[CARROLL:] Welcome back. So I'm just the MC here. I'm going to help keep the flow of questions going and all that, and I'd just like to start off by thanking these four people who prepared a tremendous amount of time to be here today.

[Applause]

[CARROLL:] Let's start with any questions for Ali or Roland from the presentations you just heard. We already have mics running around all over the place. You got one back here, Sandra? There we go.

[STUDENT:] So the devices like the camera traps and critter cam, they obviously answer a lot of questions we've had about the wildlife and ecology. But do questions ever arise from data that we didn't expect?

[KAYS:] Yeah, for sure. I mean, that's-- one of the great things about science is that you never run out of questions to ask. And a lot of times, you start out with a question, and maybe you answer that, but in the process, you learned about something new, like this whole red fox/gray fox thing. I mean, I had no idea that there would be this pattern. So we started out as this general survey of Virginia and the D.C. area and Raleigh, and we found this big difference. And now, this has us thinking well, what about Charlotte, and what about Atlanta. And more fundamentally, what is it about a city that these animals are responding to that have different types of animals moving in to different types of cities. You have places like Chicago that have coyotes right downtown and other places that don't have that nearly as much. So I think that that sort of sometimes you find this one little answer that suddenly opens up this whole other series of questions that you just hadn't even thought of before.

[PRINGLE:] Yeah, to give a concrete example, actually, of a project, the ^ISolanum^I project that we talked about in Lecture 5 was actually kicked off by--well, it was kicked off by the observation that I was only seeing those yellow ^ISolanum^I fruits in certain places where herbivores weren't. But I actually, at that point, I didn't think anything ate it because I thought it was so toxic. So we used camera traps to actually figure out what it was that was eating the ^ISolanum^I plants. We ultimately did something like 20,000 hours of camera trapping trying to get a handle on who exactly was eating it and how frequently.

[CARROLL:] Ali, you want to offer an example?

[SWANSON:] Just to say that's what science is all about.

[STUDENT:] I had a question about the camera traps. How far-- what areas have you guys had them in in the United States so far, and if you guys are planning to spread it across the state or just in specific areas.

[KAYS:] Camera trap research-- if you look at the papers published, they're going up 25% every year, which is faster than a lot of other fields. I think finally people are realizing how useful they are. They're getting cheaper. People are really starting to use it in a big way. So our own projects have been so far mostly in this region. We've built this eMammal project as a way to bring in data from citizens in a citizen science way where the volunteers actually run the cameras and then upload the data to us. And now, actually probably about a month from now, we'll start opening it up to other people. So we've been talking with other projects in a bigger area that would participate. But so far, for us in this project, it's been mostly in the southeast, from South Carolina to Maryland for that particular project. But we work in other places. I was actually just at Impala last month, and then we ran a line of cameras up Mount Kenya from

the bottom up to the top, looking at how animals change along the elevational transect. So I've been involved in a couple different projects.

[STUDENT:] My question was pertaining to the method that you use to decide where you put the WildCam because as the previous lecture was dictating, you had the elephants knocking down the Soloma trees. So I was wondering if you went to Gorongosa, and you're putting these cameras on the trees, would you have different results if you were to put them on different vegetation?

[SWANSON:] Yeah. I'm not involved in the camera trapping survey in Gorongosa, in setting those traps. But I've done that in other parts of East Africa, and I can tell you that there's a lot of studies. And from my own experience, yeah, where you place the cameras makes an enormous difference to the types of animals that you capture and to how long they survive. So I think people often target their placement depending on the specific questions they have. If they're trying to target a specific elusive species, they'll often place cameras on trails because we saw from Roland's slides that especially cats love using trails. But yeah, where you place cameras can affect the results that you're getting.

[KAYS:] One of the kind of general principles of studying ecology and deciding how to do it-- this is called study design--is to do it in a stratified, random design. So you stratify based on what your research question is--so you might do a hunted park and an unhunted park. So that's our stratification. And then within there, you want to have the points randomly distributed to some way so that you're getting sort of on average-- you want to get an on-average measure of what's going on in treatment A and treatment B. So we generally try to do that with cameras to the best we can. Like you mentioned, it can't be totally random because we need to strap it to a tree, although you can pound a stake in. There are some things you can do. So it's maybe not perfectly random, but the more random you can get it, the better your data will be.

[STUDENT:] So I was wondering, is there any intention to use these massive data sets to try to improve computer vision as fuel for neural networks or other machine learning algorithms?

[SWANSON:] Absolutely. We have a lot of collaborations at Zooniverse with machine-learning teams, not just from camera trapping photos, but for all types of photos that we have, from galaxies to audio spectrograms. So it turns out that it's really hard to train computers to learn things like what animals look like because it's a really complex problem. In places like Gorongosa, you've got dozens, well over 50 different species that a computer has to learn to distinguish. And so when you're trying to describe what an elephant looks like in pixels, if you can't see the elephant's trunk, that's a really hard problem. That's really hard to tell a computer what an elephant looks like in terms of pixels when you don't always have that defining characteristic. So we have a lot of collaborations with machine learning. And people still are a lot better than any computer we've ever trained, but they're getting better.

[KAYS:] And with all these algorithms, the more training data you have, the better they get. And so the more we're running cameras and looking at them ourselves or having the Zooniverse people look at them, the more we get these training data sets, the better the algorithms get.

[STUDENT:] So I'm just curious: have any of you tried putting camera traps in marine environments like the Chesapeake region?

