Melting Alpine Glaciers in the Rocky Mountains: Impacts on Ecosystems, Agriculture, and Economics

by Kevin Moss, 2014-15 State of the Rockies Project Student Researcher

Climate change is affecting Western landscapes in many ways, from the subtle to exceedingly obvious. One of the clearest examples is the rapidly shrinking glaciers in Wyoming and Montana. This past year, Rockies Project Student Researcher Kevin Moss investigated how the melting glaciers in the Wind River Range and Glacier National Park are affecting humans, species, and ecosystems. By corroborating scholarly articles with in-person interviews, he came to fully appreciate how crucial glacial meltwater is to the health of ecosystems and society alike.

Introduction

Global climate change is an international problem with a vast array of effects, such as increasing temperatures, rising sea level, and changing weather patterns (IPCC, 2014). One of the earliest visible aspects of evident global climate change was that of melting glaciers. This is of obvious concern given the implications for sea level rise and reduced global albedo (a measure of the Earth's reflectivity). When most people think of glaciers, they imagine large, continental glaciers, such as those found at the poles. These continental glaciers are a crucial aspect of global climate given their size and reflective capacity. That being said, continental glaciers do not tend to impact people's lives on a day-to-day basis since so few people live near them. Alpine glaciers, on the other hand, are crucial for communities and landscapes across the world (Carey, 2010).

Alpine glaciers are much smaller than the continental glaciers that are found at the high latitudes, yet these mountain glaciers are more relevant to most societies since we rely on their meltwaters for drinking water, agriculture, and ecological health. Furthermore, as precipitation patterns change and snowmelt disappears earlier in the year, glaciers become even more crucial as a bank of water for regions that rely on mountain meltwater for drinking and irrigation. In the Himalayas' watersheds, billions of people depend on the late summer flows that glaciers provide. Scientists and locals are very concerned about how to manage a diminishing supply of water with a growing population. There is also concern over already obvious ecological changes as regions of the alpine steppe transition to an alpine desert environment (Xu et al., 2009). This extensive study of the Himalayan glaciers by Xu and colleagues (2009) provides valuable insight into the melting glaciers of the Rocky Mountains.

Historically, water supply problems determined the fate of societies and civilizations. Seasonal and annual fluctuations in precipitation could force societies to move, or even cause their ultimate demise. However, with dams and irrigation canals, humans have increased their water security and can even live in areas devoid of water (think of Las Vegas, Nevada). Even with this technology, however, changes in water availability still significantly impact societies. Droughts have long ravaged the American West, and melting glaciers represent a new chapter in the history of Western water challenges. The melting glaciers in the Rocky Mountains will by no means doom Western society, but consequences for agriculture, landscapes, and communities may be severe.

Glaciers in the Rocky Mountains

Though glaciers are still present in the American Rockies, they are disappearing at an alarming rate. Glacier National Park may soon be a misnomer because only 25 glaciers remain of the original 150 that were present in 1850. Furthermore, it has been predicted that all the glaciers within the park will disappear by 2030 (Hall and Fagre, 2003). This trend is replicated in the Wind River Range in Wyoming, where 63 of the 80 glaciers in Wyoming are located (Cheesbrough et al., 2009). Between 1985 and 2005, glacier area decreased 25% in the Wind River Range (Cheesbrough et al., 2009). This melting rate is only slated to increase as the planet continues to warm and as the glaciers shrink by reducing the albedo of the landscape and warming the local environment. These two distinct alpine environments, Glacier National Park and the Wind River Range, highlight the severity of the problems associated with melting glaciers in the Rocky Mountain region, but for different reasons. Glacial melt from Glacier National Park is not tied to agriculture in the region, but is vital for supporting ecosystems. The glacial melt plays a crucial function by regulating stream temperatures for alpine macroinvertebrates and migratory trout species, while also providing water for small streams in the late summer (Pederson et al., 2010). Furthermore, the glaciers in Glacier National Park are some of the only easily

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accessible and viewable glaciers in the country, thereby serving a key educational and aesthetic role for citizens. They also serve as visual and visceral symbols of climate change in a time when the climate change conversation is seemingly polarized among the American public. On the other hand, glacial melt from the Wind River Range is important for local agriculture and ranching, especially in low snowpack and hotter than average years.

