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Predicting the Impact of Glacier Loss on Fish, Birds, Floodplains, and Estuaries in the Arctic National Wildlife Refuge

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Abstract

In this paper we explore the impacts of shrinking glaciers on downstream ecosystems in the Arctic National Wildlife Refuge. Glaciers here are losing mass at an accelerating rate and will largely disappear in the next 50–100 years if current trends continue. We believe this will have a measureable and possibly important impact on the terrestrial and estuarine ecosystems and the associated bird and fish species within these glaciated watersheds.

Keywords: glaciers, birds, fish, shrubs, arctic, climate

Climate-Driven Change of Glaciers and Its Potential Impact on Physical Hydrology

Glaciers throughout the Brooks Range are losing mass at a rate that is accelerating with time, and most will likely disappear in the next 50 years. Research on McCall Glacier in the eastern Brooks Range documents this accelerated ice loss over the past 50 years (Nolan et al. 2005). It is clear that glacial retreat began in the late 1800s in this region, following the strongest advance since the last glacial maximum. From at least the 1500s to the 1800s CE, these glaciers expanded by storing water from the annual precipitation cycle, but now they are losing this mass, discharging more water than current annual precipitation levels. A variety of modeling predicts disappearance of glaciers in the near future (Delcourt et al. 2008), largely driven by a rise in the late-summer snowline, such that in many recent

years there is no remaining accumulation of the past winter's snow. On inland valley glaciers like these, the position of this snowline is likely to be 10 times more sensitive to air temperature than to precipitation (Oerlemans 2001), and our local records show greater changes in air temperature than in precipitation over the past 50 years. McCall Glacier is one of the five largest of the over 400 glaciers in the Arctic Refuge, with an area of about 6 km² and an average thickness of about 75 m (Pattyn et al. 2009). Average size of glaciers in the region is about 1 km² and likely less than 20 m thick. Our measurements here and at many other glaciers in the area indicate area-averaged ablation rates from 0.5 to 1.0 m/a. Thus, even without sophisticated modeling, it is clear the bulk of the glacial ice here will disappear soon, and our photo comparisons indicate that many glaciers already have disappeared in the past 50 years.

Table 1. Glacierized area as of 1956

	Glacier area (km ²)	Watershed area (km ²)	Percent
Jago	126	2,208	5.7
Okpilak	139	1,011	13.8
Hulahula	116	1,841	6.3
Sadlerochit	38	1,698	2.2

Table 1 summarizes glacierization (percentage of land covered by glacier ice) characteristics of the four most heavily glaciated watersheds in Arctic Alaska, all located within the Arctic National Wildlife Refuge. The average glacierization is 6.2 percent over the entire area, about the same as that in the Hulahula River. These percentages have been decreasing over time as glaciers shrink; we recently acquired new digital elevation models and air photos of nearly all of these glaciers, but as yet we do not yet have updated measurements. While these glaciated watersheds are

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not huge by Alaskan standards, they are still large and located within an ecologically-sensitive area that is expected to be especially vulnerable to the effects of climate change, as we hope to demonstrate in this paper.

Stream discharge here in summer is dominated by glacier meltwater, in contrast to the rest of Arctic Alaska. Nonglaciaded watersheds in Arctic Alaska such as the Colville, Sagavanirktok, and Kuparuk Rivers (which collectively drain about 80,400 km² of the North Slope) typically issue an average of 61, 44, and 52 percent, respectively, of their annual discharge to the Beaufort Sea during two weeks of snowmelt in the spring (McClelland et al., in press). We installed a discharge gauge on the Hulahula River in fall 2010, but do not yet have a full year of measurements. In the meantime, we have compared rates of river contribution averaged over watershed area to determine relative contributions of precipitation versus glacial melt. Annual precipitation in Arctic Alaska is usually less than 30 cm/a, with roughly half falling as snow and melting in early June. Current glacier ablation rates are usually over 80 cm/a averaged over the glacier area, or roughly 5 cm/a averaged over the watershed areas (assuming 6.2 percent glacierization). So, the glacier contribution is in the same order of magnitude as rain and snow contributions, and after the spring freshet glaciers dominate flow compared to the infrequent rains, much of which gets intercepted during overland flow. As glacier ablation rates continue to rise because of increased warming, the fraction of water contributed by glaciers may initially increase. When glacier reserves are depleted, however, their contribution will plummet.

This paper represents the initial attempt by the authors to integrate our individual research projects to contribute to a multidisciplinary understanding of how climate-driven changes in glaciers may affect ecological trajectories over the next 50 years.

