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Webinar Transcript

From Icefield to Ocean: Impacts of Glacier Change in Alaska

Speakers:
Shad O'Neel, USGS Alaska Science Center
Eran Hood, University of Alaska Southeast

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Ashley Fortune: Hello everyone from the U.S. Fish and Wildlife Service's National Conservation Training Center in Shepherdstown, West Virginia. My name is Ashley Fortune and I would like to welcome you to today's broadcast of the NCCWSC Climate Change Science and Management webinar series. This series is held in partnership with the U.S. Geological Survey's National Climate Change and Wildlife Science Center. Our speakers today are Shad O'Neel with the USGS Alaska Science Center and Eran Hood with the University of Alaska Southeast.

They will be presenting "From Icefield to Ocean: Impacts of Glacier Change in Alaska."

Before we introduce our speakers, I would like to remind you that all of your phones are currently on a global mute and it will continue to be so throughout the duration of the presentation. Shad will be presenting first, followed by Eran.

After the presentation, we will open up the conference for your questions and we will give you additional information at that time. Everyone, please join me in welcoming Dr. Shawn Carter, Senior Scientist at the USGS National Climate Change and Wildlife Science Center in Reston, Virginia. Shawn, welcome.

Shawn Carter: Thanks, Ashley. It's my pleasure to introduce our two speakers today in our webinar series. Dr. Shad O'Neel has worked as a research glaciologist at the USGS Alaska Science Center since 2008. He maintains a long term mass balance observation of two glaciers in Alaska, as well as continuing the long term record of observation and interpretation at the rapidly retreating Columbia Glacier.

His research focuses on mountain glaciers, in particular assessing the relative roles of ice dynamics and surface mass balance.

Dr. Eran Hood is an Associate Professor of Environmental Science at the University of Alaska Southeast. His research interests are in hydrology and aquatic biochemistry.

Much of his recent work is focused on improving our understanding of organic matter, nutrient dynamics in the glacial ecosystems and proglacial rivers along the Gulf of Alaska. Without further ado, I guess we'll turn it over to Shad. I'm looking forward to the talk. Thank you.

Ashley: Shad, just press *6 to un-mute your phone.

Shad O'Neel: Hello. Can you hear me now?

Ashley: Yes, we can hear you now.

Shad: OK. Great. We'll just jump right in, I guess, to the talk. This is work that has been going on for a couple years looking at how glaciers are changing in Alaska and trying to connect them into the whole ecosystem from the high alpine regions of the mountains all the way down into the nearshore environment of the ocean. The slides that we're going to show today really came together in a workshop that Eran and I hosted in Juno, March this year. This was funded by the Alaska Climate Science Center and USGS, University of Alaska Southeast, Alaska Coastal Rainforest Center and the North Pacific LCC. It brought together a really unique group of scientists and resource managers and agency managers into the same place for two days.

We worked on stitching the science together from both a scientific and a management perspective to try and better understand how the ecosystem is connected, especially across the terrestrial nearshore boundary which is managed quite separately and the managers never really considered the transboundary processes going from terrestrial landscape into the nearshore ecosystem. That was our goal to try to study this ecosystem or to conceptualize this ecosystem, but also from a glacier-centric viewpoint.

Looking at it like how are the glaciers, both the variability and the change in the glaciers, impacting this whole ecosystem? That's what our goal is to share with you today.

Here's an opening slide on our conceptual model of what we're trying to do in this research. Some of it I just said, but it's the physical and the ecological interaction. Looking at it from a physical science perspective, how the biology and the ecology is interacting with the ecosystem, from a glaciological perspective.

Forward-looking to enhance our understanding of how to address this ecosystem in the future. In part, that's because there's a lot of social and economic issues that revolve around this ecosystem, from fishing to tourism are the two primary ones.

I was at a forest service Chugach assessment for climate change recently. We were asked, "How many glaciers will the tourists be able to see from cruise ships in 30 years?" At first, I just laughed off that question as something that was unattainable, but it actually is a really important question.

There's a lot of dollars behind those tourists in the Alaskan economy. If they're not seeing the glaciers, if they don't get to see iceberg calving from the boat, they're probably not going to be paying the day rate, which is a couple hundred bucks, to go out and see Alaska. That's what they're here to see, so it's a really relevant question, as is projecting future salmon populations in the Gulf of Alaska. It's a big part of our economy.

That is sort of the motivation for this work, and to try and get the management and the science on the same table so that the scientists aren't wandering off into left field looking at things the managers could care less about. But also to get the managers on the same table, to say, "Well, this is where the science is at." And try and ask questions that are scaled appropriately for our current knowledge.

A little bit of background for those of you who don't know the Gulf of Alaska system.

I lost the pointer, but I can point for the people here, anyway. I can't. It's on the left side?

Ashley: It's on the right side.

Shad: The region that we're considering goes from Kodiak all the way down to Vancouver Island. The Gulf of Alaska, the coastal ecosystem, is very wet. Average annual precip is over two meters a year. It peaks in Prince William Sound, in the middle of it all, at over four meters a year water equivalency. Pretty wet, it's the perhumid temperate rainforest ecosystem. Ice cover in this region is 15 to 20 percent but the run-off from the glaciers is disproportionately large. It's about half of the run-off that's coming from the glaciers even though the glaciers are only about only 20 percent of the landscape. Right there, you're starting to see some impact, some way that glaciers are influencing the ecosystem.

There are also strong ice-ocean interactions that are then coupled into the ecology of the near-shore environment. Nutrients are delivered in the water. They help with primary productivity, which feeds the fish, and the birds, and us, eventually.

The ice is also coupled to ocean circulation, especially in Alaska, where there's coastal current. That stuff along the coast is a baroclinic current so it's driven by density differences between the fresh water coming in and the salt water already in the ocean. And then it's sort of controlled by wind, as well.

This map on the right-hand side shows where the glaciers are in Alaska. They're colored in blue. You see that the Gulf of Alaska coast is where the majority of ice in the state is. There's a lot of focus on the Arctic right now. You can see the glaciers in the Arctic up here, they're not that big.