The aesthetic beauty of glaciers in Glacier National Park is a key driver for Montana's economy. The Rocky Mountain Climate Organization and the National Resources Defense Council collaborated on a report about the various impacts of climate change in Glacier National Park (Saunders et al., 2010). The report focuses on impacts to species and resources, but also includes a review of the economic importance of Glacier National Park. Two million visitors come to Glacier National Park every year, three quarters of whom are from out of state (Saunders et al., 2010). These visitors contribute $160 million to Glacier National Park per year and support over 4,000 jobs (Saunders et al., 2010).[1] Furthermore, in 2008, out-of-state visitors contributed $3 billion per year to Montana's economy, and 29% of those visitors cited Glacier National Park as their reason for visiting Montana (Saunders et al., 2010).

Given that the landscapes of Glacier National Park are rapidly changing with climate change, some are worrying about a drop in tourism due to the potential decrease in aesthetic appeal. A survey conducted in Waterton Lakes National Park, located adjacent to Glacier National Park in Canada, predicts a decrease in tourism due to climate change. In the most severe climate change scenario for Waterton Lakes National Park, highlighted by the loss of all 30 of the glaciers found in the park, 19% of visitors responded that they would not visit the park again and 38% responded that they would visit less often (Saunders et al., 2010). A similar decrease in tourism in Glacier National Park is entirely plausible. Given that Glacier National Park is expected to be devoid of glaciers by 2030, the economic impacts of the melting glaciers could be immediate and immense (Hall and Fagre, 2003). It is clear that a direct study of the economic impacts of the melting glaciers is needed for Glacier National Park. Fortunately, studies of the ecological impacts of the melting glaciers are more prevalent.

Endangered Species as Ecological Indicators of a Changing Climate

Studies of the melting glaciers in the Rocky Mountains have been common in Glacier National Park, given its pristine nature and the name of the park itself. These various investigations show that many species and the overall functioning of various ecosystems within and around the park are inextricably tied to glacial melt. One of the most extensive projects is related to the native bull trout, *Salvelinus confluentus*, a threatened species under the Endangered Species Act. Bull trout are found across the Northwest in different river basins, but are struggling due to the effects of invasive species, habitat fragmentation, and climate change. The same is true in the Flathead watershed, which includes flows from the west side of Glacier National Park. The bull trout habitat within the park is especially important because "approximately one-third of the nation's bull trout populations inhabiting natural, undammed lake systems are found in the park" (National Park Service, 2013). Bull trout play a crucial ecological role in the Flathead Watershed by functioning as the top native aquatic predator, so their protection is of the utmost importance. Bull trout in the Flathead Watershed are migratory, meaning that they move to spawn in a stream other than where they normally live. Flathead Lake, the largest freshwater lake west of the Mississippi River in the continental United States, serves as home for many bull trout while many of the alpine streams of Glacier National Park serve as spawning territory. These alpine streams are fed by a combination of snowmelt, glacial melt, and spring water. Bull trout also require a narrow range of temperatures for successful spawning. It has been shown that stream temperatures between 7 and 8 degrees Celsius (44-47 degrees Fahrenheit) are optimal for bull trout habitat (Gamett, 2002). Gamett also found that bull trout densities averaged 15.0 fish/100 m2 at sites where mean temperatures ranged from 7.0-7.9 °C while only 1.6 fish/100 m2 were found in sites ranging from 9.0-9.9 °C (2002). Furthermore, juvenile bull trout are not able to tolerate higher temperatures as well as adults. Given that the melting glaciers are the only meltwater input regulating stream temperatures in late summer, it is quite foreseeable that these streams will not be suitable spawning habitat for much longer.

