

# The effect of climate change on glacier ablation and baseflow support in the Nooksack River basin and implications on Pacific salmonid species protection and recovery

Oliver Grah · Jezra Beaulieu

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**Abstract** The Nooksack Indian Tribe (Tribe) inhabits the area around Deming, Washington, in the northwest corner of the state. The Tribe is dependent on various species of Pacific salmonids that inhabit the Nooksack River for ceremonial, commercial, and subsistence purposes. Of particular importance to the Tribe are spring Chinook salmon. Since European arrival, the numbers of fish that return to spawn have greatly diminished because of substantial loss of habitat primarily due to human-caused alteration of the watershed. Although direct counts are not available, it is estimated that native salmonid runs are less than 8 % of the runs in the late 1800's. In addition, climate change has caused and will continue to cause an increase in winter flows, earlier snowmelt, decrease in summer baseflows, and an increase in water temperatures that exceed the tolerance levels, and in some cases lethal levels, of several Pacific salmonid species. The headwaters of the Nooksack River originate from glaciers on Mount Baker that have experienced significant changes over the last century due to climate change. Melt from the glaciers is a major source of runoff during the low-flow critical summer season, and climate change will have a direct effect on the magnitude and timing of stream flow in the Nooksack River. Understanding these changes is necessary to protect the Pacific salmonid species from the harmful effects of climate change. All nine salmonid species that inhabit the Nooksack River will be adversely affected by reduced summer flows and increased temperatures. The most important task ahead is the planning for, and implementation of, habitat restoration prior to climate change becoming more threatening to the survival of these important fish species. The Tribe has been collaboratively working with government agencies and scientists on the effects of climate change on the

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O. Grah (✉) · J. Beaulieu  
Nooksack Natural Resources Department, Nooksack Indian Tribe, P.O. Box 157, Deming, WA 98244,  
USA  
e-mail: ojgrah@gmail.com

hydrology of the Nooksack River. The extinction of salmonids from the Nooksack River is unacceptable to the Tribe since it is dependent on these species and the Tribe is place-based and cannot relocate to areas where salmon will survive.

## 1 Introduction

Glaciers in the North Cascades Mountains of Washington State are a critical water supply source, serving as water storage reservoirs, and their response to climate change will impact the region's water resources and fish habitat over the next century and beyond. The North Cascades occur in the north central and western portion of the State of Washington and are a very likely place for the occurrence of glaciers because of the high amount of winter precipitation (~80 % of annual mean) and relatively high altitude terrain that occurs in the snow accumulation zone (Hamlet et al. 2005). More than 700 glaciers cover 225 km<sup>2</sup> and yield approximately 800 m<sup>3</sup> of runoff each summer on the average (Post et al. 1971; Riedel and Larrabee 2011).

Air temperature, alpine snowpack, glacier extent, and streamflow in Washington have already experienced significant changes since 1950. Glacier area and volume loss have been extensive throughout the 20th century, and have been well documented by many researchers (e.g. Granshaw and Fountain 2006; Nolin et al. 2010; Riedel and Larrabee 2011; and Peltó 2010). The timing and magnitude of streamflow in a high relief, snow-dominated basin, such as the Nooksack River basin, is strongly influenced by changes in temperature and precipitation (Elsner et al. 2010; Bach 2002). The Nooksack River (Fig. 1) is comprised of three forks (North, Middle, and South) that converge near Deming, Washington, and is fed by glaciers on Mount Baker, Mount Shuksan, and other nearby peaks of the North Cascades. There are at least eight source glaciers within the Nooksack River watershed on Mt. Baker and include the Deming, Thunder, Coleman, Roosevelt, Mazama, Sholes, Heliotrope and Hadley glaciers (Fig. 1). If glacial recession continues at its present rate, many of these glaciers may disappear entirely and their contribution to streamflow could be lost (Bach 2002).

Forecasts developed from regional general circulation models (GCM) predict increases in temperature and variable changes in precipitation over the next century that will affect snow accumulation, snow melt, glacier size, and streamflow. Of particular concern in the Nooksack River is the substantial loss of glacier-melt contribution to streamflow during the low-flow summer season. Summer baseflows have already decreased and stream temperatures have increased thereby adversely impacting Pacific salmonid habitat and fish survival (Elsner et al. 2010; Mantua et al. 2010). Several of the nine salmonid species and populations (i.e., evolutionarily significant units, or ESU's) are protected under the federal Endangered Species Act (ESA). Of particular importance to the Tribe is spring Chinook salmon that return to hold, spawn, and rear in the Nooksack River. These fish are vital resources to the Tribe for ceremonial, subsistence, and commercial uses. Understanding the importance and magnitude of climate change effects on glacier-generated streamflow and fish habitat is imperative to effective planning for the restoration of damaged habitat under the current climate conditions and the future recovery and protection of fish in the Nooksack River watershed under future climate conditions. Since European arrival, the numbers of fish that return to spawn have greatly diminished because of substantial loss of habitat primarily due to human-caused alteration of the watershed. Although direct counts are not available, it is estimated that native salmonid runs are between 2 and 8 % of the runs in the late 1800's (Lackey 2000). Declines in salmon and habitat due to the