have been an aquarium release or something. You know, one of the more common ways we get invasive fishes out here.

Don't dump your tanks folks, if you have fish don't do that. Messes up the native fish.

I've never seen or handle the California killifish. But out east I've found my fair share of killifishes and top minnows and even studfishes. And what does that name killifish come from? And then also, is there any difference between those three types of Fundulus species? Or do people just give them whatever common name they sort of feel like?

Do they have teeth?

Like so many things, the common names are sort of a mess. And so the genus Fundulus is in the family called Fundulidae. And all of that is in this order that has a really weird name because they're called the Cyprinodontiformes are the toothcarps, but of course they're not carps at all. So it's, it's tough to keep it all straight, to be honest.

They do have tiny little teeth. Yes. And when you get to the common name killifish, it's even more of a mess because people will use that for like top minnows, they will use it for a bunch of things that are in different, you know vastly different groups. And when most people think of killifish, they tend to think of these super colorful, really beautiful fishes. And I have to confess when I think about the California killifish, while I am enamored with it, it is not, you know, a beautiful tropical fish that most people would want to keep in their aquarium for example.

I'm guessing they blend in pretty well with their marshy habitats though with those colorations that you mentioned.

Yeah, they certainly do. And you know, it's probably the most, if I could say famous Fundulis is *Fundulus heteroclitus* conjurer of the California killifish, I believe it's called a mummichog back on the East Coast. And you know, I did a quick web of science search for publications on them. And you've got maybe like 1000 or more publications on the mummichog. And I think the last time I looked at was in the 40s, so 40-something for the California killifish.

So how many of those are yours?

Only a handful. But yeah, most of the studies on them have been either genetic or physiology because they're these super hardy fish that can withstand almost completely freshwater all the way up to like they're living in habitats in these intertidal pools in the wetlands, where sometimes it's the salinity gets up to 120. And just for reference, you know, sort of standard sea water is about 35. So phenomenally saline environments that they can live in for a fair bit of time.

So what sets the Fundulus species apart from like, other small fish that people might see? We've talked about gambusia on the show, we've talked about a bunch of little, small fish. Is there anything people can kind of key into with the California killifish or its close relatives that really kind of set it apart?

Well, yes, so one of the things that, at least with the Fundulus with this genus, and the ones that live in salt marshes, there's quite a few that live in salt marshes. For better or worse, we only really have two species of Fundulus here on the West Coast of the United States. And one of them is a landlocked freshwater species. *Fundulus lima* that probably will be extinct fairly soon, it lives in a really restricted habitat in Baja, California, Mexico, where there have been actually a lot of invasive species like gambusia that had been introduced to the area.

I mean, I think probably the hallmark of this fish is that they are numerically dominant in salt marshes. So in wetland habitat, and they have this life history, many of them do at least and certainly the California killifish does, where they make these tidal migrations whereas the tide comes in, they swim up to the very top of the vegetated marsh and feed on the sort of abundant invertebrates that are up there. And then as the tide goes out, they choose various habitats, whether it's creeks are intertidal pools, or sometimes all the way down into the seagrass beds, where they hang out waiting for the next opportunity to get back up during the spring and summer to lay their eggs.

So Katrina and I, we have a friend who has described favorite fishes as being those that are either ultra familiar or almost unattainable, really rare, hard to find. And now you've described the California killifish is your favorite fish. I'm wondering sort of where on that spectrum it falls. And then also, why is your favorite?

So yeah, so they are super easy to find if you're in a wetland habitat on the West Coast, basically from near Morro Bay, so have been sort of central California, all the way down most of the way down the Pacific coast of Baja California. And they represent sometimes as much as 80% of the fishes you would actually find in a wetland. Boy, there is so much to love about the Fundulus. And like one of those things is my PhD research. I was really set on studying how habitat connectivity works, how different habitats within the sort of salt marsh mosaic, you know, you've got vegetated marsh and intertidal pools and creeks and seagrass beds. And I was really interested in trying to figure out how these habitats are connected to each other. And you could not ask for a better model animal than Fundulus to figure some of that out because they lay their eggs up in the upper part of the intertidal marsh and in fact their eggs actually are more successful, they have a better hatching percentage, if they're exposed to the air for a while. So they lay on the highest high tide. So it's spring tides, so either full or new moon, you can know when they're going to be reproducing, it's always within a day or two of that. And then that way those eggs are protected from aquatic predators of any sort until the next high tide two weeks later. And so