[KAYS:] I never have, but there are-- that's kind of a whole other world of ecology, I think. They have to buy boats and drive around. But they have started recently doing that and getting really interesting results. One of the basic approaches they do is they take basically a GoPro. So it's not motion sensitive, but it'll record for, say, 30 minutes. And then they put a stick with a bait bag out there. And they'll drop it down, and then they'll come back, like, 30 minutes or an hour later and see what actually came there. And they find that it's a really good survey tool for the fish. They get kind of the whole community, and they can ask all these same questions about patterns in nature under water. And when they go and try to verify it-- like the other ways you do this might be by scuba diving. But of course, a lot of fish are sensitive. They think you might be a predator, so they go and hide. So they find the cameras. They're actually pretty good at detecting some rare species.

[SWANSON:] I'll just add really quickly that there is a Zooniverse project that does something very similar, Seafloor Explorer. And they're not static cameras, but they're cameras attached to the bottom of a boat. So if you have an interest in aquatic ecology, we've got lots of photos that need your eyes.

[STUDENT:] I was just wondering if the cameras that you use for the camera traps are visible, and do you think that affects the data that you collect? Like if animals, say, see the camera, and they come back to see what it is or how it affects the data you collect?

[SWANSON:] Well, I have a lot of photos that are the last photo this camera ever took.

[Laughter]

[SWANSON:] They're amazing. My favorite is there's one of a hyena a few feet away staring down this camera. And you can see the time stamp. It's, like, 10:45 at night. And then a minute later, it's the inside of its mouth. You can just see the canine and its tongue. So you definitely-- I certainly find in Serengeti the animals are quite habituated to human beings. And so they aren't hunted really. So they don't actually seem to mind. I've got images where animals, even at night, are just lying in front of the camera for hours on end. But they're definitely inquisitive, and they scent mark. But I think it varies a lot from place to place, and certainly if they're hunted, they may be a lot more skittish.

[KAYS:] Right. People say camera traps are a noninvasive way to study animals because you're not darting them out of a helicopter. It's certainly less invasive than that. But the animals know their environment. And even if it's super-camouflaged, that's a piece of plastic that wasn't there when they walked by the tree three days ago. And so they notice it. Generally, they don't care. But like she said, some species care more than others. We actually have been doing a project in my lab where we're going through all sorts of-- we call it WTF, which stands for will they flee--

[Laughter]

[KAYS:] --to see if animals do-- because you can see most of these cameras actually take little video clips. And so you can see: do they look at the camera. Do they care about the camera? And we've looked at about 120 species, and most of them don't. And most of them that notice it don't care. But you do get certain species-- the canines, like dogs and wolves species, actually really notice it. Elephants really notice it. Cows, for some reason, are really good at noticing the cameras as well. So it varies, but generally-- the other trick is most of us use cameras that have infrared flashes at night, not bright white flashes. So that means--if you get a flash in the middle of the night, a bright white flash in your face, it's going to blind you. Humans are going to avoid it, so animals certainly are too. But these infrared flashes, they glow red a little bit, like maybe the animals see the red glow. But it's not really bothering them as much. And so we use those-- they take kind of-- the pictures are black and white. They're not as beautiful as a nice color flash at night. But we do it because it doesn't bother the animals as much.

[STUDENT:] I've seen camera traps used under water actually to identify specific dolphins and their patterns and social behavior. Have you done any studies with that in Gorongosa?

[PRINGLE:] The dolphins at Gorongosa?

[STUDENT:] I'm sorry. Any social behavior patterns in the animals using camera traps.

[PRINGLE:] I guess I could try to answer on behalf of some other people. I haven't personally. I know that Paula Boule, who's running the Gorongosa lion project, is using a lot of the WildCam Gorongosa imagery, much of which she has collected, to look at various things to do with lions, and I think to do with conservation behavior and other things as well. We did something in Gorongosa this past summer, my student Jen Guyton put out carcass-cams. And so this was this issue of there being no hyenas, that the carcasses will sit for a lot longer than they do in most normal African systems, and we wanted to know what happens. And that was really fun actually and informative. But I'm not sure we're there yet. There's probably an open niche for somebody who wants to do a camera trap behavior project in Gorongosa.

[KAYS:] I think as cameras get more and more to recording video, there's more of these types of questions that we could do. And when I started running cameras, it was a 36-exposure roll of film, and you weren't getting any behavior. You were getting one snapshot. But now, we're getting more and more of that, and so you can start to ask questions about the--new questions about the animals. We've done one: you can look at the vigilance of an animal like a deer in terms of how worried they are. We've heard about how predators make animals afraid. So if a deer has his head up, it's looking around, it's being vigilant. If it has its head down, it's eating, and it's not being vigilant. So that's a nice tradeoff between either looking out for predators or getting food. And you can tell that right from the camera and look to see, well, what makes them more vigilant. Are they worried about people? Are they worried about hunters? Are they worried about coyotes? It turns out deer aren't really worried about anything. But you might find some more interesting results on another species.

[CARROLL:] So there's a lot of hands up. We'll just broaden this out that this can be broader than camera traps, anything you heard today, anything you're curious about in the realm of ecology. I think all four of our guests would be happy to field those questions. So wherever you want to go, let's broaden it as far as you like. Go ahead.

[STUDENT:] Has the cams been used for not only big animals, but for bird species in the tree canopies, for example like in the Amazon rainforest?