Our goal in this research is to really bring and focus our attention on the coast range, which has not been studied as extensively as the Arctic, but it's where there's a lot more socioeconomic issues revolving around these glaciers.

What we'll try and do is take you from the glaciers today...

That's not working, bummer. Let me try this. OK. This worked a minute ago but it's not working.

We'll go through the glaciers to the stream, look at the geochemistry in the streams, and then how the geochemistry is impacting the ecology.

Ashley: You may need to put the pointer on...

Shad: The pointer on...?

Ashley: On the side...

Shad: And then push it? Oh, there's the laser. OK, yeah. So, from the glacier to the streams, look at the chemistry in the streams, make it down to the estuary where the animals that are at the core of the ecology are. That's sort of the overview of the talk.

A couple of motivating examples before we get into the details. The first one is just ice loss in Alaska. There are a lot of recent publications documenting sustained ice loss in Alaska. This is the Chugach Range here in Prince William Sound. Red colors indicate ice loss. Blue colors indicate overall mass change for these glaciers. This is Columbia Glacier here, rapidly retreating tidewater glacier. It's lost about 50 percent of its total volume in the past 35 years.

Right next door in the same climate is Harvard Glacier, which is slowly advancing and thickening in the same climate. Here's the Juneau Icefield where we have a similar story. This is Taku Glacier which has been thickening and advancing over the past several decades. It's changed what was once a fjord into a river system and then the rest of the glaciers in the Juneau Icefield, they're all thinning and losing mass and retreating over the past several centuries.

The take-home message is that Alaska is losing mass. It's among the fastest changing glacierized regions on Earth, but it's not all climate. There's a bunch of ice dynamics woven into that signal, and if we're going to make future projections, we have to understand not only the climate, but the ice dynamics, so that is ice flow and iceberg calving, those processes are substantial players in the ice loss story.

The second motivating example is regional runoff. Eran with Ed Neal spearheaded a study that came out in 2010 in GRL on just the importance of glaciers in the regional runoff. These numbers up here now just show several different large drainage basins. We'll compare southeast Alaska to the Yukon. The Yukon is about 5 times larger than the Mississippi River, about 20 times larger in aerial extent.

If we look at the runoff from these basins, 370 cubic kilometers a year from southeast Alaska in excess of the Yukon, and close to the Mississippi River, even though the areas are much, much smaller. Again, it's just a very wet place. Gulf of Alaska wide, about 870 cubic kilometers a year of runoff, about half of that is coming from the glaciers.

Here's an example of how tidewater glaciers are talking to the ocean. What we see happening is that the water from the open ocean comes up over these sills that protect the entrance to the fjord. It's salty so it sinks down to the bottom and that's basically dragged along the bottom of the fjords where it mixes with fresh cold water coming up from beneath the tidewater glaciers.

Then it rises finally to the top and melts the glacier as this process occurs, like a thermal pump that's happening. That process, we're finding more and more, is quite strong and can basically melt the ice as fast as it's delivered into these fjords. These glaciers tend to flow fast when they enter the fjords, so we're talking 15 to 20 meters a day of ice can be melted during the summer and fall months.

So, there is a really strong interaction. It is a two-way street, though, if you dump ice out into the fjord, you can change the circulation patterns and the thermal structure of the fjord, as well. They can both trigger unstable processes.

That's sort of what motivated our research and now we'll walk through these four different components of the ecosystem starting at the top with the glaciers. I'll talk about the glaciers and the stream flow and the oceans, and then Eran is going to talk about the geochemistry and the ecology.

One of the big pushes in glaciology right now is to try and come up with regional estimates of mass change. I'm just going to talk about how we're doing that.

The traditional way is through field measurements, where we just go directly onto the glacier and we measure mass change at a point and then extrapolate over the whole glacier surface. The way this is done is by putting stakes into the glacier and measuring height changes on the stakes through the seasons. In the winter snowfalls, the stake gets shorter and then in the summer, the snow and ice melt and it gets longer.

Then we need to know the density of the material, so we dig snow pits and calculate the density profiles in the snow pits. These are two famous time series in glaciology, from the Gulkana and Wolverine glaciers in Alaska. They're in two different climate regimes. Gulkana is in the Alaska Range, the cold continental climate regime. Wolverine in red is on the coast.

You can see these are cumulative glacier-wide mass balance time series. They started in the mid-1960s at zero and then you can see the predominant trend is mass loss. The curves are below zero. The glaciers are losing materials. The wide scale is a thickness of water averaged over the whole glacier surface.

To help you visualize it, so Gulkana has lost 25 meters by 2010 averaged over the whole glacier surface. Wolverine on the coast has only lost about 16 meters.

These black points are DM differences that we've done to sort of help ground truth these point measurements. What you can see is that in the interior, there's been a pretty monotonic decrease in mass, but that's been modulated on the coast in the 1980s, basically, where we had periods of mass gain and glacier growth.

Taking it from the traditional scale measurements, UAF has been championing a program of airborne laser altimetry. It's now a [inaudible] Lidar and this has low temporal resolution, but it gets into a lot more places. Instead of just having a few stakes on a couple of glaciers, we're now getting samples 500 meters wide at about 1 meter long flow spacing out of the airplane. You can get a plot like this where this is just for the Alaska region, so it spills over into Canada.

This is all the glaciers in Alaska from the airplane program and we see these course temporal changes of always losing mass since the program started, but accelerated mass loss in the early part of the first decade of the 2000s, then a slight rebound and now it's down again. That's the kind of information we can get out of the airplane.

Then there are remote sensing observations from space. I'll show some examples from the GRACE satellite, which is up here. These are two satellites and they have a high-precision laser that ranges between the two satellites. The precision is about the width of a human hair. As those satellites orbit the earth, they're attracted or repelled from each other depending on what the mass is below them. So when they fly over the ice, they get a little bit further apart, or they get pulled together. Then if the ice goes away, they get a little bit further apart.

From that, we can calculate time series of regional mass change of the glaciers. You have to do a lot of sophisticated modeling of terrestrial water storage, so groundwater exchanges, snow loading and unloading, stuff like that to get to this time series.