Given the listing of bull trout as "threatened" under the Endangered Species Act, their shrinking habitat, and the negative effects of invasive lake trout, the United States Geological Survey has conducted a large amount of research in order to protect the top native aquatic predator. Much of this research has revolved around the invasive lake trout, which were introduced to Flathead Lake in the 1890s. Lake trout, *Salvelinus namaycush*, a predatory fish that commonly grows up to 40 pounds, feed on many of the same species as bull trout (Guy et al., 2011). This diet overlap leads to an increase in competition between the species and a decrease in the bull trout population (Guy et al., 2011). The lake trout population did not begin increasing until the appearance of *Mysis relicta*, a non-native shrimp, into Flathead Lake in 1981 (Spencer et al., 1991). Mysis served as a gigantic food source for the lake trout population. Mysis were introduced in an attempt to boost the kokanee population in the Flathead Watershed, but the plan ultimately backfired when they fed heavily on the phytoplankton species that kokanee depended on (Spencer et al., 1991). The kokanee population was eliminated, which reduced competition for young lake trout. Mysis also served as an abundant food source for young lake trout, causing the population to rise dramatically. Since the lake trout population began exploding, the populations of the native assemblages of bull and cutthroat trout have declined. Furthermore, lake trout have started invading the lakes of Glacier National Park.

The lake trout invasion into Glacier National Park has resulted in the National Park Service and United States Geological Survey partnering to deliver an in-depth review of the lake trout populations in Glacier National Park. They began the project in 2003 and have found that lake trout inhabit nine

[1] This figure is based on a 2002 estimate by the National Park Service, so it could be a substantial underestimate.

of the 12 lakes they can access in the park. Furthermore, a 2007 report categorized 93% of the bull trout population within the park as "compromised," with only 6% of the population considered "secure" (Fredenberg et al., 2007).