[SWANSON:] I know in some places, there are researchers using video camera traps to study nest predation on birds. And I don't know about other studies with birds. I'm sure there's lots--

[KAYS:] So the cameras trigger on moving heat, and the smaller the animal is, the closer to the camera it has to be to trigger. So you do get pictures of mice, but only when they're right in front of the camera. So just in terms of birds, you get good pictures of turkeys and pheasants and less good pictures of juncos and chickadees. There has been almost no research with camera traps in the canopy because you've got to climb, and then you get lots of false triggers. But there was one really cool paper published last year from Peru. And they ran camera traps in the trees, and the thing that I thought was really interesting was 90% of the pictures--so you think about the canopy of the rainforest, you think about toucans and monkeys and parrots. You should be thinking about kinkajous and night monkeys because 90% of the pictures they got were nocturnal animals. So 90% of the activity was happening at night.

And they did get the monkeys and the toucans, but that was only 10% of the pictures they got. So I think there's a whole-- in terms of patterns of nature in the tropical canopies, there's a lot more that we can learn about that.

[STUDENT:] So my question is kind of completely unrelated from the other questions that were just asked. But kind of bringing it back to calculating carrying capacity in the logistic curve that we talked about a long time ago. Do unpredictable events in the environment, like diseases, droughts, forest fires, kind of disrupt or impact calculating the growth rate, and does this cause a limitation in the accuracy of calculating that?

[TARNITA:] Yeah. That's a great question. When we talk about logistic growth, basically we assume a population that grows just based-- it has all the resources it needs, and those resources set a carrying capacity or space. But everything else can interfere with that. So the moment you start to have competition between species-- so competing with other species will change how high a certain species can get. Similarly, predation will do the same thing. Even if your species is growing exponentially, you have a top predator that's just going to keep it at a certain level. Disease is going to act in exactly the same way. So all of these, then, I would model as separate factors. I wouldn't put them somehow-- all of them crammed into a carrying capacity. I would dynamically make a model that takes all of these factors into account. So the nice thing about Gorongosa was that there are basically almost no predators. There's, like, 30 lions compared to the 35,000 waterbuck. So you could ignore most of these factors, and that's why we could get such a nice description of what was happening just based on this simple logistic growth. But now, as everyone else is recovering, I would have to make models that include all of these other kinds of interactions, including disease, which is a really important one. And then you have to think about social animals and that they are more likely to transmit disease, for example, as opposed to animals that are much less likely to be in contact with others who may get infected. So yeah, that's a very good question.

[STUDENT:] I was wondering: you seem to--I'm not sure if you know the answer to this. Since in Gorongosa, you seem to be focusing more on larger herbivores and carnivores. Is there anything on the micro scale that's been disrupted since the civil war that has really affected things, like with smaller animals, secondary predators, or anything like that?

[PRINGLE:] Yeah, almost certainly. And even the fact that the vegetation has changed pretty dramatically-- and I showed two different sets of graphs in different lectures, one showing the increase in tree canopy cover over the last 35 years, and one showing a switch in the composition of the floodplain grassland community. And so that is going to have implications for various types of herbivorous insect and small mammal. We just can't say very much about it because nobody's done it. Right now, there's a very small community of people working in Gorongosa. I think a lot of people want to. And soon, there will be more. But it's pretty early in the game. And so people are really focusing on a few big conspicuous things, and we know very little, for example, about how rodents-- I showed the graph that when you experimentally exclude large mammals, small mammals double in abundance. That happens over and over again when people do these experiments. Nobody's studied the small mammals in Gorongosa yet. So the answer is yes, but it remains to be determined exactly what and to what extent.

[CARROLL:] Do you have it right here? Go ahead.

[STUDENT:] Do you have any really interesting or weird experiences in the field that-- like an instance or something?

[Laughter]

[CARROLL:] Roland?

[Laughter]

[KAYS:] Well, I have a fun one that I thought about because he was talking about hyenas earlier, and when I was a grad student, I did a field stint in Costa Rica with a class, and they sort of taught us, if you're trying to get in touch with someone in the field, you give a kind of a yell. So I kind of developed a characteristic yell, which was to whoop. And I go,

[makes whooping sound]. Because you can do it really loud, and it carries really well. So last month, I was up in Mount Kenya-- do you know Georgia Titcomb?

[PRINGLE:] Yeah.

[KAYS:] So Georgia and I were outfitting camera traps, and we'd gotten separated a little bit, and we were in the bushy part. And so I gave a whoop. I went

[makes whooping sound]. And I heard a whoop come back. And I thought it was her. So I whooped back, and then it didn't whoop back. And I was like, why isn't she whooping back. Where is she? And finally, I was just, like, well-- I went back to the trail and just waited for her. And she came back, like, freaked out. She was, like, that was a hyena--

[Laughter]

[KAYS:] --right by her. So that's why she didn't whoop back.

[Laughter]

[CARROLL:] Ali?

[SWANSON:] Sure. So I worked in Serengeti, which-- and I don't know what the setup's like compared to Gorongosa. But we have research houses. There are a whole bunch of long-term research projects. And we have--there's a lion house that has a lion project. There's a cheetah house. There's a biodiversity house. And after dark, even though the houses are only about 100 or so meters apart, you're supposed to drive, you're not supposed to be on foot because we are right smack-dab in the middle of prime lion territory and buffalo territory. And buffalo are a little scarier than lions, especially at night because they're very aggressive. And so my friends and I are walking back from cheetah house to the lion house, which we weren't supposed to be doing. And Daniel, this birder with amazing eyesight, he all of a sudden stops. And he's, like, I think I see something. And we're like, what: what do you see. And he's like, [makes sound]. And he starts making this little kissy noise that you make to get carnivores' attention, which we make to get lions to pick up their heads so we can see their whisker spots. Not a great idea. And so we're like, Daniel, what do you see. And he's like, oh, no. It's probably just a buffalo. And we're like, one, that's not okay. And then two, we shine our mag lights over, and there is this tawny creature jumping maybe 40 meters away, at which point, we're like, that's a lion. And so we slowly, trying to keep our calm, walk back to the house. And the lion lets out this [makes guttural sound], like this sort of bark-- they sort of bark-- because it was a denning female with cubs. At which point, we walked very quickly back to the house, and everyone was fine. But there's just a lot of, yeah, stupid stories.

