Jennifer Stock: This is Jennifer Stock and you're listening to Ocean Currents. This show is once a month where we dive into the big, blue ocean and talk with ocean experts to share their expertise about research, explorations, expeditions, policy, and stewardship associated with the marine environment especially in our national marine sanctuaries. This show is brought to you by the Cordell Bank National Marine Sanctuary, one of the three contiguous national marine sanctuaries along the central California coast working to conserve these incredible marine ecosystems.

So, I bring this show to let us all hear a little bit more about what's happening out on the ocean. When I used to live on Catalina Island and I had a very rough job as a marine science teacher at the Catalina Island Marine Institute, we taught a lot of hands-on marine science labs and immersed students in the ocean with snorkeling during the day. Little did I know that when I accepted the job that it also would be snorkeling at night and with kids and we get them all suited up with their wetsuits and their fins and these little inky-dinky flashlights that you're not going to see much with, but get them in the water and most of the time we'd just do a lot of splashing around, getting comfortable and then the real action took place when we shut the flashlights off and what we saw in the water was just incredible and that's what we're going to talk about tonight is this incredible phenomena that happens in the ocean much more than we know, much more than we think we know.

It's called bioluminescence and so, many of us see this on the shores here and kayaking and on the beaches and I've invited Steve Haddock from the Monterey Bay Aquarium Research Institute to come talk about his work and his information about bioluminescence. So, thank you, Steve, for joining me today. So, a little background on Steve. Steve Haddock is a scientist who specializes in bioluminescence and zooplankton at the Monterey Bay Aquarium Research Institute in Moss Landing.

Steve is working on deep-sea gelatinous zooplankton, soft-bodied animals. His research is on bioluminescence, biodiversity, and ecology of deep-sea and open ocean tinaphors, cyphonophors, radiolarians, and medusae, which are all jelly-like organisms that live in the ocean. So, in addition to assembling evolutionary relatedness among these groups, he's interested in the cloning of these proteins in these jellies and what are some of the applications that those could have. His background is a bachelor's of science from Harvey Mudd College and he has a PhD from the University of Santa Barbara, or University of California in Santa Barbara. He also holds an adjunct professorship in the ocean sciences department at the University of California in Santa Cruz and has an incredibly long list of publications and a fun website, which I hope he shares with us later for the public.

So, thanks so much for coming, Steve.

Steve Haddock: (Unintelligible)

Jennifer Stock: Alright. So, I just want to start with some basic terminology. I've read and I've heard many terms of which I believe is all really meant to be one term, but can you help define and clear up the confusion of these terms of bioluminescence versus fluorescence?

Steve Haddock: So, probably starting with bioluminescence, if you think of a glowstick, which people are probably familiar with, you break this little tube and the two chemicals mix together and as a result of the chemical reaction some energy is released and that energy is released in the form of light, photons of light. So, that's chemiluminescence. If you take a similar chemical reaction and you put it inside of an organism, so these chemicals are combining within living cells, then that's what we call bioluminescence. So, it's a chemical reaction happening inside of an animal.

It could be anything from a bacteria up to a fish and then the result of that chemical reaction is light coming out. So, bioluminescence you'll see in complete darkness. There's lots of confusion with fluorescence and people sometimes use the terms interchangeably, but fluorescence is actually converting one color of light into another color. So, for example, sort of blacklight posters. Sometimes you'll see these posters. They don't always have albums painted on them, I guess, but you know, these sort of dark environment you have one of those blacklights or some purple-y light shining on it. That's actually stimulating the fluorescents and what happens is those photons are being absorbed by pigments and then they convert those photons from, say, a purple-y color out into a green or a red color and the same thing can happen in a lot of biological systems.

In fact, laundry detergent has fluorescent whiteners in it and the way that works is it takes the UV light that you don't usually see and converts it into wavelengths that we can see. So, it does make things whiter than white. It makes things brighter than they would be under normal white illumination.

Jennifer Stock: So, does...somewhat bends the light a little bit so you can see those wavelengths? Or is it actually converted?

Steve Haddock: It actually takes the energy...the molecules get excited. The electrons in the molecules get bumped up to a higher energy level and they're not stable up there. So, they fall back down to where they were before and then that energy gets re-emitted in the form of light.

Jennifer Stock: As light. Ok. So, big difference. There's the living light and then there's this change in wavelength and absorbing and changing of excitement levels. So, that's the difference and I think a lot of people when they say fluorescence they mean bioluminescence a lot of times. How about...what is the...so, the actual property of bioluminescence, what is the light a result of? What biological process is the organism doing when putting out this light?

Steve Haddock: It sort of depends on the organism. I mean, in a very generic sense, we call the chemicals that are involved in the bioluminescent process a luciferin, which is the little molecule that actually emits the light and then there's the luciferase or variation on the luciferase called the photoprotein and those are proteins that just accelerate this chemical reaction and actually trigger the light emission from that own small molecule. So, you have a little luciferin is the light emitter. It doesn't do anything, it doesn't react with oxygen or do anything under normal conditions. When you add one of these other molecules it speeds up that reaction and so, the organisms will have cells in their bodies that are generating one or both of these chemicals and also controlling when they get turned on and start emitting the light.