Potential Impacts on Riparian Ecosystems

We have some evidence that indicates that the spread of vegetation within the floodplains of these glaciaded watersheds is limited by the geomorphological instability related to increasing glacial discharge. We attempted to assess the effect of glaciers on floodplain stability by comparing time series of vertical air photos at locations along a river fed primarily by glaciers (Jago River) to a river fed by nonglacial sources (Kongakut River). Old and new imagery was

opportunisticly acquired, and comparisons between images were made where spatial overlap occurred. None of the imagery was acquired when water levels were high so that no vegetation would lie undetected under water. In each area where repeat imagery was overlain, we created a single (virtual) transect zig-zagging from one side of the river to the other and placed points every 50 m along the transect. Transects ranged in length from 5,850 m to 22,850 m, totaling 70,650 m and consisting of 1,413 sample points. The placement of the transects was constrained by the available imagery but otherwise could be considered random within the floodplain; points not within the floodplain were excluded from this analysis.

Three of the five Kongakut River transects showed an increase in vegetation in the floodplain since acquisition of the old imagery (old images acquired between 1948 and 1982). Of the two remaining transects, one showed equal number of vegetated points in old and new imagery, and another contained no vegetation in the floodplain in old or new imagery (Ø). Overall, floodplain vegetation along the Kongakut River increased over time ($p < 0.05$). There was an insignificant positive downstream trend in percent change in vegetated floodplain points, which was 0 percent, Ø, +30 percent, +48 percent, and +33 percent. The single long reach of the Jago River assessed using this technique contained equal number of vegetated points in old and new imagery (0 percent change).

The increase in floodplain vegetation along the Kongakut River is similar to the trend observed in North Slope floodplains west of the Canning River (Tape et al. 2006). Possibly, a decrease in discharge or decrease in aufeis volume is causing the increase in vegetated bars along the Kongakut River. The absence of trend in the Jago River floodplain suggests that glaciaded watersheds are not following the same trajectories, but our observations thus far are too limited to make conclusive generalizations. Work is currently in progress to acquire high-resolution air photos of both glaciaded and nonglaciaded rivers in this area to further assess the role of enhanced glacial discharge on vegetative-growth dynamics.

Potential Impact on Fish Ecology

The loss of glaciers and their meltwater may reduce instream connectivity and cause fish habitats to become fragmented, especially in late summer when anadromous Dolly Varden (*Salvelinus malma*) are returning from estuarine/marine areas to reach

spawning and overwintering areas in these glaciated watersheds. As an integral part of the aquatic ecology of Alaska's North Slope, these fish are particularly vulnerable to the effects of climate change (Martin et al. 2009) and also support a number of subsistence fisheries (Pedersen and Linn 2005). Anadromous Dolly Varden occur in most of the larger drainages north of the Brooks Range (Viavant 2009), and like other fish in the region, these populations have adapted to habitats and physical conditions that include a short growing season, extensive ice cover, summer water temperatures <math><10^{\circ}\text{C}</math>, and long periods of darkness (Reist et al. 2006). During the spring freshet, the mature individuals migrate from overwintering areas in rivers to estuarine and marine waters for summer feeding (Viavant 2005). In glacial streams, these fish primarily return to freshwater in August when glacial meltwater provides adequate discharge to allow migration (Martin et al. 2009). Juvenile fish overwinter in their natal streams for 2–3 years before making their initial journey to saltwater (Fechhelm et al. 1997).

The population of anadromous Dolly Varden in the Hulahula River has been the focus of several studies from the 1970s through the 1990s (Viavant 2009), with more recent, complementary work providing detailed information about Dolly Varden abundance and behavior. Helicopter surveys of index areas in the river estimated relative abundance at 9,575 and 3,653 Dolly Varden in mid-September of 2007 and 2008, respectively (Viavant 2009). Another study used sonar to estimate number of Dolly Varden returning to the Hulahula River in fall: 10,412 fish in 2005; 7,471 in 2006 (Osborne and Melegari 2008); 23,158 in 2007; and 12,340 in 2008 (U.S. Fish and Wildlife Service, unpublished data). Subsequently, a radio telemetry study in 2007–08 identified overwintering at four sites (U.S. Fish and Wildlife Service, unpublished data). The telemetry study also showed that a small fraction of the fish overwintering in the Hulahula River in one year overwintered the following year in nearby streams. Genetic studies distinguished the Hulahula River population from other stocks and provided a basis for understanding stock-specific ecology (Crane et al. 2005). Thus, we have some evidence that these fish can explore alternatives when faced with changing river conditions and perhaps have a means to track that.