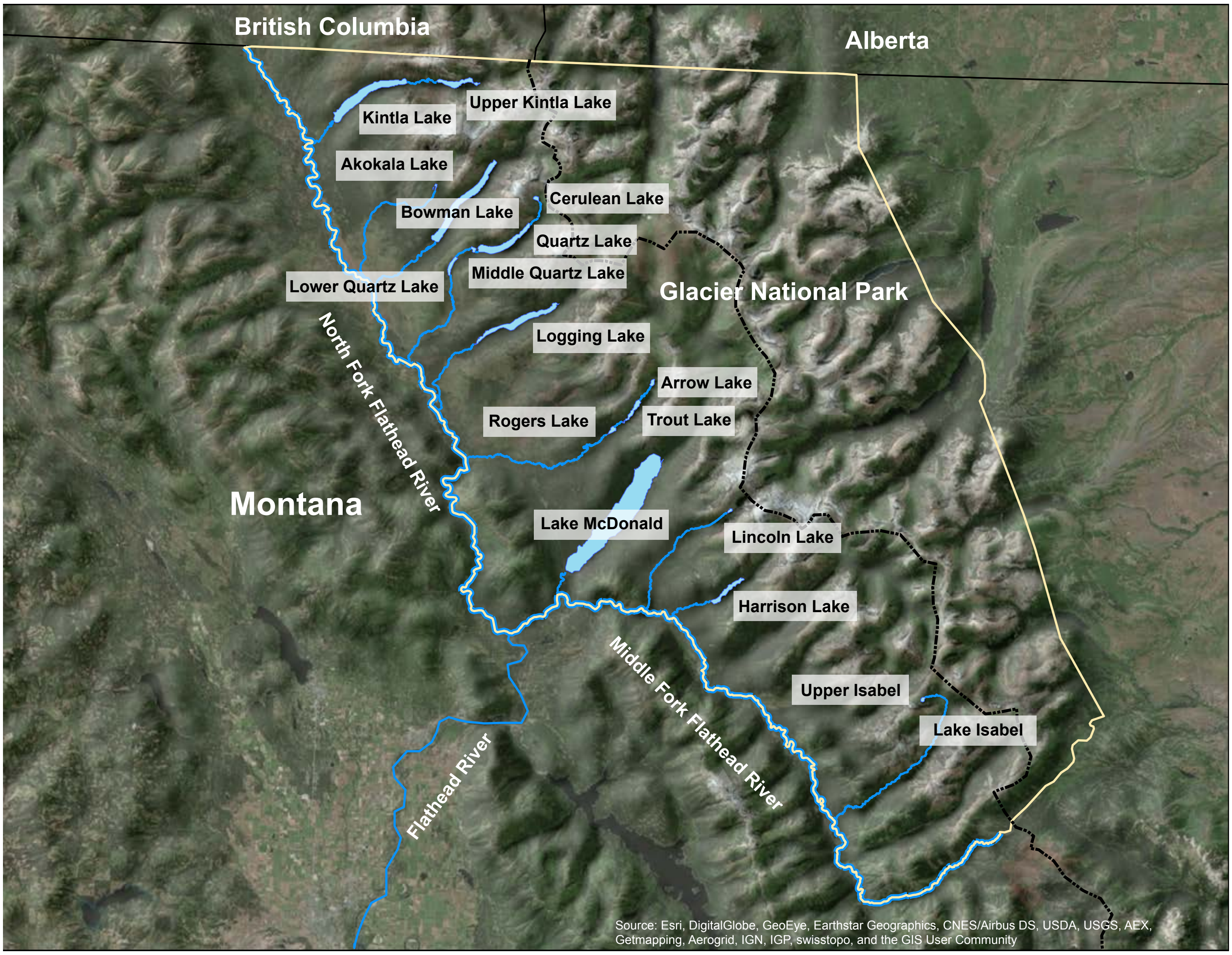
The Interplay of Glaciers and Ecology

As the State of the Rockies team travelled to Glacier National Park, we were able to meet with Carter Fredenberg, biological science technician and one of the lead scientists working on the bull trout issue for the USGS. He is working on a team that has been conducting suppression experiments on lake trout in the Quartz Lake system. Quartz Lake is the largest lake with the native fish assemblage in the park, making it an ideal study site.

Fredenberg and his colleague, Joe Giersch, aquatic entomologist for the USGS, discussed some of the challenges with environmental management in the face of climate change. The question of whether to attempt to preserve nature in its found form, or merely protect it as it changes, is a crucial one in the 21st century given how quickly landscapes are being altered. In the case of melting glaciers, there is no direct work that can be done by any individual or local agency to slow the melting because climate change is a global problem; therefore, management decisions must focus on the effects, not the cause, of the problem. This is where the question of preservation versus protection comes into play. Some conservation groups or agencies attempt to protect landscapes in the face of climate change via "adaptive management," an environmental concept that highlights the need to be flexible in environmental management as landscapes change and species migrate. The National Park Service, on the other hand, is chartered with the preservation of landscapes for future generations. This distinction is highlighted in the management plan that has been drafted for the protection of bull trout in Glacier National Park.

The action plan splits the 17 lakes on the western slope of Glacier National Park (seen in **Figure 1**) into three categories: secure, vulnerable, and compromised. "Secure" lakes refer to those with a bull trout population that is physically separated by a barrier, such as a waterfall, from lake trout populations. These five small backcountry lakes constitute only 6% of the lake surface area in the entire park, but they represent the most pristine bull trout habitat. The action plan states that the priority for secure lakes is the "long-term maintenance of current conditions" (Fredenberg et al., 2007). Three of these secure