[Laughter]

[TARNITA:] Well, most of my mishaps are math mishaps.

[Laughter]

[TARNITA:] So I say I sometimes wander absentmindedly in the savanna. And we were once in a park with a ranger. It was one of the parks where you're not allowed to go out of the car without a ranger. And so the ranger, kind of seeing me being a little bit absent-minded, doing my things in my head as I was looking for ants, started to tell me what needs to be done as we run into animals, if we run into animals. So he was going through this list of very scary things, and I kept processing them somewhere in the back of my head. And at some point, we get to buffalo, and he says, if you see a buffalo, run as fast as you can and climb up a tree. And so that one was like, what. What do you mean? I haven't climbed up a tree since I was 4. I don't even know if I can do that anymore. And he said, don't worry: when the buffalo follows, everyone knows how to climb up.

[Laughter]

[PRINGLE:] Yeah, along those lines is something that happened this past summer when we were doing this darting operation. So it was myself and my colleague, Ryan Long, and a vet, Rui Branco. And the very first animal that we saw was a nyala, and that's actually a pretty uncommon animal, relatively speaking. We're trying to get kudu, bushbuck, and nyala. And the first, kudu and bushbuck, are easy. Nyala is tough. And we were expecting to have a really hard time finding them. But the very first animal we saw was a nyala, and we thought, oh, my God: this is--you know, the sun's really shining on us today. This is going to be a good day, a good trip. And for whatever reason, the dart fired, hit the animal, everything looked good. And we start following it, waiting for it to get sleepy. And it didn't get sleepy.

[Laughter]

[PRINGLE:] Or it got a little bit wobbly actually. I was thinking about this when you were saying the [makes kissing sound] noise because the vet, Rui, started snapping his fingers like this. And the nyala would come walking towards us because an animal with a lot of opioids in the system, for whatever reason, it comes to investigate that, even though it would normally be scared. So it was clearly affected, but the dart had clearly not injected. So we just followed this thing around. It was capable enough to stay on its feet and keep leading us around but sort of slow enough that we could kind of keep ... And eventually, we were completely lost.

[Laughter]

[PRINGLE:] And we hadn't thought to kind of-- we thought this was going to be a quick operation. Nobody brought their--actually, we had one GPS, but it was almost running out of batteries. And so Ryan and I sat with the ranger, and Rui decided he'd go back to the car to get another dart so he could try to put another dart in this thing. And so we sat, and we sat-- And we sat, and we sat. And Rui didn't come back. And then there was these elephants, and we didn't have any cell phones. It was a mess. And it was like total rookie mistakes all over the place. And then we saw elephants coming in, and the ranger started to get worried. And I thought, no, Rui's going to be so pissed at us if we leave, and he told us to wait here. And no, no, we need to go. The ranger was quite worried. So we said, all right, let's go. And we go, and long saga. We get back to the road. We see Rui's footprints on the road going in both directions--

[Laughter]

[PRINGLE:] --which made no sense. And we were completely confused. And it was around about sunset, and we were kind of obviously facing up to the possibility that we were going to have to go back and organize search parties and go out looking for him, when we find that he's been picked up on the road. He's been treed-- chased up a tree not once but twice by elephants, two different trees. And he survived, but he said by about this much. He was trying to get up one tree, and the elephant hit the tree right behind him, and his iPad. And then in the process of getting up the tree, he dropped his iPad, which had the GPS on it. So it was chaos. And then from then on, we always carried our backpacks with all of our supplies into the field.

[CARROLL:] That's Rob's recruitment speech for Princeton--

[PRINGLE:] It is SO much fun!

[laughter]

[CARROLL:] Sandra, do you have someone? There we go.

[STUDENT:] My question is what are each of your backgrounds, and what motivated each of you to go into ecological research?

[CARROLL:] Let's swing back. Let's start with the mathematician because I think that's the unusual journey to start with.

[TARNITA:] Okay. Yeah, so I had this path that I thought was kind of completely focused when I was-- ever since I was 5 years old until I was 22 years old, I thought I was going to do math and nothing but math. It had to be the most abstract kind of math. I wouldn't even see numbers anymore. Everything was just in the most abstract kind of-- I was doing geometry, so I was really interested in geometric shapes since then. And during my PhD, I started to have this moment. When you start a PhD, you start to narrow your point of view. You start to address problems that are very focused. And there's a whole lot of math that goes into it, and then I was working on a problem that maybe five or six other people in the world cared about. So it started to feel slightly claustrophobic to have done so much math and then now being in this field that was kind of isolating. And so I thought maybe I should just try something else. I mean, all of a sudden, there was this identity crisis. I was convinced that I knew what I was supposed to do, and now, I just wasn't so sure anymore. And I met my PhD-- my former, who then turned to become half of my PhD advisor, Martin Nowak, who was a professor both in the math department and the biology department. And I picked up his book from the library, started to read it, and started to get completely fascinated with the kinds of questions that math can help answer in biology. And I started my first project. I loved it. And since then, I've just been in love with it. It's just been this kind of taking a while to really realize what my true passion is and how all of the math that I had learned can actually apply for the kinds of problems that, even when I'm frustrated and I feel things aren't working according to plan on some days, I feel that I'm motivated by these questions, and I care a lot about the answers to the questions. So that's my path.