You can actually see the seasonal addition of snow and then removal during the summer in this plot. But the overall trend is one of mass loss going from 2003 to the present. We come up with the number of minus 66 plus or minus 5 gigatons a year, sort of arbitrary units. For non-glaciologists, I changed it into something more common. This is 26.5 million Olympic-sized swimming pools of ice every year. So, we're losing substantial amounts of ice from Alaska on an annual basis.

How do these methods stack up? Our goal right now is to try and integrate the field measurements with the air born measurements with the satellite measurements.

Here's a plot that shows for Wolverine Glacier, the annual balance is in the middle, winter balance, so this is snow accumulation, and down here is ice melt during the summertime, comparing the snow pit and stake measurements to the satellite observations.

This is a one-to-one line. If all the measurements fell on the one-to-one line, they'd be saying the same thing.

For Wolverine, it's on the coast where there's lots of ice around our little glacier that we measure, so the GRACE satellite is doing pretty well. You go up into the Alaska Range, the Brooks Range, where the ice-covered landscape is more sparse and it doesn't work so well yet.

We've also looked at comparing ICESat to GRACE. ICESat is a satellite laser ranger. Here are the tracks of ICESat over Alaska. Here's the comparison from 2003 to 2009 between ICESat and GRACE.

All these different measurements are starting to tell us the same story. We're starting to get a pretty good handle on how glaciers are changing in Alaska.

The next step in the system is to take the glacier change and try to understand how the runoff is making it into the streams and how the stream flows are affected by glacier change. This is a schematic from a paper by Jasson and others in 2003 that conceptualizes how we think the glaciers should respond to climate change.

You can think of a step-change in climate, the easiest is to think about climate warming, you would end up with a change in mass balance as a result of that. That would be smoothed out from the climate change. You change the temperature, the glacier takes a while to adjust.

Then we would expect there to be a pulse of runoff, a long term pulse in runoff associated with this net decrease in glacier volume. But then eventually, as the glacier reaches equilibrium, you'd expect runoff to go back to a lower state than it started at.

Why is it so complicated? Why can't we just tell you how much water is coming off the glaciers? It has to do a lot with the sub-glacial hydraulics. The way water is transferred through the glacier is complicated. On top of a lot of the glaciers, we've got snow and firn, firn is just old snow. That stuff is like a sponge, and the water gets stuck in the sponge and takes a while to move through that system.

Once it gets into the ice, there's a network of cracks and tubes and pipes, the plumbing system of the glacier. That stuff is impacted by the viscous properties of ice. During times when there's low pressure in those, the overburdened stress will close those pipes down. Then the pressure changes in the pipes. The system evolves through the annual cycle, going from a low volume, high pressure system in the spring to a high volume, low pressure system in the fall.

The transit times for a water particle change dramatically, depending on the geometry of the plumbing system. In the end, though, what we see if we look at the stream hydrographs is a picture like this. This is going from January through December and there's a bunch of river hydrographs here.

The ones on the bottom, those basins don't have glaciers in them. Snow melt dries and then there's decay and water flow through the basin as the summer goes on. But for the glacier systems, we see the same early season rise in snow melt. But then as the snow and ice continues to melt through the summer, we get a lot more flux through those basins and it continues later through the summer.

This is a pretty nonlinear system. About five percent of the basin becomes glacier ice and you see there's a really radical change in the hydrograph. It doesn't take much ice in the basin to get a strong shift in the hydrology.

Here's a plot that I've been putting together. It's the difference between the continental basin, the Alaska Range, a Switzerland kind of characteristic glaciers versus the coast. Red is Wolverine Glacier stream on the coast and blue is Gulkana Glacier stream in the interior.

What you see is a really similar ramp up in the spring. The median flows are shown. This is for all years that the stream gauge has been out. It's about 30 to 40 years of data and it's just averaged for all those years by day.

We see a really similar snow melt drive. Maximum variability in the interior comes in June and July. That's because the summer forcing is stronger there. But then for the coastal system, we see this rain dominated fall is really where the variability comes from the coast. That doesn't happen in the interior, where most of our intuition about how glaciers interact with stream flow comes from.

Trying to bring this science to the coast, we really have to change our perspective and start thinking about how precip really introduces the big variability in the coastal systems. Also, you can see that snowmelt and ice melt continues much later in the fall along the coast.

One of the goals right now is to try and be able to predict how runoff from glaciers is going to evolve over the next decades to a century for water resource management. To do this, this is all this. Each one of these circles represents a module that would have to go into a model to be able to predict runoff from the glacier. You not only need to know the total moisture going in, evapotranspiration, how much ice is melting, what kind of vegetation, and the snow accumulation and melt patterns on a spatial scale through the basin. You also have to be able to evolve the glacier over time and let the glacier geometry change in time.

Over decades, the footprints of glaciers and the vegetation changes associated with the changing footprints makes a substantial difference. This level of modeling isn't really available to us right now, but we're starting to get there.

The guys from UBC have set this up. This is the Columbia River at Mica Dam. The black here is data and then we have two different model ensembles that go out to 2100. The red is with a dynamic glacier and the blue is with a static glacier. The blue is sort of state of the art right now and red is experimental technology where the glacier geometry changes as we move forward in time.

You can see that there's divergence between the two curves, there's a downward trend in either curve. For that glacier system, we're over the crest of the long term hydrograph. We're starting to reduce water output from climate warming. But by the end, eighty years out or so, there's 30 to 40 percent difference between these two projections. If you're trying to manage a reservoir, that's a substantial difference and one that we'd rather not gamble so much on. This is the direction that we're moving with glacier stream flow modeling.

Quickly a few slides on the ocean. This is a beautiful satellite image and you can see all this fresh water coming out of the rivers in the Gulf of Alaska and making it into the ocean. That's going to be important, not only for the oceanography but for the geochemistry that Eran will talk about.

One of the big things that we're learning about the ocean is the inter-annual variability is high. It's probably in excess of the trends.

Here are some figures from Peter Winsor looking at the Seward line, which is a longstanding measurement line going into Prince William Sound, comparing two years: water temperature, salinity and nitrogen. You can see, especially for temperature, there's just really strong inter-annual variability in the ocean.