Jennifer Stock: So, they have one specific job to do and that's to create, to react together to create the light.

Steve Haddock: Yeah.

Jennifer Stock: So, they don't have any other metabolic uses besides just the light?

Steve Haddock: Well, it's..there's speculation that the luciferin part, the little light-emitting part of that actually has a lot of antioxidant properties and so it's thought to be even more of an antioxidant than vitamin C in some cases and so, people have theorized that they were around there as sort of a detoxification mechanism and that the light, you know, long, long ago was actually just a byproduct and then it started being useful and so, it eventually was co-opted and now you get organisms that have this, you know, photophore that's got lenses on it and filters and reflective surfaces, obviously very specialized for, you know, that function of bioluminescence, but where it came from kind of in an evolutionary sense we're not really totally sure.

Jennifer Stock: That's amazing. So, how did you come to studying bioluminescence and what are you studying right now in your research?

Steve Haddock: Well, I started out sort of with, you know, the general layman's interest in this kind of weird magical thing that some animals can do, but I was fortunate enough to be directed into a graduate program where my adviser was a specialist in this field. So, within a month of getting to graduate school in Santa Barbara, I was out on a research ship, diving in submarines, scuba diving with a ship full of experts on bioluminescence and on jellies and so, you know, there was no going back from that point.

Jennifer Stock: They suck you in.

Steve Haddock: That's sort of what I've been doing even, you know, almost 20 years later.

Jennifer Stock: Such a fascinating topic and so, what are some of your primary questions? What have you been working on in regards to this big field of light?

Steve Haddock: Well, one of the things that sort of strikes you when you look at the distribution of bioluminescence in, sort of, the animal kingdom and, sort of, the whole tree of life is that it just has popped up all over the place. You know, if you look at bacteria, if you look at single-celled, sort of amoeba-like organisms, and then almost every kind of thing in the ocean, jellyfish, shrimp, squid, fish, all these different things make bioluminescence. So, that sort of begs the question, first of all, what are all of these things doing with it and then the other side of that question is how do they do it? How do they get to make this light?

We see a lot of weird parallels between organisms that aren't necessarily related. So, if you take some of these single-celled organisms and some jellyfish and some shrimp and some fish and look at the luciferin, that light-emitting molecule that I talked about, some of these things will use all the exact same molecule as their light-producing thing. So, how does that come about? How does that happen?

So, by looking at the genetics of the other side of the equation of the luciferase, we can kind of see how that evolved and so, I want to, you know, in the very broadest sense figure out how they do it and why they do it, you know, and how it came about.

Jennifer Stock: There's quite a few theories about why animals bioluminesce. Have you witnessed any interactions out in your observations or out in the field where it would help lend some conclusions?

Steve Haddock: Yeah. Some of the explanations of bioluminescence are pretty obvious and convincing. The angler fish is a classic example. It's got sort of a little lure like a streetlamp, you know, with moths flying into it, but in this case, it's attracting its prey and so, you can see that pretty clearly. There are some suggestions of...well, there's actually some pretty good examples of organisms using it to attract mates. So, they'll have a very specific signal that says, you know, "I'm this species and I'm interested," and it's almost like a Morse code of dots that they send out and if a member of the opposite sex sees that signal, it will come over and, you know, that's how they find each other.

Jennifer Stock: They find each other.

Steve Haddock: A lot of the roles have to do with anti-predation. So, the defensive system. Either, kind of like, a bright flash to hopefully scare something away that's about to eat you, but also more subtlety camouflage. Things, especially in the deep sea...a lot of animals have eyes that look straight up and so, what are they doing with these eyes. Well, they're looking for silhouettes.

So, if you imagine, kind of, a plane flying overhead or if, you know, you just hold your hand up against the sky it's a very obvious dark target against that light background and so, a lot of animals have these photophores, these light-emitting organs all on their bellies specifically to make their body disappear against that light background and I've seen an example in the lab. We had a setup with a fish that did that and we turned on this diffuse light above it and I was laying, you know, underneath the tank looking up and the fish just disappeared, literally disappeared. It was like this magic cloaking device. So, it can be really effective.

Jennifer Stock: Harry Potter probably studied a little bit of bioluminescence. How about krill? You were just talking about the photophores and on the belly and krill is a very abundant and important keystone species in the California current here for so many animals and not a lot of people realize they actually are bioluminescent too. Why are they bioluminescent?

Steve Haddock: Yeah, krill are really bright and if you find one even, you know, in sort of their dying gasp, if you somehow happen to collect one they'll glow really, really brightly. They have these photophores along their bellies just like I was talking about and it's thought largely to obscure that silhouette, to make that silhouette disappear, but actually, a friend of mine studying krill...they also have little photophores near their eyes that are shining out and the function of those is still not know.

Another interesting connection with the krill is that the luciferin, again, that light-emitting molecule that they use, is the same chemical structure as it is in dinoflagellates. Dinoflagellates are these little single-celled phytoplankton that cause red tides and can cause harmful algal blooms along the coast. So, if you're kayaking at night, probably in the paddle or in your wake, the little sparkles that you see are most likely cause by these things called dinoflagellates and so, strangely, the krill and this little algal-like thing are using the same molecule to produce their light and so, there's this suggestion that actually it comes through the diet, that the krill get their reserves for making light from what they've been eating.