[CARROLL:] Ali, do you want to take a shot?

[SWANSON:] Sure. So I should say I'm actually now based in an astrophysics department, but I'm still an ecologist. So I don't know. I mean, I guess when I was younger, I wanted to do cellular biology, actually. I thought it was really interesting. And then I got to university and realized I did not like being in a lab. And so after college, I spent years doing field work, just not for very much money. But studying feral horse behavior on some of the barrier islands or chasing pygmy owls around Mexico, electroshocking fish in Montana. There were real questions behind all of them. But I really enjoyed sort of being out in the field trying to get my hands dirty and figure out how-- working towards understanding how all these different species interacted with each other. And then after a little bit of time working in state government for environmental policy--which being in an office was also not that much fun-- I went to grad school. I joined Craig Packer at the University of Minnesota on the Serengeti Lion Project. And then through that, I met Zooniverse, and now because I'm a postdoc with Zooniverse, I am surrounded by astrophysicists.

[Laughter]

[CARROLL:] Roland?

[KAYS:] Yeah, I kind of had a similar experience in that I--well, I had a summer in a lab that made me decide I didn't want in the lab the rest of my life. Although I still do lab work, but it was just like not every day all day long. I had--growing up in high school, I was super-into biology and physics, and I thought I wanted to go into genetic engineering and did that really took all those basic classes first year of college and then kind of had this revelation over the summer where I was just exhausted at the end of the day from just spending all the day in the lab. And so I started looking around, like, well, what else can you do with science. And leading up to then, I'd always been running around the woods. I was in Boy Scouts, and we'd just go run through the woods in the neighborhood. And so being outdoors had always been important. So all of a sudden, when I realized I didn't want to be in the lab, so I'm like, what else can you do with science that's not in the lab. And I started looking around, and there was actually a mammalogy class taught that semester, which is only taught every couple-- I kind of think if I'd taken ichthyology that semester, I'd probably be a fish biologist right now. But mammals was there, and I just kind of ran with that.

[PRINGLE:] Yeah, I don't have--I mean, my story is a variance on--well, not so much yours, but--

[Laughter]

[PRINGLE:] --the other two. I had a really inspirational college class taught by a professor named Dan Janzen, who's both a visionary ecologist, had some of the most creative, interesting, profound and enduring ideas in the field, and also has done an amazing-- has led, inspired, and brainstormed an amazing restoration project in Costa Rica that's actually very similar to the one that we talked about in Gorongosa. And that class and mentorship that I got from him were pretty instrumental for me. But I think everybody who gets this--who ends up in this job was somebody who enjoyed being outdoors and animals and plants and that kind of thing at some point as a kid.

[CARROLL:] Corina wants to add one more thing.

[TARNITA:] I just wanted to say, for those of you who are interested, come from kind of a math-y instinct about biology. I would say that the other thing that, for me-- what keeps me really excited in this field is that sometimes, I can tackle problems that are extremely hands-on, like this. Like I really want to understand what happened to the waterbuck in Gorongosa, or I want to understand what termites are doing. But then at the other extreme, I can use some of that mathematical intuition and ability to abstract and try to look at patterns across many different scales, so I have a lab in Princeton where I'm looking at slime molds and the kinds of patterns they form, and then I look in satellite imagery, and I look at those kinds of patterns. So you can really try to study specific systems and learn as much as you can about them and then scale up or down and try to understand how those rules apply at all these many different levels of organization and composition of ecosystems, from very tiny ones to very big ones. So that's one of the things where I find math to be very useful and kind of fun for me.

[CARROLL:] Thanks for sharing that. Eriko, in the back.

[STUDENT:] I know how earlier, you guys were talking about termites. And I just wanted to know how did you get the information. How did you study the behavior of termites. How did you guys observe the termites and their behavior?

[PRINGLE:] Yeah, I just ask because one of the things that we're very self-conscious of is how poorly we've been able to study the actual termites. We've been able to study the mounds very well using remote sensing and all kinds of techniques that ecologists are very familiar with. We can measure plants. We can analyze nitrogen composition in the soil and those kinds of things. But the actual termite behavior is remarkably poorly understood, to the point where we had a paper come out about this, and they were writing a little news story about it, and we needed to know some facts about basic termite biology, like when they go out and forage on dung or plants. Do they bring it back, do they swallow it and walk back to the nest with it in their gut? Or do they carry it like a leafcutter ant would carry it in his

mouth? And we didn't know. And we sort of turned to the real termite experts, the people studying the actual-- from the entomological side. And talking to them made us realize how very little is known about termite foraging ecology in particular, in part because they do things at night and underground. So there's, I think, a huge role for people who are interested in that to make enormous advances, even in terms of the basic natural history. And techniques like new technological developments. If you could have a tiny camera that you could stick into a termite mound and somehow a mini camera trap that you put inside the mound like that, that could have a big influence. But yeah. Does that help?