We're starting to get a lot better handle on what's happening in the ocean with new technologies, both these drifters, which are just cast overboard and then they drift around in the currents and make measurements for a long period of time, and then these autonomous vehicles. They tell us a lot. This is an experiment on the nearshore, so very shallow water.

You get an idea of how the temperature is varying. You can see the stratification. There's the salinity. Again, there's pretty strong horizontal stratification. For chlorophyll, you can start to see these little plankton blooms happening. The technology is enabling really rich data sets is the point of that slide.

One of the components of the ecosystem that is really poorly understood but quite important are the fjords in Alaska. The tidewater glaciers have their homes in the fjords. These are the glaciers that have these instabilities that can change glacier inputs to sea level rise and freshwater runoff very quickly. There's a lot of life living in the ocean and we're trying to understand how and why do you see seals, birds and whales and stuff in the fjords and how does the ocean talk to the glaciers, so both looking at the physics and the biology here.

This is a recent example from Icy Bay, where we did a bunch of CTD casts both at the entrance still and then all the way up towards Yahtse glacier.

I'm just going to summarize this plot. This is a temperature-salinity plot and you can basically fingerprint where the water is coming from. In this region, we know that the water is a mix of seawater and freshwater discharge from the glacier.

These waters are being sampled at depth. Down here in this region, you're bascially looking at seawater and ice melt only. That stuff is all sitting on the top. That provides evidence that the seawater is mixing with the discharge and melting the glacier and then exiting at the surface of the fjord.

The way that you look at the fluxes of this stuff, this is a summary melt flux curve here. We see that it peaks in September, which is probably later than you would expect. Summary melt rates at tidewater glaciers are substantial for about six months a year basically. We lose a lot of mass melting by bringing the warm ocean water in direct contact with the glacier.

This is leading us to figure out how to model the fjord circulation. Is it just a shallow circulation? Is it full depth circulation, or do we think it's somewhere in-between?

OK. I probably talked too long, so I'll turn it to Eran.

Eran Hood: Thanks, Shad. I'm going to talk a little about biogeochemistry and also ecology related to glacier systems. This first shot is a picture of me. It looks like I'm perched on the edge of a waterfall but actually it's not a dangerous spot, sampling the outflow of the Mendenhall

Glacier near Juneau. The purpose of this is that we've done a lot of work to try to understand what this unique biogeochemical signature of glacier systems is, because if we think about glaciers as an ecosystem, an ice-dominated ecosystem, they're very different from most structural ecosystems that have been better studied in terms of the biogeochemistry.

What we're fundamentally trying to understand is: this water that's coming out of glaciers, how is it different? How that's going to affect streams and aquatic ecosystems both in the freshwater and in the nearshore marine.

A little overview on glacier ecosystems. Most people don't think of glaciers as ecosystems. They think of them as static, frozen blocks of ice that are contributing water downstream, but actually, they're quite vibrant ecosystems.

From a biogeochemical perspective, some of the important characteristics are that they receive atmospheric deposition on the surface, so we can get nutrients and contaminants and other things that are deposited in the snow load on the glacier surface.

We have primary productivity and heterotrophic productivity, so there's a lot of microbial activity on the surface. I'll show some pictures of that. There's also a lot going on underneath the glacier. There's organic matter that's left from times when the glaciers receded back you get forests in organic soils growing up and then the glacier re-advances until you actually have organic matter underneath the glacier.

You have weathering processes going on. You have microbial communities, so there's a lot going on underneath that. Then in the region were we are, there's actually a lot of contribution from the side, so we get water and nutrients and things off of the hill slopes. We have these forested hill slopes. They're contributing water down in here.

All of that mixed together is the signature that we're getting out of the bottom of the glacier. Actually, that last picture where I was sampling the Mendenhall Glacier, now the terminus is right here. That waterfall I'm standing on is right on this cliff right there, so all of this is gone in the last six years or so that we've lost.

Ok, so just kind of a tour of some of the environments. What are we talking about in terms of environments here? Super glacial environment. The main environment is what are called these cryoconite holes. These are mineral deposits. There are a lot of algal materials, so it's this dark material that melts down into the glacier.

They're essentially little ponds and there are all kinds of algae and microbes that are living in this pond that are fixing carbon from the atmosphere. They're photosynthesizing. They're respiring carbon dioxide out. Then the products of that biota are being exported out of the ponds and streams, which eventually go into moulins underneath the glacier and are exported out.

In this super glacial environment, we're looking again, to measure a lot of atmospheric deposition of different things. We're also interested in better understanding these microbial habitats. How much activity is there? How are they modifying the inputs that are coming into the top of the glacier and then sending that to the sub-glacial environment?

The sub-glacial environments are actually a lot harder to study. This is kind of like an example. The glacier started to peel back here, and so you can see all this soil and sediment in the basal zone.

We now have a lot of work by Mark Skidmore and others that have looked through boreholes and things and sampled down to the bottom of the glacier. There are really a lot of microbial communities there. It's very microbially active, underneath the glacier.

It's hard to study, but what we know is that the inputs that are coming in from the top are being modified at the bottom of the glacier before they come out. Understanding these processes of, well, what are the inputs from the super glacial and then how are they modified? Underneath the glacier, it's going to tell us a lot about what's coming out of the glacier.

That signature that we get that's being exported to the rivers and the nearshore downstream is definitely being impacted by the residence time and these biogeochemical processes that are going on underneath glaciers.

If we go downstream from the glacier, we can start looking at some simple examples of the physical impact of runoff from glaciers. This example right here is showing a series of watersheds in southeast Alaska. This is the percentage of the watershed that's covered by glaciers; so a watershed with no glacier to one that's half-covered, to completely glacial-dominated.

If we look at just the temperature signature of the water, we can see in the non-glacial or low-glacial streams, they warm up a lot during the summer. In the glacial streams in contrast, the peak temperature is in late May or early June. Then all summer, they get colder because the glacier turns on. We have a really strong dichotomy in terms of the temperature. That's important because temperature obviously influences metabolism of organisms and aquatic ecosystems.