they are feeding up on the vegetated marsh. So they're transferring this energy from those invertebrates down to the seagrass beds where they in turn get eaten by honestly, pretty much anything that can fit its mouth around a Fundulus will eat a Fundulus. So birds, fishes, whether they be California halibut, or various, you know, sport fishes like bass and stuff. So they really are a common prey item. And it's just a tremendous amount of food that they go through. There was a paper by these Mexican scientists who studied down in Ojo de Liebre, which is about halfway down the Baja Peninsula. And they found that every year, these fish were eat eating almost 2000 tons of biomass just from that one species in that one day.

I'd like to hear more about these marshes and kind of how they've changed through time and how important they are to not only these fish, but just some of the other wildlife that people might really like.

In California, particularly Southern California, even historically, we never had a ton of wetlands, they're much more isolated because of the geology of our coasts, there aren't these long, sloping plains. And those few wetlands that we do have been pretty well developed by humans. So you know, it used to be the famous phrase about "drain the swamp" you know, that was considered a good thing, you're gonna go and take a wetland and drain it and turn it into, you know, who knows a parking lot or something. And so here in California, we have lost somewhere around 95% of our coastal wetlands. So there's not a ton left. And yet, there are these really interesting habitats that have a bunch of rare and endangered species in them. And so while I wouldn't try and claim that the California killifish is rare or endangered, there are so many things that rely on them, like their species of the least turn is one of the birds down here that is an endangered species does feed on Fundulus. So yeah, it's a it now we're left with these sort of very small, isolated, restricted habitats. And in part, you know, one of the things that makes Fundulus so interesting to me, is their whole life history is so set up to avoid getting washed off of the marsh, that these little populations that are in the remaining wetlands are super isolated, and the eggs hatch with, for a fish, a pretty big, little juvenile fish, they hatch at about maybe seven or eight millimeters long, which is, you know, substantial for a just hatched fish. And then their whole life history is all about not getting sort of advected or washed off of the marsh and going out anywhere. And we've done both genetic work and work on their otoliths on a little ear bones. And we have found that they just do not move much at all. If it's a large enough bay, you can find in different parts of the same bay, really distinct signatures that suggests that there's very little movement between these habitats.

So I gotta ask, based on that, is there any concern that you're getting these sort of micro populations where you're just having isolation, and you could have, you know, inbreeding depression, or something like that weren't there to isolate from one another? It could be that we don't have as much diversity as we think.

Yeah, you're absolutely right. There could be a possibility of getting inbreeding depression or something like that. On the other hand, you could also have fishes that are super adapted to their specific environment, you know, if there's differences between wetlands, and so it's a little complicating for wetland restoration and creation efforts, because you might have to worry a little about well, I don't want to just put any old fundulus into this particular habitat. We want ones that have sort of evolved and adapted to be able to survive there.

I am curious what it is about the habitat and the waters out there on the west coast in California that results in a lower species diversity of Fundulus and you have back east.

Part of it is undoubtedly the lack of habitat, the fact that there just is not as much habitat, and also the thought right now is that the way we otter flangeless is that they actually came through the Isthmus of Panama back before it closed off. So a couple of million years ago.

What elements are...and you know, potentially isotopes of those elements...are you specifically looking at what they'll do with micro chemistry?

otoliths are the little ear bones that fish have. And what's really fascinating about them is for many, if not most fishes, they put on a new layer of bone every day. And as they do that sort of matrix of calcium carbonate is grabbing on to some of the chemicals in the water around them. And so, in theory, since the water chemistry is different in every wetland, and sometimes even in different parts of a wetland, you can basically use this technique where you count the number of rings on the otolith. And you can go back, chemically sample one of those individual rings and say, look, the chemistry was really different where this fish was living when it was three months old. And that chemical signature matches up with this part of the marsh so we can then tie their life history together a lot better. It is a huge sort of shotgun approach, where they use inductively coupled plasma mass spectrometer, the ICPMS. And they use a laser, blast a little section of the otoliths, and then they'll look at every element they can find. And if you pardon the expression fishing expedition, where you're looking for what you can find, and it is just amazing how different they are even between pretty close habitats.