Figure 1: Lakes in western Glacier National Park



lakes, Upper Kintla, Isabel, and Upper Isabel, are glacial tributaries, thereby making their future existence as habitat for bull trout a bit unclear. Since these lakes are devoid of lake trout and other invasive species, the bull trout in these lakes could function as specific indicator populations of stream temperature increases in the late summer and fall as the glaciers continue to melt. The "vulnerable" lakes, Akokala and Cerulean, are those that do not contain lake trout but are also devoid of natural barriers to their immigration. The management strategy for these high priority lakes is the "active evaluation of methods to maintain or improve the status in these vulnerable bull trout waters" (Fredenberg et al., 2007). "Compromised" lakes are those that already contain lake trout populations. There is great variety in how to manage these lakes given their differences in location and bull trout and lake trout numbers, but suppression of lake trout is ongoing for some of the lakes (Fredenberg et al., 2007).

Quartz Lake, the highest priority lake among the compromised ones, has the least impacted bull trout population. Quartz Lake has terrific spawning territory in the stream at the head of the lake and supports a complex assemblage of native fish species. Quartz Lake is connected to Cerulean Lake, Middle Quartz Lake, and Lower Quartz Lake, known collectively as the Quartz Lake drainage. Quartz Lake is located below Cerulean Lake and above Middle and Lower Quartz Lakes. Bull trout move freely along the Quartz Lake drainage, evidenced by the similar genetic profile of the bull trout across the four lakes. This intermixing only makes protecting Quartz Lake even more important because an increase in the population of lake trout in Quartz Lake could have negative effects throughout the drainage. Because the bull trout situation in Glacier National Park is a high priority, there is hope for success. The environmental assessment to continue suppression of lake trout in Quartz Lake states that, "results from the recent experimental effort to remove lake trout from Quartz Lake and suppress the population have been promising," which gives hope for the persistence of bull trout in the park (National Park Service, 2013). However, prospects for bull trout outside of the park are not as promising due to the challenges of enforcing stringent population control measures and suppression projects. Furthermore, lake trout have become a popular trophy fish given their large size, which has slowed efforts to diminish the population on Flathead Lake.

The ecological impacts of the melting glaciers in Glacier National Park are not solely limited to bull trout. High alpine macroinvertebrates require the cold temperatures that glacial runoff provides. These macroinvertebrates have not been widely studied, but are recognized as a potential indicator species of climate warming in mountain ecosystems (Muhlfeld et al., 2011). Much of the research in Glacier National Park has focused on the meltwater stonefly, *Lednia tumana*. The meltwater stonefly, endemic to Waterton-Glacier International Peace Park, was petitioned for the Endangered Species Act in 2007. The Fish and Wildlife Service determined that the listing of the meltwater stonefly was warranted, but that listing the species is precluded by higher priority actions. The meltwater stonefly is currently still listed as a candidate species under the ESA (Fish and Wildlife Service).