[TARNITA:] And also I should say there's a lot of work on termites, so we know certain things about them. There's some information about how large the termite colonies can be or how long-lived they are. So there's some information about these things. What's missing is how do they actually forage, how much do they travel per hour, per day. Do they come back to the colony every night? These kinds of things, where you would actually have to follow individual termites in their foraging behavior on these tens of meters of foraging tunnels: that's extremely hard to do because basically, it's happening underground at the scale at which you can't really see. So then we take a lot of what we know. We know that termites are eusocial, so they form these big colonies like ants do, so we can try to learn some about their social behavior from ants. Ants are much easier to observe. So there are a lot of things that we can learn from other animals that have been better studied. But yeah, that's a big-- that's something that we're definitely getting very much into and trying to understand better.

[CARROLL:] Another PhD waiting to be done.

[Laughter]

[TARNITA:] Or a couple.

[STUDENT]: Oh, hi. I remember watching a short film called The Guide on the website. In the film, everyone was just so disrupted by the war and everything, they were trying to rebuild their society and community. So they were cutting down trees for money and all this stuff, so what environmental restoration movements have they been taking in order to restore the niches that have been destroyed by the war?

[PRINGLE:] I could talk a little bit about that. Maybe Matt could talk a little bit about that.

[CARROLL:] Let me introduce Matt Jordan, who's here from the Gorongosa Restoration Project, and I'll tell you a little more about what Matt's doing.

[Applause]

[CARROLL:] Give them 30 seconds on how you wound up in Gorongosa and then maybe address the question of--

[JORDAN:] [Interposing] Okay. So I did the Peace Corps in Mozambique. And then after that, I went to Gorongosa.

[Laughter]

[CARROLL:] It's the short story--

[JORDAN:] [Interposing] It's a long story, but we can talk offline about my background or whatnot. So in terms of the interventions that are being done, there's basically... fiscalização, which is the rangers. So there's anti-poaching efforts. There's health, community health efforts, so trying to-- basically, you have the buffer zone of the park where

all the people live and trying to uplift that community through health, through education so that they have less incentive to get into the park and poach and encroach on the park and move into the park. So one particular thing is we're growing coffee on Mount Gorongosa to try to stem the deforestation. We can talk a lot more about that at some point as well.

[CARROLL:] Thanks, Matt.

[Applause]

[PRINGLE:] I guess I could follow up quickly on Matt's comment that the guiding philosophy, I think, for the restoration project is precisely that nothing is going to-- it's not going to end well if people are still desperately poor and hungry. And so the park has not just an obligation. It has a moral obligation, but it also has a pragmatic imperative to do things like the coffee project, like the community health project, like digging wells. Schools have been built-- an enormous investment by the park in trying to build a neighborly relationship with the communities in the area.

[CARROLL:] Yeah, as much money is being spent outside the park as inside the park.

[PRINGLE:] Yeah.

[STUDENT:] This is a question for all of you. What was the most challenging part of your research?

[Laughter]

[CARROLL:] Let's give that to two of them. Anybody feel like leaning forward first? Roland? I think everyone leaned back. I can see Roland out of the corner of my eye.

[KAYS:] Probably getting funding. It's easy to come up with ideas, but then to form that into a proposal, find the right place to send the proposal, and then the funding is super-competitive. Often places like National Science Foundation fund 5% of the grants sometimes. So if there's a hundred grants that are submitted, you've got to hope that yours is that top 5% to get the funding. So I guess just sort of on the practical side, we've all got a variety of different projects going. But that's the first step. If you don't have that going, you can't really get past that.

[PRINGLE:] Yeah, I think maybe along very similar lines, I think one big challenge that we all have to wrestle with is just sort of constant little rejections-- rejections of grant applications, rejections of papers. So work that you put a huge amount of time and effort and love into that falls short of somebody else's standard. And that's just-- that's a continual thing in this particular line of work, and you just have to really be robust to those setbacks and to kind of not take it personally, not take it as any indication that your ideas are not worthwhile and keep pushing.

[KAYS:] But just to follow up on that, the scientific process is often this peer-review process with the journals. So you submit a paper, and your peers, who you don't know, review the paper, and they send it back to you anonymously. Sometimes, they're quite harsh, and so you have--like he said, you have to sort of be robust in that. But also this is an opportunity to learn. You've just had three experts tell you how to make your project better. That's a really great opportunity. And so you have to have this balance between-- and sometimes, it's hard to know should I argue with this reviewer, or should I sort of accept it. It's sort of the classic thing. But part of the scientific process is-- and also then we get papers to review, and when we critique them, we try to be fair and nice about it and as constructive as possible because in the end, we all want better science to come out.

[STUDENT:] So I know we talked about how you use camera traps to do surveys. But do you use any other forms of surveying besides camera traps?

[TARNITA:] Yeah, the aerial surveys. People do that from helicopter or fixed-wing planes. And of course, there are certain-- with anything that's aerial at that height, you're getting the big ones, and you're missing the small ones, and it's much easier to count in the floodplain than it is to count-- so it's good to basically mix all of these approaches. So you approach-- you take the problem from every possible angle. You have the aerial views, and then you have--from the air, it looks like waterbuck is all over the place. From Roland's perspective, it looks like baboons are all over the place. But you only--also from my perspective, when I am actually on the ground. So it depends where you look from. So I think we're combining all of these.

[KAYS:] I guess the other--I like to kind of contrast the two cameras and tracking collars. We heard a little bit about tracking collars. But tracking collars, you put on, and they record-- especially now with the GPS-- they record everywhere one animal goes: whereas cameras record a place, and they record every animal that goes in front of that place. And so they're studying the same thing. They're both studying animal movement, but from a different perspective. And so the nice thing about the tracking collars is no matter where that animal goes, you get to see that: whereas with the cameras, you're only getting a small area, but you don't have to dart them all, and you don't have to-- and you get even the shy species, even the rare species. But usually, you don't know which individual it is. And you don't know where they are when they're not in front of the camera. So they're really complementary. They're both useful for answering different questions. But it's kind of the flip side of the same phenomenon, which is animals moving through the environment.