Jennifer Stock: Eating animals that also produce light. That's interesting. Metabolically, I'm curious if, you know, once they eat something if it would digest and change the composition of it, but the light seems to retain?

Steve Haddock: The luciferins are...even if you look at a non-bioluminescent organism, something that can't make light, they accumulate a lot of luciferin in their liver and some of their body parts. So, it's kind of out there in the food chain and it's available and we think that that's partly a way to explain how you can get this diverse set of animals that are all using this same one light-emitting molecule.

Jennifer Stock: So, what happens when salmon eat krill and humans eat salmon.

Steve Haddock: Uh-huh. Well, I think by that time the molecules are pretty well broken-down.

Jennifer Stock: Okay.

Steve Haddock: You're much more likely to see salmon bioluminescing if you leave it out on the counter at night...

Jennifer Stock: Yeah.

Steve Haddock: ...and you can get glowing bacteria that are just out there on the seawater. They'll start glowing on your piece of salmon.

Jennifer Stock: Interesting. I actually read about that with other types of bacteria on food and bioluminescing bacteria. I want to just talk about this one angler fish that...usually the lure is a bacteria in the lure that's glowing to attract potential food and a potential mate. Now, there's one angler fish that I've read and I can't remember the name of it. It's a big...the female is much bigger than the male and the male comes over and, I'm not sure. he somehow fuses with the female and that's how they breed with the male...just becomes a part of the female. Do you know what I'm talking about?

Steve Haddock: So, that's actually not one angler fish, but pretty much all of the angler fishes do it.

Jennifer Stock: Oh, really?

Steve Haddock: Yeah. So, the males are non-bioluminescent and they're like the size of your big toe compared to the rest of your body or maybe your hand, at the most, the males compared to the females and so, somehow, once they encounter each other it's such a special moment, I guess, that they, you know, literally bond for life and the male will latch on with the mouth to the female and their circulatory systems and everything combine so that he doesn't eat anymore and he just becomes this little appendage on the female.

Jennifer Stock: I could think of some analogies there, but I won't go there. That's just an amazing life history and you're saying a lot of angler fish do this, pretty much all of them.

Steve Haddock: Pretty much all of them, yeah, do that, yeah.

Jennifer Stock: Wow. Now, there was also a deep sea siphonophore that you were talking about. A siphonophore is a long jelly-like animal.

Steve Haddock: Right. So, some of the things that I work on seem really obscure and, I mean, they probably are because most people don't see them. We use a lot of special techniques in order to be able to study them and one of those groups of organisms is this siphonophore which is sort of like a bunch of jellies chained together along a tube and anyway, this siphonophore that we found is a really deep-living one and it sort of turns the table on fish and it does an angle fish-like thing.

It has little tiny lures on the end of a transparent stalk and these lures happen to be attached to...right to this battery of stinging cells. So, they have like a thousand little stinging cells that are really painful. I can attest to their potency, but then they have this little lure and inside the lure is a bunch of bioluminescent material and so, they have a little glowing light that they can flick around just like a prey at them that some little deep sea fish may be looking at and instead of just casting out a web and hoping randomly to have fish run into it, they can actually, kind of, do something about it and lure fish in.

Jennifer Stock: That's amazing. This is a gelatinous animal. So, it doesn't really have a brain. It just has this function on it. That is insane.

Steve Haddock: It's, I mean, you can sort of piece together maybe how that came about because there's actually, sort of, five species in this one group and we found that all of them seem to have this...variations of this lure, but some of them are, sort of, more simple than others. So, maybe, you know, just having this one little thing that was glowing was enough to cause an advantage and then eventually, you know, it developed this fairly ornate structure.

Jennifer Stock: So, how are you finding these organisms? What are some of the methods for going to find some of these gelatinous, creepy...

Steve Haddock: Yeah?

Jennifer Stock: ..animals.

Steve Haddock: They're not creepy. They're beautiful.

Jennifer Stock: They're creepy..

Steve Haddock: Well...

Jennifer Stock: ...but they're beautiful.

Steve Haddock: ...in the shallow waters we can actually find all kinds of new and different and weird stuff just by scuba diving. So, we do what's called blue water diving and you just go out in the middle of the ocean. You don't really care how deep it is and usually, the deeper the better because it means you're halfway to Hawaii, but we use a series of lines to kind of give you some orientation, some framework to refer to and then you just jump in the water off of a small boat and you collect things with jars and so, we can get a lot of bioluminescent and fluorescent jellies that way and these are things that are too fragile to catch with a normal plankton tow. I mean, I think when most people do marine biology they throw a net in and you get up a lot of neat stuff, but the really fragile things are...it's like trying to fish a piece of tissue paper or something, even more fragile than a piece of tissue out of the water.

So, for shallow stuff, scuba diving, we can do it. Then for deeper stuff, I'm fortunate enough to work at the Monterey Bay Aquarium Research Institute where we have a couple R.O.V.'s and these are remotely operated vehicles. It's almost like a video game, but it's real and there's sort of a Volkswagen-sized submarine on the end of a tether. The tether sends power and has fiber-optic communication so we can get video images back and then you control it with the joystick, go out, find animals, and very selectively can sample and explore the deep sea. So, that's what we use to get a lot of our specimens.