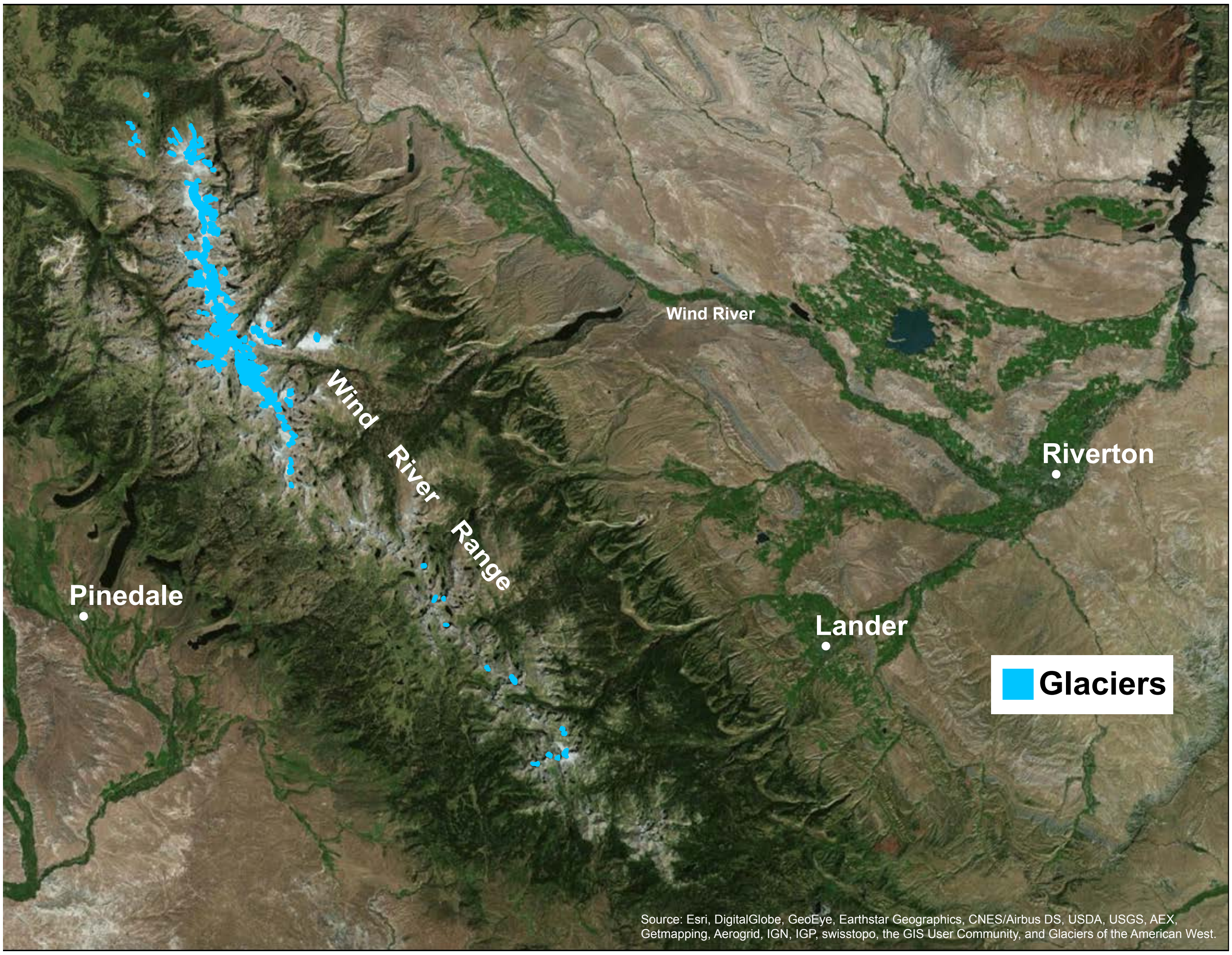
Its habitat consists of streams located below glaciers, permanent snowfields, and alpine springs. When discussing the habitat of the meltwater stonefly, Giersch stated that alpine springs offer the ideal combination of stable temperatures and aquatic chemistry. According to Giersch, these alpine springs will be the only available habitat for the meltwater stonefly and other rare alpine invertebrates once the glaciers melt. He stated that the continued existence of the meltwater stonefly and other invertebrates is dependent on what type of stream in which they are currently located. The first macroinvertebrates to disappear will be those living in streams below permanent snowfields because they will not be able to survive as the streams transition from permanent to seasonal flow. The next group to die off will be those living in glacial melt streams because the glaciers will probably last a bit longer than the permanent snowfields. This leaves the alpine springs as the final refuge for alpine macroinvertebrates. Giersch predicts an 80% reduction in habitat for the meltwater stonefly once the glaciers have completely melted.

Giersch stressed that the ecosystem role that the meltwater stonefly and other alpine macroinvertebrates play is not very well understood. Craig Thompson (Colorado College '75), professor of engineering and applied science at Western Wyoming Community College, echoed a similar sentiment. He has studied aquatic ecosystems in the glacial meltwaters of the Wind River Range and in Switzerland since 1983. Thompson is frustrated by the fact that so little research is being done on these ecosystems and rare macroinvertebrate species in the Rocky Mountains. Since little is known about these species, Giersch and Thompson are both concerned about potential ecological ramifications if they go extinct.