[PRINGLE:] Although a little side note to that-- we've talked a little bit about DNA metabarcoding. And environmental DNA approaches are increasingly used as a complementary survey technique, so there's DNA everywhere of many things. And so you can take a sample of pond water, for example, and sequence the DNA in that pond water and sort of survey in that way organisms that might be present in that pond but hard to find in any other way, especially for things that are-- like microbial bacteria, things like that.

[KAYS:] I'll mention one more-- it doesn't work very well in Gorongosa, but when it snows up here, you guys can go out and look for animal tracks, and you can see where they go. You can see what species are living out there. It doesn't take too much homework to figure out which species is which. And jumping on the trail, especially of a predator like a coyote or a fox or a fisher, and seeing where they go, seeing where their hole is, seeing what prey they're eating. You can really learn a lot. It's really, really fun to try it. So I love a fresh snow, especially if it's just a little bit, which you tend to get around here. You can see the tracks really well, and it's a great way to learn about the animals.

[CARROLL:] Right here in the center. NICOLE: Hi, I have actually a question about the camera collars and GPS collars. So do you ever see that those collars, when the animals are wearing them, it affects how they act and how their peers react to them? And how do you combat that? In addition to that, how do you take off the collars, and after how much time?

[PRINGLE:] The first question, does it affect their behavior, and how do we combat it. So we typically operate under the assumption that the effect, if there is one, is negligible, given that we're using collars that are at a very small fraction of the overall weight of the animal, which is not to say that it has no effect. And actually, maybe Roland, who's more of an expert probably in tracking collars than I am, could comment on this as well. But we just-- our default assumption is that it's not really having a big impact on the animal. And someone could come along and show that there is some impact, I guess, that would force us to reevaluate that assumption. But to the second question, how do they come off, the ones we use, it's varied depending on the collars. But the ones that we use actually have a

little tiny explosive charge that you can-- we could do it from my computer here, blow off a collar somewhere in Gorongosa. And so you don't have to recapture it. There's a--you just have to put it down once to put the collar on, and then the collar drops off and sends out a radio signal, and you can use just VHF tracking to track it down.

[TARNITA:] And the animal survives.

[PRINGLE:] Yeah, it doesn't blow the head off. Yeah, it's just a very, very small little... But I don't know, Roland-- either of you guys have, yeah.

[SWANSON:] I was going to say I've got-- so in Serengeti, we have radio collars, VHF collars online. It's a bit old-school. They're not GPS. So the battery packs are a bit smaller, but we've had them on pretty much continuously for almost 50 years-- well, maybe 35 years for the radio collars. So we've been able to analyze demography. And we found absolutely no effect on lion survival of the radio collars between our collared lions and uncollared lions. But it does seem to be species-specific. So there are researchers who look at leopards who have been collared in parts of South Africa. And it looks like, in those cases-- especially when leopards are collared young, and the collars have to be put on tight enough so that they don't fall off, that can actually compromise their lifespan. So I think it's very species-specific.

[KAYS:] Yeah. I mean, this is always the first question we ask, if we were going to tag an animal, is, is it going to have an impact. Because if it is, then if it's a big impact, then we can't do it because it's not moral. And also, you're going to be collecting crap data if your device is affecting it. So generally, weight is the biggest concern, and attachment method is the second concern. And so when you're talking about these big mammals, weight's not as much of-- there's plenty of leeway there. Generally, people are sort of looking at 3% to 5%, and you were probably way under that for these big mammals. And attachment--so mammals that can wear collars: that generally works great, and it's generally not much of a problem. Something like an anteater, it's a lot trickier because they have no-- their head is smaller than their neck, and so you can't use a collar, so you've got to try-- we tried harnesses. We eventually just glued it on their butt, and it lasted for about three weeks.

[Laughter]

[KAYS:] Animals that fly are a whole other equation. And so this is always a concern. And this is part of why getting smaller tags is always better. And technology is getting smaller every day, which is great. So we're working on getting smaller, better technology. I'm prototyping now a GPS ear tag because this juvenile thing is a super-big problem. You can't give a collar to an animal that's still growing because--but this juvenile dispersal stage is the most important stage, where they go someplace else, and we don't know where it goes. So if we could get an ear tag to work, that would be really, really great.

[CARROLL:] Far left here.

[STUDENT:] Do you think that tourism has a detrimental effect on the animals in the parks?

[PRINGLE:] Me? Yeah, tourism--I mean, obviously, it depends a lot on the number of tourists and the rules that they're subjected to and how well they follow them. And so there are certainly places you could go, the Maasai Mara Reserve in southern Kenya, and while it's still got a lot of gorgeous wildlife and gorgeous habitats, there's been a lot of unethical off-road driving that has degraded the habitat quite a bit. So they can, certainly, have-- they're capable of having negative effects--littering. By and large, in terms of how do I conceive of ecotourism as a thing, I see it as beneficial, notwithstanding the potential for some negative impacts because I think without ecotourism, we're in deep, deep trouble in terms of tropical nature conservation. So we need to have it. And then the question is, how do

you do it responsibly in a way that doesn't degrade the habitat for the enjoyment of others and for the welfare of the organisms.