Jennifer Stock: You also get video footage as well, but some of these clear ones are probably really hard to detect on the film.

Steve Haddock: Yeah. The pilots are kind of sick of me because, you know, as we got better and better cameras I can sort of track down smaller and more transparent things and so, they'll collect something...you have to drive this VW essentially around a thing the size of a pea or smaller...

Jennifer Stock: Wow.

Steve Haddock: ...to put it into the sampler. You know, you don't necessarily suck it in. You actually move the ROV around the animal. So, sometimes when we bring them up to the surface, I like to go show them what they actually collected because it's just so tiny that you can barely see it when you're holding it, you know, in a jar right in front of your face.

Jennifer Stock: Incredible. I was just at the Monterey Bay Aquarium Recently and they have a new exhibit that is kind of like being in the control station for MBARE with the ROV and there's some cool videos...

Steve Haddock: There's a few more blinky lights than in real life.

Jennifer Stock: ...that's what I thought. It looked a little bit more like outer space.

Steve Haddock: There are a lot of blinky lights.

Jennifer Stock: Yeah. Do there....actually, with some of the small ones, like you're mentioning this tiny little pea-sized thing, do they have some type of a magnifier that you can see it with. How do you see that?

Steve Haddock: It's just the lens on the...so, we have high-definition video cameras...

Jennifer Stock: Oh, okay.

Steve Haddock: ...and zoom lenses and so, you know, once you're fully zoomed in, the whole screen, the field of view on that screen is maybe about an inch or two inches, you know, of view. So, you can actually get really, really nice shots, almost microscopic of things that are down there.

Jennifer Stock: Well, it's definitely some of the best instruments I've seen. I did a tour of the Western Flyer and was really impressed by the levels of jobs and everybody, what they do to all work together on these dives. It's amazing. So, what are some of the different colors of bioluminescence in the ocean? I've seen a lot of the green...well, I think it's green. I'm not sure if it really is or not, but dinoflagellates on the surface, but there's some other colors.

Steve Haddock: Yeah. I mean, most of it actually is sort of blue-green and one weird thing that happens with your eyes is when you're looking at really dim light sources, your rods take over and your rods are monochromatic. So, you'll get a lot of reports of white bioluminecence or things where you just can't quite make out the color and it's because you're not perceiving the color. You're using these sort of black and white sensors that you have for low-light vision, but for the most part, things in the ocean put out blue or green light and this makes sense because that's...if they're trying to mask their silhouette they're trying to match the background light and the background light has been filtered down to this fairly uniform blue color, blue-green color, and the other thing is that the eyeballs, presumably it's targeting some kind of organism's eyeballs. Those eyes and those visual systems have evolved to see that same color of blue light.

So, it is true that most of the bioluminescence is blue or, say, from blue to green. There are some weird things that actually make yellow light. There's some worms, and we still don't know really why, that make yellow light and there's a few fish that make red light that they use as almost like a sniper scope. So, they...since most things can't see that red light as far as we know...and this actually, this red light is so red it's almost infrared because if you're looking at it, you know, I've seen these fish bioluminescing, they're flashing in front of my eye and we can see it on a low-light camera. You almost can't even see it with your eye because it's just so, it's so red.

But anyway, there's a few examples of things that can make red or yellow, but most of them really are that blue to blue-green color.

Jennifer Stock: It's interesting if you think about being in the deep sea and it's just dark all the time, there's a whole different communication system going on amongst the animals down there and you just think about...thinking of these little, like, fireworks shows going on and they all mean something.

Steve Haddock: Yep. Well, it's been described as sort of a bioluminescent minefield because if you go down... I've done some night dives where you try to go down and keep things as undisturbed as possible and use dim red flashlights and, you know, or have the lights off and just see how much bioluminescence really goes on. So, you get an idea of these little background sparkles going off and then you move something through the water and then, all of a sudden, everything around you is lighting up. So, they're, kind of, sort of, seems like they're, sort of, hanging out there and, like, you know, when they get disturbed they send off this little shout of light and the other thing about that is that some of these things are, say, a millimeter or less than a millimeter.

So, the dinoflagellates, for example, those red tide phytoplankton little organisms I was talking about, you know, they can be well under a millimeter and yet, they can make a signal that we can see, you know, 20 feet away underwater, maybe ten feet, you could see one of these individual cells. So, if you think about how powerful that ability to transmit, you know, to communicate. So, light is such a powerful communicator down there in the ocean.

Jennifer Stock: Is there a unit of measurement for describing the power of light put off by bioluminescence?

Steve Haddock: There actually...there are a lot of units and it gets confusing because when you read in the literature, you know, somebody is using microwatts per centimeter squared and there's actually micro-Einsteins and lumins and candle-power. So, there's a lot of different units that we use to, sort of, describe the, kind of, amount of light, the number of photons that are hitting a certain target, and then there are also units of, like, nanometers and angstroms when we talk about the wavelength, which is a way of describing the color and that's also a way of describing the energy. If you're talking about flash kinetics, you're just talking about, you know, microseconds. So, there's a lot of different ways to quantify the light, you know?