And these guys, I mean, they're small, as you mentioned, I'm guessing their otoliths are very small. How big are you talking?

Right. Their otoliths are surprisingly big for a fish their size. And so, you know, for an adult Fundulus a few millimeters across.

So like a piece of quinoa or something?

Certainly big enough to see with the naked eye, although you wouldn't be able to count the rings without putting it under a compound scope.

And are these guys, they're not living much more than a year are they? I mean, they're pretty short lived species.

There are some old references to Fundulus parva back in, like the 1800s I think? Were just from some of the initial sort of survey trips out here and on the Pacific coast. But really, it wasn't until the 1970s that this, his named Jean Fritz published this '75 paper on Fundulus. And, you know, he just counted the scale annuli. So the rings on the scales instead of on the otoliths. He estimated that they lived at most 18 months. But I've definitely had them in the aquarium for over three years, three or four years. So it's tough to know. And we actually just finished a study where we had to do the age validation and

prove that they were really putting on a ring on their otolith every day. Now that we've done that, we can go back and start trying to get a better handle on the longevity.

Got it.

I'm curious if you guys ever thought about doing any kinds of studies, where you would say, you know, "alright, we're going to take some fish. And we're going to move 'em. And we're going to leave them in like a big enclosure, something where they won't get out, and you can recover them easily, and move them to another Marsh like say, I don't know, 50 miles up the coast." And then seeing and having like a control one where you keep them in the same place and seeing if your students could determine which fish were moved from point A to point B just to kind of ground truth. That is rather than saying, "Oh, look, we think we could detect something's different. And they all look like they're kind of similar and staying in the same place."

Yeah, that actually guy that gets to a really important part of that is that, right now, we're just using this otolith microchemistry as a way to say, hey, we have no idea why this wetland is different than that wetland. But I can tell you that every single fish that we pulled out of this wetland has this signature that looks, you know, distinct from this other one. And I think that the idea of being able to say, to do a more controlled experiment, or potentially you could even say "Yeah, but why is that different?" You know, because some of those chemicals are coming just from being in the water that has those chemicals, but a lot of it also comes from the diet. So you need to understand like, "oh, how would that work?" But yeah, so and I think your idea of transplanting and putting them in an enclosure of some sort would be fantastic.

So, kind of looking towards the future. What other questions you're going to be kind of pursuing about this fish or the marsh habitats of California.

I'm really excited about now that we know that they're putting on one layer to their otolith every day by and large. And we did an experiment where we found that, not surprisingly, may be the width of that layer on their, their otoliths reflects how well they were feeding at a given time. So if you give them a ton of food, that layer gets thicker, and if you give them less that day, we'll have a thinner. What we're trying to do is figure out how much lag is there, what excites me is that then I could go out and take a fish that has basically been recording data for me out there in the wetland. And I can look at its feeding pattern. And a lot of the studies that you see on the California killifish, people talk about it as though it's doing just what the mummichog does, but there's some really good reasons to suspect that they aren't. And one reason at least that might be somewhat different is: yes, they feed best up on the high tides, when they can feed off the vegetated marsh, there are going to be times of the month or times the year where these fishes are going to be constrained by how much food they have, even though some, you know, similar fish on the Atlantic coast would not be. So one of the exciting things for me is I can now potentially take those otoliths out of the fish and then examine them and say, "hey, look, two months ago, when we had those, you know, a couple of weeks where there were no good daytime tides, you can tell from the width of the otolith that was affecting the growth of the fish at that particular point in time.

That's cool. Is there anything folks involved with wetland restoration or mitigation should be thinking about in their work based on what you just mentioned about kind of the diversity of these wetlands and how these fish are showing differences?