[KAYS:] We had a project in this area, the eMammal camera trap project, where we had volunteers setting cameras. And I mentioned the stratification idea. So we stratified them on trails, near trails, and off trails, to see if the people with who-- we counted the people using the trails to see if animals were avoiding the trails. And I showed you one example where bobcats in hunted areas avoided the trails that had the most people on it. But other than that, generally overall, we found relatively little impact. So it seems like in this area, I think the animals are just used to it. The animals that are still here-- bobcats--the habitat was much more important than the hikers for most of these species. So it's actually a good sign that you can go out and hike in your favorite park without being worried about that having an impact on animals.

[PRINGLE:] Ali, what's your Serengeti perspective on that?

[SWANSON:] It's pretty variable. I mean, for the most part, lions are incredibly habituated, just like you saw the images of lions lounging by the cars. But I think when there are females who are denning with young cubs, you can often sort of see signs of distress if they are being surrounded by tourism. And so I think it's really about responsible behavior, which is sometimes hard to encourage.

[STUDENT:] I was wondering how good of a representative is Gorongosa National Park of the entirety of the African savannas. You had mentioned a little bit about there being less predation there. So are your studies in that area-- do they give a good example of everywhere in Africa?

[PRINGLE:] That's a great question. And I would say the answer is-- well, probably not, in the sense that it's a kind of a unique, no-analog situation that's happening there. But at the same time, the exception or the kind of outlier can be a really ideal opportunity to test the general rule, you know what I mean? So there's been a major perturbation, a natural experiment, as Roland put it. And that creates an opportunity to test ideas. So yeah, the scarcity of predators, as I think I mentioned, is a big issue that I'm sure is having a big impact on the behavior. And one way that we're going to be able to gauge that is to see, as things recover, to what extent do the situations change. So I think it's really important to be monitoring it from this stage so that we have-- we have the baseline from the 1960s and '70s, and now we're building a new baseline for the kind of postwar, pre-full recovery state. And as things recover more, we'll have a longer time series. But I think more generally in ecology, you always have to be thinking about that. How representative is your study site, because there is a lot of variability. You can run the same experiment in two different places and get very different results. And the two savannas that I talk most about, Mpala in Kenya, and Gorongosa, are really incredibly different. One's a semi-arid, high altitude sort of bush thorn scrubland, and the other is... Gorongosa is very lush and green and more of a wetter savanna. We're also interested in that contrast. So the processes may not be representative. But in that case, we're interested in why not.

[TARNITA:] And I want to add to that that certain processes may be different, and you can contrast them. And certain processes we find to be quite similar. So some of the mechanisms underlying them, they may look a little bit different, the outcomes, but the mechanisms seem to be the same. So the termite work that I talked about with the spatial pattern created by the termites and then on the termite mounds getting this productive vegetation, we get exactly the same patterns in Kenya and in Mozambique, even though the actual vegetation on the mounds look strikingly different in the two places. In Kenya, you get mostly grasses everywhere. But they may be taller and greener grasses on the termite mounds: whereas in Mozambique, you saw you get these basically forested areas on the termite mound and grasses in between them. But the mechanism, the actual patterns, seem to be the same. And so it's very important to try to find those rules, that even though they're quite different places, still apply.

[CARROLL:] Time for just one more question. Eriko, in the back?

[STUDENT]: It seems to me that you would need a good deal of geospatial intelligence for tracking patterns, especially with the termite mounds. So what photogrammetric and remote sensing technologies would you be using for that? Like, LIDAR or...?

[TARNITA:] Yeah. That's a great question. We're trying to go at it from every angle, as I said. So sometimes, satellite imagery might be enough, and that's great. If it's as striking to see them as you saw in Mozambique, that's kind of easy. You see these green patches of trees that are sufficiently big that you can see them in satellite imagery. But the problem is that when we do that, we may miss the ones in Kenya that are covered by grasses everywhere. And so we don't see them as strikingly different, so then we use NDVI imagery that's picking up a frequency-- it's basically what's popping out is the greenest grass--so the one that's most productive, the one that's doing the best. Even though you otherwise would see a sea of grass everywhere, you see those patches where the grass is kind of most productive. But then you realize from that scale, we're actually missing certain patterns, like the patterns in between the termite mounds. And so there, we would use a helicopter. But that also might be too high, so you may use something like a drone, and we're starting to use drones in Kenya and in Mozambique. And then even the drones sometimes may actually fly too high, and we've used this very advanced technology of a fishing pole to walk around about 10 meters' height and take photos from that height because it was basically the only height from where we could actually accurately see this pattern that was happening on, like, a 20 centimeter scale. So we're trying to-- now that we've started to look at these patterns, we realize how many we've missed because we're not looking at them in the right way. And so we're trying to go-- LIDAR is a great example of technology that's been used. So yeah, any and all. And if you have any ideas, I'd love to hear about them.

[CARROLL:] We've actually reached the end of our time, but I want to turn it around and ask all of the students a question, which is after today, have we encouraged any aspiring ecologists here in the audience? How about hands, not just-- give us nods, but some hands. Do you think--have we stirred any hearts and minds here with all this? Because that's certainly one of the things that we look-- and look back there at the teachers.

[Laughter]

[KAYS:] And who wants to do a field trip to Gorongosa?

[TARNITA:] Who wants to do some math?

[Laughter]

[CARROLL:] There you go. If the buses could just turn towards Dulles, it's only about 24 hours of traveling away to Mozambique. But anyway, will you join me in thanking all of our guests again?

[Applause]