Jennifer Stock: And the light itself is not actually a heat...there's no heat associated with it, right?

Steve Haddock: It's very efficient chemically. So, yeah. It's not like an incandescent bulb where you heat something up until it starts emitting some of that radiation as photons. It's actually a chemical reaction and it is really efficient from that point of view.

Jennifer Stock: Interesting. We were just talking a lot about a lot of bioluminescent organisms like dinoflagellates and soft-bodied organisms, but there's actually a lot of bacteria that bioluminesces well and I was reading about this place called the "Milky Sea" that you were involved in somewhat mapping and discovering. Can you talk about that a little bit?

Steve Haddock: Sure. So, bacteria are unique in the bioluminescent realm in that they, sort of, glow continuously once they reach a certain accumulation, a certain concentration and as long as there's oxygen around, but in the ocean, actually, most organisms that are bioluminescent make their own light. They don't use bacteria. They have their own chemicals, their own luciferins and luciferases that they use, but there are some things that use bacteria and these bacteria are pretty much all over the place in the water. So, if you get a piece of crab or something and just let it grow up, there will be bioluminescent bacteria on there.

There's one place where the bacteria seemed to, sort of, go out of control at times depending on the conditions and this has been known for hundreds of years, actually, it's sort of been the folklore and in the marine folklore and that's what's called a milky sea and sailors have reported sailing along, you know, through the water at night, dark night, and all of a sudden they'll like they're on top of a cloud or something because the ocean below them is just this milky, uniform, continuous glowing. So, it's different, again, from what...if you were in a boat, the little sparkling...

Jennifer Stock: Not agitated, it's just the glowing.

Steve Haddock: Yeah. So, there was a report that one of...a merchant ship sent in a little mariner's notice thingy and said, you know, "We're steaming along and all of a sudden the water was just milky," you know, or surrounding the boat and they steamed along for six hours in this, you know, large tanker ship and then they reported, "Well, we left," you know, "Suddenly, we're back in the dark water," and so, this friend of mine, Steve Miller, is a satellite oceanographer. He does remote sensing of the earth and he wondered if he could actually see bioluminescence from one of the satellites.

Jennifer Stock: Wow, that's cool.

Steve Haddock: Nobody really thought that you would be able to do that, but, you know, he's sort of undeterred and he went ahead and tried to search for records. So, he got this shipwreck of where they reported the exact coordinates when they had entered it and when he went and looked at the satellite data and we mapped it onto the ship's track, it just matched up exactly, you know, along the lines of what they had reported and so, we were able to capture this milky sea from space, essentially, from this satellite in space peering down on the Earth. It was happening off the coast of Africa, sort of, off the horn of Africa there.

It was 185 miles long. It had the area of the size of the state of Connecticut and so, if you, sort of, superimpose that over California or off the California coast, if you were to drive from San Francisco to Santa Barbara, sort of a six hour drive, you would be surrounded by milky seas...

Jennifer Stock: That entire way.

Steve Haddock: ...the entire way and it would just be glowing out both windows as far as you could see. So, it was billions of trillions of bacteria that were involved in this.

Jennifer Stock: So, do we know what type of bacteria this is? Is it regional to that area or...?

Steve Haddock: There's a, sort of, small subset of bacteria that we think it could be, but no one's actually gotten out there to really jump in and get a sample. There's been one research ship, this guy Dave Lapota sampled a milky sea, but they didn't have really good surface samples and so, there's some candidates that we think it might be, but it's still pretty mysterious. I'm trying to get out there and actually, you know, jump in, sample it, film it.

Jennifer Stock: Yeah and a lot of people might think that, "Oh, it might be toxic," but this has actually been...was reported, like, in 1870 with the book, 2000 Leagues Under the Sea, talking about something..

Steve Haddock: 20,000 Leagues Under the Sea.

Jennifer Stock: ...like that. Yeah. 20,000 Leagues and so, it's interesting. It sounds like it's been there for a long time and I wonder if it varies year to year.

Steve Haddock: Well, I'm, on average, there's been, you know, only like 200 reports of it in the published record of these, sort of, mariners'-type reports, but 200 records in, you know, maybe 150 or so years. So, it's pretty much happening annually and it's almost always in the Indian Ocean where it's really warm water. So, I think it's conducive to bacterial growth and I think that's why we don't really get them off here, but...

Jennifer Stock: That's interesting.

Steve Haddock: It will be great someday to go and sail through one of those.

Jennifer Stock: Wow. That would be really cool. So, what are some other things that you're working on with bioluminescence right now? You mentioned something earlier about cloning proteins.

Steve Haddock: Yeah. So, one of the ways that you can get at both the mechanism, the, sort of, chemistry, and the evolution, how these things come about is by looking at the genes that are responsible for bioluminescence and for fluorescence and so, what we can do is by various means, try to pull out the DNA and figure out the underpinnings of that luminescence and you can, sort of, trace the evolutionary history. You can make trees, phylogenetic trees. So, this is like a tree of similarity that shows which genes are most similar to each other and essentially, trace out how bioluminescence might have evolved.