Several harvest assessments have noted the importance of Dolly Varden from the Hulahula River to the Kaktovik subsistence fishery (Pedersen and Linn 2005). From October 2000 to September 2002, all fishing efforts by village residents in early winter occurred in the Hulahula River, with Dolly Varden

being the only species captured (Pedersen and Linn 2005). Users reported that three sites in the river are traditionally used, but two sites were noted as the most productive for winter Dolly Varden fishing. No summer fishing took place in the Hulahula River.

Although the information about Dolly Varden from the Hulahula River is not complete, the existing data provide the most focused and comprehensive set of information available about this species on the North Slope. More information of this kind that could be used to evaluate the importance of seasonal meltwater and the effects that the loss of glacier may have on these fish would guide future management of this resource and provide a foundation for modeling climate change effects on migratory species in other aquatic systems. An integrated, multidisciplinary approach that links Dolly Varden ecology with concurrent assessments of glacier characteristics and stream attributes will be critical for assessing the sustainability of this resource for future users on the North Slope.

Potential Impacts on Shorebird Ecology

In 2010 we investigated shorebird and invertebrate abundance on three deltas, two of which were associated with rivers that received significant inputs of glacial meltwater (Jago and Hulahula Rivers) and one that has little glacier influence (Canning River). Our preliminary analyses suggest the differences between deltas fed by glacial versus nonglacial rivers may influence patterns of shorebird use. Glacially influenced deltas had siltier substrates, and the lagoons around the deltas were less salty during the period when shorebirds used them. Freshwater occurred along two-thirds of the waters' edge of glacial-influenced deltas, but much less freshwater occurred in the delta not glacially influenced. Characteristic conditions found on the glacial deltas and in adjacent waters were likely caused by inputs of silt, clay, and freshwater from melting glaciers in the Brooks Range. The delta with little glacial influence is a branch of the Canning River, which appears to have very little freshwater output during the late summer. Conditions here may illustrate what could happen on some glacially influenced deltas once late-summer meltwater from glaciers is no longer present.

Tens of thousands of shorebirds migrate to coastal habitats of the Arctic National Wildlife Refuge after breeding on the Arctic Coastal Plain of northern Alaska and Canada, and habitat differences apparently affect availability of shorebird food resources. The greatest

concentrations of shorebirds are found on mudflats associated with river deltas, which provide important foraging habitat for post-breeding shorebirds (Taylor et al. 2010). Shorebirds likely depend on these delta mudflats for food resources to begin migration. For some species, food requirements are further increased during this period because of the molting of new flight feathers.

Two groups of freshwater invertebrates, Oligochaeta and Chironomidae, were more abundant in the silty habitats of glacial-fed deltas. The nonglacial delta had low invertebrate abundance, presumably due to the absence of freshwater invertebrates in the sandier and saltier habitats found there. Invertebrate abundance remained low on this delta until a storm surge deposited saltwater invertebrates (Amphipoda) on the mudflat. The life histories of freshwater versus saltwater invertebrates differ, with implications for shorebirds. For example, freshwater species spend multiple years in mudflat habitats (Butler 1982, Danks et al. 1994), while occurrence of saltwater invertebrates is unpredictable. Chironomid larvae spend at least three years in mudflats before pupating and turning into adults. Larvae that are present in mudflats for multiple years provide a more predictable and stationary food resource than those of species with a yearly life cycle or species that are mobile. For example, saltwater invertebrates like Amphipoda retreat from mudflats each winter (Evans 1976, Craig et al. 1984) when the mud freezes. In the summer amphipods are generally unavailable to foraging shorebirds until they are washed onto mudflats by storm surges and become stranded in puddles. Because storm surges are unpredictable events, we consider saltwater invertebrates to be a less dependable resource for shorebirds.

In 2010, we sampled triglyceride levels in semipalmated sandpipers (*Calidris pusilla*) early in the post-breeding season before the occurrence of any storm surges. Triglyceride levels provide a measure of fattening rates (Williams et al. 1999, Guglielmo et al. 2002). We found triglyceride levels were higher for birds feeding on the glacially influenced deltas compared to mudflats without glacial influence. We assume the difference was due to the low abundance of invertebrates on the delta without glacial influence. Soon after our sampling a storm surge occurred, coinciding with a pulse in shorebird migration. After the water levels dropped we observed thousands of shorebirds feeding on both saltwater and freshwater invertebrates on all three deltas. It appears that shorebirds utilize saltwater food resources

opportunistically, but they rely on freshwater invertebrates as a more consistent resource.