Yeah, so I mean, honestly, it makes me think about that initial study that I did, where they had just built a manmade wetland that was contiguous with a natural marsh. And what we found was that the fish did not perceive them as being equivalent habitats, there were differences in the size structure of the Fundulus between those two habitats and in the usage patterns. And one of the things that seems to be super important, besides the things you might think of like, oh, you need the right vegetation and the right invertebrates for them to feed on, is these really subtle aspects of the geology and geomorphology that make a difference. So a natural marsh has all these super reticulate creeks or it's a an intertidal pool, like where a lot of the juvenile Fundulus live. And when you're creating wetlands or trying to restore wetlands, there's a tendency to, let's go in with, you know, I don't know a bulldozer and just dig a big channel and now, and "congratulations, we're done, because now there's fish in there." But understanding how to effectively create the sort of microhabitats that these fishes need is something that's really tricky. There have been some great projects done down at the Tijuana River National Estuarine Research Reserve. And they've done these giant marsh projects where we'll dig a bunch of small channels in this block, we'll just put in deep channels and seeing how the differences work. The problem is we aren't great at creating wetlands, right? You can dig those tiny little channels, but there's a good chance they'll wash away quickly.

Super interesting.

Do you have any inspiring words for the next generation of scientists or fish biologists kind of coming up through the ranks about this fish?

Boy, for me at least once you start studying a good model organism that is good for an answering the questions you want to ask. I think you can't help but fall in love with your study animal. And honestly, that is my piece of advice to anyone starting off in this field is just be open. And you know, I had no idea I would end up loving Fundulus as much as I do.

That's cool. Good work. You have anything else you want to say about the fish?

If there's one story that I really wanted to tell you guys, so there is this scientist Kevin Lafferty who's at USGS up at UC Santa Barbara in that area. And Kevin studied this trematode parasite and its life history in this Salt Marsh, this parasite lives in birds. That's its definitive or final host. And it lives in the intestines. As an adult it it sexually reproduces, sheds eggs that are then left on the surface of the vegetated marsh. There's this super abundant snail called the California horn snail down here. It is a detritivore. So it's sort of just grazes along the surface of the sediment, ingest those eggs. And then those eggs end up getting into the snail. And at this point, they asexually reproduce. And what they do is they basically go and castrate the snail. Oh, hang on to where it's gonads used to be, and gets its energy from the snail to keep asexually reproducing more.

Oh, they come up with that. It's crazy.

The snail often...it's as many as 90% of the snails in our salt marshes are castrated by these parasites. But they're still doing their snail thing. And they think they're putting all this energy into reproduction, but they're really putting it into parasite reproduction.

And then the next stage for those parasites is they become these little cercaria. This type of larva that has it looks sort of like a tadpole, but with a forked tail, very small, and today's swim around looking for another intermediate host. Often, in fact, I would say usually the fundulus they burrow into the Fundulus, and then migrate to the brain where they form a cyst. And when they do that, they actually alter the behavior of the Fundulus. So the fundulus then start swimming close to the surface, and sort of flashing, you know, you've seen fish before where they sort of quickly dip to one side. That makes them easy prey for birds, which then come down and complete that life history. And it all starts over again.

Nasty.

That is horrifying. And reminds me of the conversation we had with Frank von Hippel I think in season one about stickleback, it was a very similar parasite that changes the behavior of the fish and makes it like they made even lighter colored right.

Yeah, I think that more than anything it kind of make some sort of sickly. And yeah, but yeah, that's the same thing.

What a what a horrifyingly creative thing of that parasite to do.

Yeah.

It is a native parasite in this ecosystem, right?

Yes, yes, it is.

That's horrifying. Good story though. That's cool.

Awesome. Well, thanks for joining us.

Yeah. Thank you. That's awesome. All right. Well get out there and enjoy all the fish, especially the ubiquitous and charismatic California killifish.

Alright. Thanks, you guys.

Thanks for listening the Fish of the Week! My name is Katrina Liebich. And my co host is Guy Eroh. Our production partner for this series is Citizen Racecar. Produced and story edited by Tasha AF Limley. Production management by Gabriela Montequin. Post production by Alex Brower. Fish of the Week is a production of the US Fish and Wildlife Service, Alaska Regional Office of External Affairs. We honor thank and celebrate the whole community, individual tribes states, our sister agencies, fish

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