So, we're trying to clone these genes from a lot of the deep-sea organisms that we have access to and a lot of other new bioluminescent species that we find.

Jennifer Stock: Are there some applications in the biomedical industry for these proteins?

Steve Haddock: Yeah, that's one of the...it's not really necessarily a driver for the researchers, but some of the proteins that were discovered 40 or 50 years ago are...they're now just ubiquitous in the medical industry. Every issue of scientific journals practically has one of these proteins being used in it and the reason that is is because they have such interesting optical properties. You can take this little piece of DNA and put it into the system that you're interested in studying.

You could be studying cancer, you could be studying how the nervous system develops, you could, you know, be studying almost anything. If you insert this piece of DNA in there, somehow associated with those cells that you're interested in, you've labeled them with this little glowing or fluorescent marker that you can observe over time in a living organism. You don't have to dissect it out and figure out, well, where was this gene turned on, where was it turned off, how did that tumor progress over time? Or something like that. You can just look at the fluorescence in the living organism and track it. So, it's a really useful tool and as a result, there's interest, you know, we do the, sort of, basic research and then other people just take it and run with it and make tools out of the genes that you can find.

Jennifer Stock: For the biomedical industry. Interesting. Do you think there would ever be a...well, I guess that once you've cloned the protein there really wouldn't be a bioprospecting worry as far as going to harvest bioluminescent animals, right?

Steve Haddock: Right, right. That's what's so great about, I mean, you used to have to study these things by collecting literally thousands and thousands of jellyfish and grinding them up or firefly tails, you know, grinding them up and trying to figure out what the chemicals are. Now, if you just take one organism, even one little piece of tissue, you can get the gene and then once you have that sequence, yeah, then you can study the protein all you want without collecting anymore animals.

Jennifer Stock: Wow. You just mentioned fireflies and that brings up...I wanted to ask, are there bioluminescent animals in freshwater or some local terrestrial examples of bioluminescence?

Steve Haddock: Well, we don't get fireflies out here, unfortunately, but actually, you can see there's bioluminescent fungus that you can see in, sort of, old rotting wood and I've seen, you know, some firewood in the fireplace and going out to get a log and it's, like, glowing with this sort of purpley-blue glow. It's called foxfire and that's caused by bioluminescent fungus that you can find out here. Also, kind of, in the leaf-litter hiking I've seen bioluminescent millipedes. So, yeah.

It's really strange why they would be luminescent, but there's actually some millipedes that are luminescent.

Jennifer Stock: So, how do you do that, hiking in the dark? I guess you're taking some very careful steps and you're really looking for it.

Steve Haddock: (Unintelligible)

Jennifer Stock: So, I guess, around here we have tons of stuff and tons of old trees and decay and we have a lot of mushrooms out here in West Marin. So, probably have a lot of glowing fungus, too.

Steve Haddock: I would think so. So, usually the mushroom itself, ones you see, it's not the luminescent part. There are some, but I don't think we get those around here as much, but it's, sort of, the part that's just developing on the wood. So, if you look at it in the light, you don't see it. It's just a very transparent film.

Jennifer Stock: Interesting. Now, what about freshwater ecosystems? Are there bioluminescent animals in freshwater ecosystems?

Steve Haddock: There's really very few. There's some insect larvae that are found in freshwater and then there's, in New Zealand, there's like this freshwater limpid, which is a little type of shelled snail and other than that it's really taken off in the ocean. I mean, if you look in, especially in, the deep sea it's kind of cliché, but it really is true to say that it's...if you pull something out of the trawl it's much more likely to be bioluminescent than not. It's a lot easier to name the few things that are not bioluminescent to go through and name everything that is bioluminescent.

Jennifer Stock: Yeah. On your website and, we'll give out the name of that website in a little bit, but you list all these different animals that are bioluminescent and I knew a couple of them, but it was a much longer list than I expected. There was nudibranchs, some octopus, sharks? What sharks are bioluminescent?

Steve Haddock: There are some deep-sea sharks that are, sort of, like dogfish. It's a small, couple-foot long little shark called the cookie cutter shark is one prominent example and those guys are actually an interesting case. They have a mouth that's shaped like a little circular cookie-cutter and they take little chunks out of, like, dolphins and tuna. So, they're like these little sharks and Edie Winter actually hypothesized that they're using their bioluminescence as a way to trick the fish.

So, we talked about counter-illumination before, this....eliminate your silhouette. Well, these guys have a little dark stripe along the bottom that's not perfectly counter-illuminated. So, their shadow looks like a little fish and the thought is that a larger fish comes up and says, "Oh, there's one of my prey items," goes and swims up, and the cookie cutter shark takes little nips and swims off.

Jennifer Stock: So, cookie cutter sharks, they're kind of just snackers with other animals, right?

Steve Haddock: Yeah.

Jennifer Stock: They're not really big-time...they wouldn't eat another animal. They just kind of snack on them a little bit?

Steve Haddock: They seem to take plugs out of much larger animals, yeah.

Jennifer Stock: Cool.

(music)

Jennifer Stock: We're here with Steve Haddock, who is an expert in bioluminescence. Let's talk a little bit about some of the biodiversity of some of these deep water animals. What are....how diverse...how many different types of animals are in the deep sea?