Since there is a paucity of research on alpine macroinvertebrates in the Rocky Mountains, looking to other, more researched areas is helpful. A study conducted in the French Pyrenees found that decreased meltwater contributions from glaciers actually increased taxonomic richness and total abundance of stream macroinvertebrates (Brown et al., 2007). In the article they stress the difference between alpha, beta, and gamma diversity. Alpha diversity refers to the species richness in a particular area while beta diversity refers to the species diversity between sites (Whittaker, 1972). Gamma diversity is reflective of the overall diversity of different ecosystems within a region (Whittaker, 1972). In the study area, they found that reduced meltwater contributions increased alpha diversity but decreased beta and gamma diversity. The increase in alpha diversity was due to more species of macroinvertebrates being able to tolerate the warmer streams while the loss of beta and gamma diversity was due to the loss of unique sub-ecosystems and rare, endemic species (Brown et al., 2007). Though the results of this study are interesting and could be indicative of future trends, it is unwise to assume the exact process would be replicated in either Glacier National Park or the Wind River Range. Alpine ecosystems have unique and subtle ecosystem interactions that could impact how the macroinvertebrate community responds to reduced meltwater inputs. Thompson summarizes the problem as follows:

> 1. We are losing alpine glaciers on every continent. 2. Alpine glacier meltwaters support a vibrant aquatic ecosystem. Since we don't know what role the aquatic insects play

Figure 2: Glaciers in the Wind River Range, Wyoming



in the larger terrestrial ecosystem, we don't know what will happen when they are gone. 3. As alpine glaciers recede, basic ecosystem drivers like temperature, elevation, nutrient input and disturbance will change. Take the glaciers out of the alpine ecosystem and you take away the giant temperature buffer and much more. Who knows what will happen when the glaciers are gone?

To better understand how various ecosystems in the Rocky Mountains will respond to melting glaciers and reduced meltwater inputs, Thompson recommends a greater commitment to alpine research and the creation of a regional collaborative of scientists who would conduct research together and discuss findings.

Continuous research into the interplay of climate change, melting glaciers, and ecology is needed in the Rocky Mountain region. A better understanding of how the landscape and ecosystems are changing in the 21st century will guide sound policy decisions throughout the future. More research is also needed in regards to how climate change and melting glaciers will impact water availability for agriculture, municipalities, and personal use in the arid West. With shifting precipitation patterns, earlier melting snowpack, and a growing population, water security is of critical importance for society and the environment. Water security in the West is a widely studied and debated issue, with communities, farmers, politicians, environmentalists, and more weighing in. One of the many aspects of the water debate revolves around how to manage water in the late summer months, once seasonal snowmelt has been depleted. In an exception to the rule, communities near the Wind River Range enjoy glacial melt throughout the summer and early fall. But local farmers and ranchers are starting to wonder how much longer the glaciers will last and what will be done once the glaciers are gone.

Wind River Glaciers and the Impact on the Agricultural Economy

Wyoming has the second-most glaciers of any of the lower 48 states (Washington has more), and 63 of the 80 glaciers in the state are found in the Wind River Range, as seen in **Figure 2** (Cheesbrough et al., 2009). These glaciers have not been nearly as widely studied as those in the Glacier National Park, but the scientific community has garnered much useful information about the potential effects of the melting glaciers. There are no concrete predictions for when the glaciers will all disappear, but it has been shown that the glaciers shrunk by an average of 25% between 1985 and 2005 (Cheesbrough et al., 2009). There was also a significant feedback between size and melting rate, for glaciers that were less than 0.5 km2 shrunk by 43% on average while those larger than 0.5 km2 only shrunk by 22% on average (Cheesbrough et al., 2009). This positive feedback is due to the decreased albedo of the landscape around a melting glacier, which causes the immediate area to warm, thereby accelerating the melting of the glacier. The Wind River Range as a whole has also been shown to be warming, for the date of spring snowmelt onset is up to 20 days earlier than it was in the mid-20th century (Hall et al., 2011). This earlier snowmelt only serves to make the glaciers even more crucial as a stable source of water.