We can even actually see some very subtle diversions. This is in August right here. This watershed has some glaciers up at the head waters. We had a warm period of a week and you could see the stream with no glacier warms up a couple of degrees. Well, this one with just a little bit of glacier cover actually got colder and stream flow came up during that period. Glaciers can really buffer both the temperature and the runoff in these streams.

This is another example of turbidity here (water's clarity or light penetration). We see the opposite, so this is on a log scale. Basically, the streams that have no or little glacier coverage have relatively clear water. Then we have a lot of glacial flour being delivered into the water, so there's a lot of turbidity. It's highly variable because the release of this glacial flour isn't necessarily correlated directly with discharge like you see in non-glacial rivers. Just a sense of how the physical structure of these rivers that are impacted by glaciers is very different.

What about biodiversity? If we look at the rivers that are down in front of the glaciers here, this is a recent paper that was published. The point was to look at the impact of glaciers on taxonomic richness in glacial rivers.

What they found is, and they looked at streams in Alaska, the Andes, and in the Alps. In all these cases, if you're heavily glacierized...This GCC is the glacial coverage in the catchment. If your watershed is dominated by glaciers, you have pretty low richness because it's a very cold, very turbid, very harsh environment, so there's only a certain type of organisms that can live there.

As the glaciers become a smaller part of the watershed, the richness increases and it actually peaks somewhere about 5 to 30 percent glacial coverage. Then it goes back down again when you lose the glaciers completely. This tells us that in terms of both the physical and the biogeochemical structure of the system, that having some glacier in there contributes the heterogeneity that adds some richness to these glacier systems.

Organic carbon is something that we don't usually associate with glaciers. We usually associate organic carbon with wetlands and organic soils. This is essentially if you make tea, that's organic carbon. It's very important for heterotrophic microbes because that's the energy source for them.

It turns out that when we've looked at glacier ecosystems, they're actually pumping out a lot of organic carbon to downstream systems. That's eventfully going to be put forward up into the higher trophic levels.

By sampling these glacier rivers, what we can do is look at the concentrations of organic carbon that's coming out. We can look at the stream flow. We multiply that together and we get a mass export.

For example, for the Mendenhall Glacier here, it's exporting about 12 to 18 kilograms of carbon per hectare of glacier area per year, which probably doesn't mean a lot to you in terms of an absolute number. Just for the sake of comparison, if we look at the boreal forests, and we compare the carbon export from a whole bunch of watersheds, which is another northern ecosystem, it's somewhere on the order of 22 to 86 kilograms per carbon per hectare per year.

The take-home message there is that if you looked at this ecosystem and you looked at this ecosystem, you would say, "Well, there's a ton more carbon in here coming out there." But, per unit area, a glacier is actually about at the low-end of what you get from a boreal forest ecosystem.

The primary reason for that is that the water fluxes from glaciers are so much higher that even with a low concentration of carbon, you can actually push out a reasonable amount of mass flux. The other critical point here is that because the carbon here is not plant-derived, it's actually much more biologically available to heterotrophic microbes.

When we've done experiments where we incubate and we feed the carbon from these kind of watersheds and these kinds of watersheds to microbes, they'll readily metabolize the carbon coming out of the glacial watershed a much larger percentage of it because they're less structurally complex molecules that aren't really plant-derived.

Glaciers are also an important source of iron. This slide is from work done by John Crusius and Andrew Schroth along mostly in the Copper River area. Basically, the iron is important in terms of limiting micronutrients in marine environments, so we can get iron from glaciers directly in this glacial flour. In this plume, we have dissolved and colloidal and particulate forms of iron.

We can also get cases where we have re-suspended glacial flours. As storms come in, the glacial flours settle out, you resuspend it, and you could dissolve iron from there.

Then another example is from dust storms. There are all these areas that have been deglaciated where there are a lot of glacial flours sitting around. There's not much vegetation. When we get the strong outflow winds that can push all this dust out into the ocean and then that's also acting as the source of iron.

Why is iron important? In this case, it's important because in this nearshore region what we have are these high nitrogen/low chlorophyll waters and they're basically mixing in here.

Then when we get these iron inputs, we can get very high primary productivity. You could see these plumes of plankton, so that's an important input in terms of the glacial water that's coming in.

Here's a shot of that there. You can see all this chlorophyll phytoplankton production here in these kind of nearshore regions.

Ultimately, there's a pretty strong correlation between chlorophyll a concentration and resident fish yields. Basically, it's just a metric of productivity in these systems and iron can play an important role in that productivity.

There's also potentially bad news to look at and that is how our glacier ecosystems are responding to inputs of contaminants. There's the Grim Reaper right there.

There's been a number of studies recently that are starting to look at this idea that glaciers are more of flow through systems compared to forested and other terrestrial systems, because they don't have soils and other places to stabilize contaminants.

Here's POPs (Persistant Organic Pollutants) from glaciers and then DDT in the Antarctic ecosystem from glaciers. The point being that some of those contaminants that are being transported up to these higher latitude areas can get onto the glaciers and then be coming out of the bottom of the glaciers.

We also need to look at the glacier dynamics that are important. This is a profile shot of a glacier. The basic idea is: depending where you're depositing stuff on the glacier surface, if you deposit it up at the highest elevation, the flow line will be longer and so it might take 100 years for it to get through the whole system.

If you deposit material down near the equilibrium line, it might have a shorter flow path and be coming up to the surface after only 25 years. There are actually cases that they've seen in Europe where the equilibrium line changes and the contaminants that are deposited are leapfrogging each other.

Because, if you deposit contaminants up here, they're going to be sitting in the glacier and not come out for a long time, whereas, if you deposit them down here, they have a much shorter transit time.

The upshot of this is looking at sediment cores in lakes. This dark line down here, which I've circled in red, is a lake that has a glacier above it. You see during the 50s and 60s that there was a high level of contaminates going into the sediments and all these things.

They have pollution controls and then everything comes back down. Then we have this delay. Then all of a sudden, in the glacier fed lake, we see the contaminants going up again in the soils.

That's basically reflecting the transit time through the glacier. Glaciers have this memory that allows them to store the contaminants and release them at a later time period, so that's something we need to think about.