Steve Haddock: We don't even really know how many are down there. One thing that's kind of interesting to me is how people are just, they're fascinated with every new species. You know, there's like newspaper releases on, "Scientists discover new species of," something and it's weird because you get almost jaded with the amount of new and...it's almost frustrating sometimes when you're looking at the deep sea and especially at these fragile things, you almost don't want to find a new one because it just means more work for you down the road, but yeah, so many of these jellies and things like that and I also actually, I like to call them undescribed species as opposed to new species because they're really not new, you know? They've been around for millions of years.

They're basically new to us and we just haven't, kind of, cataloged them in our little organizational system yet.

Jennifer Stock: Well, we've got a caller. Alright. Hello, you're live on the air.

Caller: Hi, I have a question about bioluminescence.

Jennifer Stock: Alright! Thanks for calling in.

Caller: Well, I was on a scuba dive recently in Indonesia and I had a very interesting experience. We were on a night dive and turned off the lights. So, lots of little sparks, which is normal, but every so often we'd get a big blob that would appear, about the size of a cantaloupe, and it would persist for about a minute and the really weird thing is, if you turned the light on and looked at it, there was nothing there, at least that you could see, and if you put your hand there, there was nothing there either. We later figured out that what they were epitokes, which is the reproductive segments of marine worms that break off from the marine worms and come up and burst with gametes, eggs and sperm, and I guess what was going on was the eggs and sperm were bioluminescent.

So, why would that be and that's a very strange thing.

Steve Haddock: Well, actually, so, those polyketes that you were lucky enough to see, and I've seen them in the Caribbean, but not down in the South Pacific, they do what I was talking about before with the ostracods, or these little shrimp that send out, sort of, the Morse code signals. The polyketes, these little worms, actually have, sort of, a mating dance that they do where, I actually can't remember if it's the male or the female, but basically, the female hangs out in the water column and the male swims around it and puts out this bioluminescent material into the water. So, you know, you said you couldn't really see it with the lights on afterwards, but I think it could have been that exudate that they were putting out. So, the actual sperm and the eggs, technically, aren't the things that are probably luminescing at the time, but they happen to be there in the water at the same time that they're putting out these bioluminescent chemicals and so, their displays are tied with the lunar cycle and so, you get these swarms at certain times and the natives actually have, the islanders have ceremonies that involve catching a whole bunch of these things and actually eating them...

Jennifer Stock: Oh my god. Interesting.

Steve Haddock: ...at the time that those worms do their bloom. So, that's pretty great that you were able to see that.

Caller: I have heard that they eat them in Fiji, but I do know the interesting thing to me is that the epitoke is, well, more brainless than a polykete worm and I guess is off on its own and I know that they're supposed to explode at some point or, at least, open up. So, I'm curious how, if they don't have the thinking part of the worm in them they can react too light?

Steve Haddock: Well, I think the other half of the equation does still have its faculties more or less in tact.

Caller: Okay.

Steve Haddock: But, yeah. There's actually...there's some things like that where, especially with the jellyfish it's like, these things have fairly elaborate bioluminescent mechanisms and no way to really see it. So, but, I think your case where it's a mating situation is a little bit different. So...

Caller: Oh, okay it's just a way to bring them together. Thank you very much.

Steve Haddock: That's neat. Thanks.

Jennifer Stock: Thanks for calling. Great question. We still have a few minutes left if anybody else wants to call in. Again, the number is 415-663-8492 or you can try 415-663-8317 and ask a question about bioluminescence.

Steve Haddock: There's another thing I wanted to mention that people can actually try because, you know, we use some fairly specialized equipment in our lab in order to...low-light cameras to record the bioluminescence or special filters in lights in order to see the fluorescence, but if people want to do, like, class projects...I often get emails from people, you can actually order bioluminescent. You can order bioluminescent dinoflagellates, those little phytoplankton, from various either, sort of, semi-...almost industrial, like, educational supply houses. So, if you do a little bit of a web search on bioluminescent bacteria, you might look for photobacterium or you might just look for dinoflagellates and there's a couple different places that will sell you a little batch and I've tested them out, both of them, and they're really great.

You get, like, this little glowing tube of bacteria or a little glowing bag of dinoflagellates.

Jennifer Stock: Wow. One way I've used to demonstrate that it's a chemical reaction and, this isn't great because it's a wasteful use of a glowstick. It's plastic and glass and then you have to throw it away. So, I'm not a big fan of that, but the way those things work is there's that little glass tube inside that you crack open and if you cut off the top of the glowstick and pour everything out into one petri dish and then take out that little glass tube, put that in a separate one, then you can actually mix them and show how it produces light. It's a way to demonstrate the chemical reaction, but I think the bacteria would really be much more applicable in classrooms.

Steve Haddock: Another thing that's a way to see fluorescence is we just use, you have to have, sort of, a short wavelength light to excite it and then you want to block that light out and look at the longer wavelengths in order to detect it and so, I have on my keychain just one of those little blue L.E.D. flashlights that I carry around everywhere and if you get one of those, that's a pretty good excitation source. So, then you just need a piece of yellow cellophane. It could be, you know, a bread bag, an old bread bag or something or even some yellow goggles. A lot of the sunglasses today, you can buy, are just yellow filters and you can go out and see a lot of fluorescence.