The importance of the glaciers is not lost on Meredith and Tory Taylor, local farmers in Dubois, Wyoming who own an outfitting company that takes scientists into the Wind River Range to conduct research. They have been living in Dubois for decades and have seen the melting occur first-hand. The Taylors do not think enough people in the community understand the severity of the issue and the need for improvement in water storage methods as late summer flows decrease with the melting glaciers. Between 4 and 10% of warm season (July-October) flows are directly attributable to glacial meltwater (Cheesbrough et al., 2009). This figure was calculated using the stream gages at Dinwoody Creek above Lakes, Bull Lake Creek above Bull Lake, and Green River at Warren Bridge, three locations representing the primary sub-watersheds into which the melting glaciers drain. This "4-10%" figure is potentially significantly higher upstream of the gages. This is why the Taylors think that upstream users in the high valleys, such as themselves, are more tuned in to the issue of the melting glaciers. Not surprisingly, they say the biggest impacts of the melting glaciers have been on agriculture and downstream users. Given that Wyoming produces the 8th most barley and 20th most hay in the United States, while also supporting an $800 million cattle industry, the economic impacts of reduced late-season flows could be substantial (Cheesbrough et al., 2009). The Taylors are somewhat frustrated by the lack of response to this issue. They discussed how the conservative political atmosphere of Wyoming is preventing acknowledgement of the problem. They also mentioned that Governor Mead has proposed dam construction projects, but in locations Meredith describes as "not ideal." She is also concerned about the significant loss of water due to evaporation that these dams would create. Though the Taylors know that continuing to farm in the area will become more challenging, they are not hopeless. Tory believes that "farmers near the headwaters will get by," albeit with lower returns and less year-to-year consistency. He is personally more worried about the broader symptoms of global climate change, such as more frequent hot days and systematic vegetation change in the valley. Fortunately, when I visited during the summer of 2014 the Taylors were enjoying one of the best rain years ever in the valley, on top of what was already a high snowpack year. Tory joked that it was the occasional good year, like 2014, that causes people to forget about the issue of the receding glaciers and slows the conversation about how to deal with the consequences.

Next Steps

Dealing with diminishing water supplies in the American West will be one of the most challenging environmental issues of our time. Water shortage issues are multifaceted with no easy solutions. A growing population and demand for food are obviously chief factors, but climate change is beginning to have a more obvious impact on the availability of Western water. Sporadic and sparse snowfall has already impacted landscapes and agriculture, and we may soon lose our primary buffer against unpredictable snowfall: glaciers. As nature's water towers, glaciers serve a crucial role by supplementing late-season snowmelt and keeping water levels and temperatures at a relatively normal level. Glaciers and their positive impacts are easy to take for granted, but they will soon be absent from the landscape in the American West. A reduced water supply will not only stress species and ecosystems, but also farming and economics.

The issues surrounding melting glaciers in the Rocky Mountains are only going to become more complex and difficult to manage with time. From changing species composition to water security challenges and economic losses, the effects are broad and diverse. The problems will cross federal, state, and private boundaries, raising many difficult management questions along the way. The main way to deal with the increasing impacts of melting glaciers in the Rocky Mountain region is through regional collaborative efforts, much like Craig Thompson recommended. Problems such as reduced irrigation water, altered landscapes, and changing species composition are all landscape-scale problems requiring regional solutions. Without swift and effective action, the impacts of melting glaciers in the Rocky Mountains will be immense, affecting economies, ecosystems, and agriculture.

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