In terms of Alaska and the Gulf of Alaska in general, one of the interesting points that we're looking at now a lot is mercury. There's reason to believe, if you look at these atmospheric transport models, that China is the biggest emitter of mercury and a lot of the plume ends up coming over in our direction.

We're starting to look at the deposition of that on glaciers and the extent to which that is coming out the bottom of these glaciers. I wouldn't say it's high, but it's also not insubstantial, from looking at the initial results we have in terms of mercury from glacier outflows.

Hopefully, I've convinced you that runoff from glaciers is unique among terrestrial ecosystems. It has very bioavailable organic matter at higher levels than you would think.

There are nutrients like phosphorous, which I really didn't talk much about. It's a rock-derived element, so you can get actually reasonable phosphorous fluxes simply because of the mechanical weathering that goes on with glaciers.

Micronutrients such as iron and then we're also looking more at contaminants. The upshot of this is that the signal that comes out of glacial water is biogeochemically very unique compared to water from forested ecosystems or other type of terrestrial ecosystems.

Ecology, I'll start by saying I'm not an ecologist but I have some slides. Here's a nice breaching whale.

We are trying to link down because that's ultimately the question, right? If the biogeochemistry of these things is different, how is that impacting ecology downstream? This is work that was done by Yumi Arimitsu, who's at USGS and UAF, in Glacier Bay. It's looking at the zooplankton and euphausiids, which is basically krill and plankton. Surprisingly, from these surveys that they've done in the Bay, they see very high concentrations.

This is the upper Bay right here that's completely glacial dominated. If you look at a picture of Glacier Bay, it's green down here. The glaciers have retreated all the way up the Bay. It's the end of the life age.

There's still tidewater or near tidewater glaciers at the headwaters of the Bay. Despite the fact that it's dominated by the dark turbid cold water, there are very high concentrations of some of these zooplankton up here. Obviously, there's something in this system that the biota are thriving on.

There has also been a lot of work done on sea birds. Basically, what Shad talked about in terms of that circulation that goes on in these fjords in that upwelling is very important, because the submarine glacier discharge at the tidewater glaciers such as discharging underneath and then resulting in the upwelling.

You have the mixing. There's mortality of zooplankton by the osmotic shock from the freshwater, so that stuff is all coming up to the surface. You see very high bird populations at the face of these tidewater glaciers again, an ecological impact of these glacier systems.

Harbor seals are another example. Harbor seals have very high fidelity to glacier habitat. They provide refuge from predation both in terms of them being able to haul out and also acoustically.

Apparently, all the noise from the icebergs moving around and calving and stuff like that actually interferes with the acoustics of Orcas that are trying to hunt for the seals, so that they do better.

And these are also very important for pupping in terms of seal habitat. So, understanding how iceberg calving dynamics are influencing habitat for seals.

Then if we think about the ecological patterns, there are actually some very unique patterns that people are seeing. This is, I'm going to say it's a candlefish because that's my memory, which is basically a forage fish.

The normal routine for these is that they come up to shallower depths at night and then they migrate down deeper during the day. But what they see in the glacier systems is that there's so little light penetration that they actually just stay near the surface, closer to the surface all the time.

Some of the tows that they're doing, that might be why they're getting higher abundances. It's because the stuff that normally photo migrates by the photo period is just staying up near the surface because there's not as much light.

It also gets to the question of, in terms of the structure of the food web, how is it different? Here's the standard structure. We have the high phytoplankton production, which is grazed on by zooplankton, then consumed by forage fish, and then on up the chain.

Here, if we go to the glacier ecosystem, we don't have much light availability in those glacier-dominated fjords because of all the glacial flour. Phytoplankton production is actually very low, but there's still a high abundance of zooplankton.

We're doing work right now to try to understand what is supporting that part of it. It could be heterotrophic productivity because of all the bioavailable carbon coming out of the glaciers, but we really don't know.

We do know that we can have high concentrations of zooplankton and forage fish even though right near the glaciers the amount of phytoplankton production is actually relatively pretty low.

To summarize what we've showed you here, basically as Shad pointed out in the beginning, we're really trying to think of this icefield to ocean ecosystem in a more comprehensive, holistic way.

If we start up at the top, we have climate drivers which are influencing the glacier volume dynamics. That's influencing the amount of flow. The hydrology is changed and not only the hydrology, the biogeochemistry, because it's a unique biogeochemistry that comes into these nearshore marine systems and it influences the circulation in terms of these density-driven coastal currents.

Also, both the physical changes in terms of the currents and also the biogeochemistry can have influence on productivity and marine ecosystems. Then if we go to the tidewater glaciers,

We have this feedbacks between the glaciers and the ocean, right, talking to each other, and so the dynamics of ice loss in these systems is a result of these ice/ocean feedbacks.

There are the calving glaciers. Those provide habitat for other organisms, and then, ultimately we have all these socioeconomic concerns as well in terms of tourism and things like that. Shad gave that example of how many glaciers are we going to be able to see. Well, that is actually an important question that we need to be thinking about.

All right, so thinking about the glacier influence on the ecosystem, glaciers are vibrant ecosystems. We don't think of them that way. We think of a forest as a vibrant ecosystem, but actually glaciers have relatively high productivity for what they are. They have a really pronounced influence on streamflow volumes, seasonality, and variability. They can supply a sort of unique suite nutrients to downstream, either freshwater or marine, ecosystems.

The Alaska coastal current, again, is driven by freshwater because it's a density-driven current. Ultimately, what we need to better understand is how our freshwater and marine food web is being influenced by glaciers. So, if you go back to that slide that Shad had of glacier runoff over the next 100 years, depending where you are you're going to have more glacier runoff or you're going to have less glacier runoff, and there's this tipping point.

Some areas we're going to see an increase in runoff in the coming decade. Some areas that have already gone over that tipping point, we're going to see a decrease. But either way, if we understand better how the glacier runoff is tied into these downstream food webs, we'll be able to make some better predictions.

Finally, glacier change is going to have economic impacts on fisheries, and hydropower, and tourism, certainly, and so, again, trying to think about this in a more holistic way I think is going to be much more productive than everyone studying their little piece of the puzzle in isolation.