You can look in your cupboard. The mustard is probably going to be fluorescent. You can check, your Cheez-its are probably fluorescent.

Jennifer Stock: Why?

Steve Haddock: Well, in the case of the mustard, chlorophyll, the molecule that plants use to absorb light is also fluorescent. So, if you shine this light on a leaf and use your little filter it's going to look bright red to you because it's fluorescing that chlorophyll that makes it look green in the light is actually fluorescing and looking red. So, if you get together your little fluorescent kit, you can, sort of, have some fun.

Jennifer Stock: I just have this image of you walking around all these random areas with interesting goggles and filters on your flashlights and is that pretty accurate for you?

Steve Haddock: No, no.

Jennifer Stock: I wanted to ask, you were talking earlier about getting down to this level of DNA and proteins and, you know, there's the whole collection that you were talking about. You get the samples in jars, but then you have these organisms, but how do you get all the way down to that molecular level? What instruments do you use and techniques to get to that level?

Steve Haddock: I mean, we use, sort of, normal genetic tools. It's kind of like the same way that bioluminescent and fluorescent proteins that we can pull out of the deep sea end up being used in a normal biomedical lab somewhere. In industry, we can take the industrial tools and just apply them to our deep sea questions. So, all you really need is the little frozen piece of tissue to start out with. You grin it up and do some things, again, that you can, sort of, do in your kitchen if you have an advanced kitchen to pull the DNA out and then, from there we'd use little tricks to amplify up the portion of that...of interest and, you know, sequence it and study it from there.

Jennifer Stock: Interesting. Interesting tools. We have another called. Thanks for calling! You're live on the air.

Caller: I had a question about the vertebrates, the larger critters that bioluminesce and how many of those make their own bioluminescent material and how many of those are ones that are harboring or growing or cultivating other critters that bioluminesce inside of them to do the work for them.

Steve Haddock: Sure. That's a good question. So, the bioluminescent vertebrates are pretty much fish. You know, sharks and fish, bony fish and birds none of the other things has anybody found that has bioluminescence and within the fish, they have a bunch of different ways that they can go about making light. So, the angler fish, of course, has a classic example of bacteria. There's other fish that have really cool little bacterial cultures near the bottom and then they have, like, a reflective light pipe that goes all along their belly that takes the light from that bacterial culture and uses it as a counter-illumination signal, like the camouflage signal that I was talking about.

So, there are a bunch of fish that use bacteria. Then there's, I think, most of the fish, though, use one or the other of these luciferin, luciferase reactions that we talked about and even within that there's a couple different chemistries. So, if you try to add up how many times bioluminescence has evolved, it gets a little bit tricky because you say, "Well, okay. It evolved in fish," but then if you think, "Well, it actually probably evolved in fish, like, four or five times because some of them use bacteria, some of them use one luciferin, some of them use another." So, probably the most of them are actually either making their own luciferin or getting it from their diet. There's one good example and I think in Sausalito they had a problem with this midshipman fish, which is like a singing fish and the people in the boats had these mysterious alien noises and it actually ended up being from this toadfish.

Well, that guy has photophores all along the bottom and in the northern populations like up in Washington, they're not bioluminescent, but down here and down towards Santa Barbara, they're brightly bioluminescent and what it has to do...they have to get that from an organism in their diet. So, they are actually getting the chemicals from their diet. So, almost every little variation that you can think of they're able to do.

Caller: Thank you.

Jennifer Stock: Cool. So, we're just running out of time here and, Steve, this has been so interesting, fascinating. I feel like we've just touched the surface of bioluminescence and there's probably so many more questions that we have. We might have to have you come back sometime. Do you have...do you want to share the website that you have that...there's some really cool photos on there?

Steve Haddock: Yeah. If you just Google bioluminescence, you don't even have to spell it right, hopefully if it's still up there, the first link that you get should be this thing called the Bioluminescence Web Page which I set up when I was at Santa Barbara and it has a lot of information. Some of the stuff we talked about and some other things on it.

Jennifer Stock: You can also...

Steve Haddock: Just Google bioluminescence.

Jennifer Stock: ...or Google Steven Haddock, H-A-D-D-O-C-K and it's...very much...that's how exactly I found a little bit more about bioluminescence and your work was by Googling those two things. So, the internet is an incredible resource. There's a couple of different bioluminescence web pages and you can learn how to correctly spell it too in case you're ever in a spelling bee, but thank you again for coming all the way up here today. It was great having you.

(Music)

Jennifer Stock: I think tonight's show, just hearing about the diversity of animals that produce this light from bacteria to squid to some fishes, even vertebrates, and fishes and sharks including land bioluminescent organisms like fungi and lichens, it just really displays how interconnected our world is in regards to things feeding on each other and how they depend on each other and how they've evolved and especially in the ocean. So, Steve has really helped illustrate that tonight with just the one topic of bioluminescence. So, thanks for joining us tonight on Ocean Currents.

(Music)
(Bubble Noises)