There had been little previous research on the relationships between shorebirds, invertebrates, and delta mudflats along the coast of the Arctic Refuge. Our work suggests that glacially influenced deltas in particular provide an important resource for post-breeding shorebirds. Loss of Brooks Range glaciers will likely lead to decreases in sediment transport and freshwater inflow in rivers that are currently influenced by glaciers. These decreases in turn are likely to result in sandier delta mudflats and saltier lagoons, with potential implications for invertebrates and the birds that feed on them. Our observation that deltas with no glacial influence lack freshwater invertebrate species suggests that these species will disappear in currently glaciated watersheds as their mudflats become sandier and saltier with the loss of glacial meltwater and silt. Therefore, we hypothesize that loss of glaciers will have a negative impact on shorebirds as they prepare for migration, and we plan to investigate this further.

Potential Impacts on Marine Foodwebs

Glacier loss could impact estuarine ecosystems within the Arctic National Wildlife Refuge by altering the quantity, quality, and seasonality of river inputs. For example, differences between river inputs with and without significant glacier influence may be important in determining amounts and pathways of terrestrial carbon and nitrogen movement through coastal food webs. A comparison of stream and river water chemistry among catchments with different percentages of glacier coverage in southeastern Alaska demonstrated that concentrations of dissolved inorganic nitrogen are negatively correlated with glacier coverage whereas concentrations of soluble reactive phosphorus are positively correlated with glacier coverage (Hood and Berner 2009). Bioavailability of dissolved organic matter is also positively correlated with glacier coverage (Hood et al. 2009). If the correlations described above hold true for glacier-fed streams and rivers within the Arctic Refuge, then the glaciers may be a particularly important source of soluble reactive phosphorus and labile dissolved organic matter in mid to late summer that is not available in rivers without significant glacier inputs.

Although concentrations of dissolved inorganic nitrogen were negatively correlated with glacier coverage in the Hood and Berner (2009) study, it should be noted that high nitrate concentrations have

been linked to glaciers and (or) proglacial features in some other studies (Apollonio 1973, Hood and Scott 2008). Thus, robust conclusions about the importance of glacier-fed streams and rivers as sources of nutrients and organic matter to coastal waters of northern Alaska will ultimately require focused studies in this region. We can expect glacier loss to be accompanied by a general decrease in mid to late summer export, including a decrease in relatively labile dissolved organic matter associated with microbial activity within and beneath glaciers (Hodson et al. 2005), but specific trajectories of individual waterborne constituents remain uncertain.

While we now recognize that terrestrial organic matter inputs to the Arctic Ocean are larger and more labile than previously thought, many questions remain about the influence of these inputs on food webs. Is terrestrial organic matter a major energy source supporting metazoan consumers, or is most of the energy from terrestrial organic matter lost during microbial processing? Does decomposition of terrestrial organic matter serve as a source of or a sink for inorganic nitrogen in coastal waters? Most of the labile river-supplied organic matter delivered to coastal waters probably enters the microbial food web. Yet, a recent study by Dunton et al. (2006) provides evidence of significant carbon and nitrogen from terrestrial organic matter making it into Arctic cod collected from lagoons along the northern Alaska coast. This finding suggests that either there is a strong link between the microbial and metazoan food webs or there is a direct pathway for terrestrial organic matter into the metazoan food web. In order to effectively predict how productivity in arctic coastal waters may be influenced by future climate change, we need to gain a better understanding of how terrestrial inputs contribute to coastal food webs under current conditions. Present contributions and future losses of glacier inputs may be particularly important within the Arctic National Wildlife Refuge.

Discussion

There are many uncertainties regarding climate change and its impact on Arctic landscapes and ecosystems, but we believe we have identified a straightforward and testable hypothesis linking these together. Glaciers here exist solely at the mercy of climate, unlike tidewater glaciers that have strong nonclimatic influences and major ice sheets that can influence their own climate; a 1–2°C warming has caused them to enter a trajectory where they will likely disappear in the near future. Even if climate remains constant from this time

forward, most glacier ice here will disappear because the late-summer snowline is higher than the elevation of most of the mountains. While direct effects of current climate change on fish and birds may be subtle and difficult to detect, the indirect effects on downstream ecosystems caused by the loss of glacial meltwater and silt may be enormous and predictable. Thus we hypothesize that loss of glaciers in the Arctic National Wildlife Refuge will exert strong influence on downstream ecosystems, affecting fish, birds, shrubs, and marine ecology. In this paper we have attempted to share what we know of these influences and predict future trajectories. We are just beginning to investigate relationships between climate, glaciers, and ecology in this region, and we welcome input from the broader scientific community as we pursue this work.

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