All right, and with that, I think we're finished. I'd be happy to take any question, or Shad would as well.

Ashley: Excellent. Thank you. Shad or Eran, could you please bring us back to the screen where we can see the participant list and the chat box by pressing the stop button?

Shawn: Yes. Did that work?

Ashley: Could you do it one more time? [laughter]

Shawn: I can see all the panelists, or participants. Is that...?

Ashley: OK. Maybe mine just didn't go back. To our participants, if you're not there with the participants and the chat box, bring yourself back by clicking the return button, the big blue button there. It looks like it worked for many people in the chat box. They're letting me know. Thank you very much. All right. We're going to open up the conference to questions. To ask your question, if you could please select the raise hand icon that is located between the participant list and the chat box, I will call on you by name when it's time to ask your question. Please note that we do have a global mute on so you'll have to un-mute your own phone and then press star six to remove the global mute.

Also, you can text chat your questions. Just type them into the chat box, and I'll read them aloud to get them into the audio record.

So thank you, again, Shad and Eran, for your presentation. Our first question will be from Bruce Marcot, and he says, "In the graph of the indexed taxon richness, biodiversity versus percent glaciation, what taxa were included?"

Eran: I don't actually know specific taxa, unfortunately. You'd have to look at...I'd be happy to send you the paper -- my contact information is here -- because I didn't do that study. It was all macroinvertebrates, and beyond that, I couldn't tell you exactly what taxa they were looking at. I'd have to go back and look at the paper.

Ashley: OK, thank you. Are there any more questions?

Eran: We have a local question. Is that ok?

Ashley: That's perfect. Go ahead.

Woman 2: How do you know that your zooplankton production is actually localized there at the face of the glacier and not just that it's entrained up the fjord and they're really zooplankton that are dependent on chlorophyll from other areas, and then the current that you're talking about just bringing them to that location?

Eran: Another hard question. Shad?

Shad: They’d have to be coming in at the bottom.

Eran: Yeah, that's the one thing, they'd have to be coming in the bottom of the fjord and then up to the top.

Woman 2: But there are zooplankton that are deeper depths, yeah, and they vertically migrate so they could get swept, when they are down at that during the day.

Eran: Yeah, and, you know, I actually...I don't know. They're not seeing it at other places so it would have to be stuff that was at deeper depths that was coming up there, but they're doing vertical sampling at other places as well, and they're not seeing it. So there would have to be a reason why or a mechanism by which it became concentrated there relative to the other places that it was coming from, because I mean it looks like they're just sampling, and basically there's a big grid that they're sampling there.

Woman 2: Great.

Eran: ...and not picking up in the most of the places. So it would have to...

Woman 2: So we see the same thing with fronts on the ocean where it might not be that everything is produced right there, but it's definitely concentrated as a hot spot so it could act just like a front.

Shad: But it's still the end result is the same. There's food available there so...

Woman 2: Right, but that would make sense why you don't have many phytoplankton, but you do have a lot of zooplankton.

Eran: It wouldn't be...yeah, in terms of the phytoplankton food production, it would be another solution to the problem.

Woman 2: Yeah, and it doesn't matter to the fish, right, if they just want the zooplankton.

Eran: Yeah. How about a non-ecology question? [laughter]

Woman 2: I don't have any of those...

Eran: We have another local question.

Ashley: OK.

Woman 3: I mean it's actually more of a nuts and bolts question. When you're talking about the mercury and the iron and the phosphorus, do you have ways to trace where they're coming from so that you know they're coming from the glacier versus other sources, and how far have you traced that like into the nearshore or into the streams that you're looking at?

Eran: Well, most of the work that we've done thus far has sort of ended at saltwater because I don't usually do...so we're basically looking at river fluxes, and the way that we've done it is to look at gradients and glacier coverage, and so that allows us to say, OK, this stream, which has no glacier but is the next watershed over, so it's receiving the same amount of precipitation, the elevation range is similar, that sort of thing. I mean, you obviously can't control all the differences, but you can start to see if it's on the same type of bedrock, the same basic ecosystem, what the differences are.

Another thing that we're doing is sampling, actually, the inputs to the glacier and then the direct output to the glacier, and then down at the river. So we can't entirely control for those things, but much more in the glacier system, we're trying to sample all the pieces and say, OK, what's going in, what do we see in the super glacial streams, and then what's coming out the bottom, and also using a lot more isotopic tracers recently to try to sort of identify things in terms of the unique isotropic signatures.

Woman 3: We're trying to stay away from the ecology, but really my interest is how could you trace that carbon into...?

Eran: Well, actually, the main thing that I didn't talk about is that the carbon from the glacier ecosystems have an ancient C-14 age, which is a really unique tracer and what's not clear right now entirely...so the carbon is actually very old. If you carbon date it, the carbon age is thousands of years old, but yet it's highly bioavailable, which is exactly backwards from what you'd expect, because in most rivers, if the carbon is old it's because nothing wanted to metabolize it, and so it's what's left over. So we have this sort of paradox with glacier rivers. What's not clear is that if there's a small percentage of it that's making the bulk age old, or if it's a large percentage of it is old and bioavailable. We're actually doing a lot of food web sampling now to see if we can see that signature in the food web, and I sort of doubt that we will, in a way, but I don't know, and so that's one tracer that we're looking at right now.

Woman 3: Thanks.

Woman 4: Hey, I have a question.

Eran: OK.

Woman 4: Hello, this is Becky in Talkeetna, Alaska, and I turned into this very, very interesting reports on the glacier because I'm with the Coalition for Susitna Dam Alternatives, and we are looking at the studies that they're doing on the glacier runoffs into the proposed Susitna Dam Reservoir. My question to you is, do you know of any project, or any examples you could point me to where what's happening with the glaciers is having some impacts on current hydropower projects? Thank you.

Eran: There's a group that's funded by the state that's starting to study the Susitna Glacier a little bit, but that's the only thing that I'm aware of that's directly investigating the Susitna for hydropower.

Woman 4: There's not like any other hydropower systems that are where the reservoirs are driven by glaciers, glacier fed systems, that you know of that are starting to have some serious concerns with the impacts?

Eran: There's a lot in Europe and Scandinavia. There's a big concern there in terms of hydropower. I actually went to a glacier conference in Europe, and there was a huge number of employees of hydropower companies at this conference, which I didn't understand at first, but that's a big concern there. But the real question that you're getting at is where are you on that curve, because in some areas if you lose volume you're increasing generation capacity for some period of time, and then eventually your generation capacity is going to go down once you cross the tipping point. But I'd look to Scandinavia and Europe, because they have a lot of glacierized regions that are hydropower producing.

Woman 4: Thank you very much - very interesting discussion. I learned a lot, especially about the biochemistry, etc., etc., of coming out of the glacier systems -- very interesting.

Eran: Thank you.

Ashley: Thank you, and I noticed that some people are signing off, so if you'd like to listen to the recorded version of this, it'll be posted in one to two weeks, and that link is on the announcement that you received. But we do have some more questions.

Eran: A lot have backed up heavily on the questions of ecology.

Ashley: [laughs]

Eran: It's all about phytoplankton, which is unfortunate. [laughter]

Woman 2: Where's Yumi when you need her…

Eran: Is the lack of phytoplankton at the base of the food web in fjords unique in ocean systems or are there other examples? There's probably someone in this room who could answer that question for me.

Woman 2: Hydrothermal vents?

Eran: Yeah, from what I understand, again, most of this work...if you're interested in the whole phytoplankton, zooplankton, Yumi Arimitsu, who's at USGS and UAF, all that work is her Ph.D. thesis, and so she would be a much better person to ask, and anyone is welcome to email me, and I could put you in contact with her, because I don't know the answer to that question. I would say I would think it was unique, but I don't know for sure.

Woman 2: Well, there's chemosynthesis down in depths in the ocean at the benthic level, but...

Eran: That's a pretty unique specialized case as well.

Woman 2: Right.

Woman 3: Actually some upwelling systems can have really low phytoplankton just because it's constantly getting pulled offshore so like...

Eran: Oh, OK.

Woman 3: ...on the nearshore coast of California they can be really low, because it's constantly being...

Eran: You don't see it, yeah.

Woman 3: Yeah. So there's a difference between like standing stock versus how fast it's turning over.

Eran: Oh, OK. So there's another phytoplankton question here. We missed why it is that it makes sense that there would be less phytoplankton close to the glaciers.

Shad: There's just no light penetration in the water there.

Eran: Yeah, so the lack of phytoplankton is light penetration. What else are they feeding on? And that was the question we were debating here is we don't know, or maybe they're being imported from somewhere else. Maybe they're feeding on phytoplankton somewhere else and being carried in, or there's something else like heterotrophic productivity that's at least in part sustaining them. OK. Let's see. For the Gulf of Alaska area, is there an average glacier recession rate or mass balance loss rate, and if you could project forward, what would the area look like 30 years from now? I'll let Shad...

Shad: So the average rate is 26.5 million Olympic size swimming pools per year, and projecting forward is complicated because of the changes in ice dynamics. So, going 30 years forward we expect glaciers to be thinner. Some of the glaciers have smaller footprints, and there will probably be more late calving glaciers, but in terms of the tidewater glaciers getting...projecting a mass loss rate is complex because we don't have a handle on the rapid changes possible from the tidewater glaciers. But I would say that right now there are 12 glaciers in Alaska that are advancing. One hundred percent of those are tidewater glaciers, and I would speculate that we'll see a decrease in the number of advancing glaciers and an increase in the number of retreating glaciers.

Eran: Well, I mean, 12 out of how many?

Shad: Twelve out of a quarter million.

Eran: Yeah, yeah. It's a low number anyway. But they're big glaciers, some of them.

Shad: Right. I don't see any other staff questions.

Ashley: We do have one from Susan Walker. In your hydrograph of receding glaciers which shows an increase in stream flow and then tapering until equilibrium, can you discuss where on the hydrograph Alaska interior glaciers are currently, such as the Vulcan -- did you guys just answer this?

Shad: I don't think we really know yet. There's not a continuous stream flow record for any of those rivers so it's really hard to pin that down.

Eran: Yeah, as a very general rule of thumb, if the glacierized area of your watershed is above 10 percent, there's a good chance that you're still going on the upward side of that, and then as you get below 10 percent and then eventually lose the glacier you're definitely going to have a lower water yield. So certainly, some of the heavily glacierized systems are really going to be going up in stream flow for a while, but in areas where you have a lot of small cirque glaciers and things like that, you might already be on the back end. But it's really watershed specific so that rule of thumb I'm giving is just sort of a way to conceptualize it and take a guess about where you might be.

Shad: Is there another...

Ashley: Yes, we have another one from Bruce Marcot.

Eran: Are you tracking elevation changes upslope in the ablation zone? If so, what are the trends?

Shad: Yeah, we're getting better at measuring thickness change of glaciers over large regions. That's basically how the altimetry program on the iSat satellites work. The trends are predominantly thinning except for surging glaciers and the 12 advancing glaciers. The rate increased in the late 1980s and has been fairly sustained since then, and then there are a substantial number of outliers which are the calving glaciers, which can be thinning over an order of magnitude faster than a terrestrial glacier, and those are sort of the big picture trends for thickness changes.

Ashley: OK. Thank you. I am not seeing any more questions. Shawn or Holly, do you have any closing remarks?

Shawn: Nothing except thank you for a really informative and wonderful set of talks. Really appreciate it.

Shad: Yeah, thank you.

Ashley: Thank you again to Holly, Shawn, Shad, and Eran. I'd like to just announce that our next webinar is going to be on May 9th at 2:30 p.m. eastern, and this is the second part of the series. Yin-Phan Tsang and Damon Kruger, both post-doctoral researchers at Michigan State University and Bill Herb, a post-doctoral researcher at the University of Minnesota in Duluth will be presenting on “Fish Habitat and Climate Change, A Coarse Scale National Assessment with Finer Scale Assessments of Midwestern Streams and Lakes”.

So, please watch for an announcement. Again, that will be on May 9th at 2:30, and Holly will be sending you all the link once this webinar is edited, captioned, and posted to their website. Thank you all again for your attendance.

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