Aniakchak Sockeye Salmon Investigations

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Introduction

Aniakchak National Monument and Preserve provides unusual and dramatic landscapes shaped by numerous volcanic eruptions, a massive flood, enormous landslides, and ongoing geological change. The focal point of the monument is Aniakchak Caldera, a restless volcano that embodies the instability of the Alaska Peninsula. This geological instability creates a dynamic and challenging environment for the biological occupants of Aniakchak and unparalleled opportunities for scientists to measure the adaptability of organisms and ecosystems to change.

The sockeye salmon *(Oncorhynchus nerka)* is one member of the Aniakchak ecosystem that has managed to adapt to geologic upheaval and is now thriving in the park. Aside from just surviving in the harsh environment, these salmon are also noteworthy for providing essential marine-derived nutrients to plants and animals and as a source of food for historic and present day people in the region.

With this backdrop, researchers from the National Park Service (NPS), U.S. Geological Survey (USGS), and University of Alaska Anchorage have begun to study how the volcanic landscape of Aniakchak has contributed to the local adaptations and relatedness of its different sockeye inhabitants. More specifically, the goal of the research is to measure the evolution of shape and genetic similarity of sockeye populations across a diverse range of habitats that reflect the violent history of the monument—Surprise Lake, located in the semi-dormant Aniakchak Caldera; Aniakchak River, a high gradient river flowing through the denuded route of a massive ancient flood; and Albert Johnson Creek, a sinuous, low-gradient creek draining into the Aniakchak River. By understanding the role of extreme habitat variation in shaping the ecology and evolution of sockeye, this project will help NPS managers identify the role of geological events in creating species diversity and promote management actions that protect ecosystem functions and resource users.

History

Aniakchak Caldera was formed 3,500 years ago by a tremendous volcanic eruption on the Alaska Peninsula *(Figure 1)*. More than 12 cubic miles (50 km^3) of material were extruded *(Miller and Smith 1987, Riehle et al. 1987, Begét et al. 1992)* causing massive landslides, debris flows, ash deposits, and a tsunami in Bristol Bay. Following this eruption, the caldera filled with water, forming a large lake similar to Crater Lake in Oregon *(McGimsey et al. 1994)*. Between 3,400 and 500 years ago, the caldera wall ruptured and the lake (now known as Surprise Lake) drained, causing a catastrophic flood that scoured the valley below *(Figure 2)*, depositing car-sized boulders in the floodplain

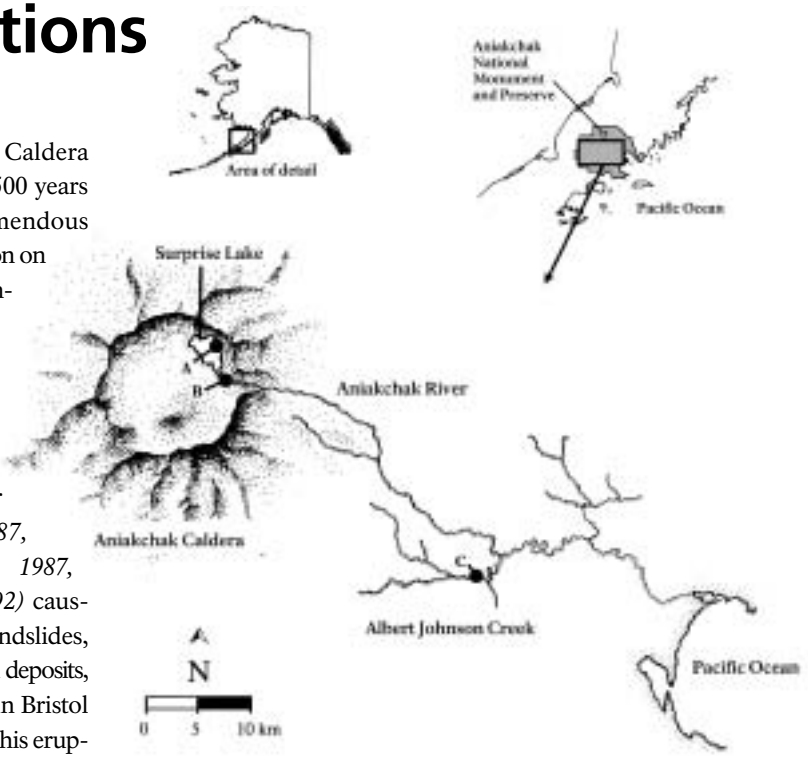

Figure 1. Map showing location of Aniakchak National Monument and Preserve on the Alaska Peninsula. Letters A, B, and C correspond to sockeye salmon spawning areas in Surprise Lake, Aniakchak River outlet, and Albert Johnson Creek, respectively.

Opposite Page: Surprise Lake surrounded by the Aniakchak Caldera.

National Park Service photograph

National Park Service photograph

In 1931, Aniakchak erupted again, covering the caldera with ash and debris, wiping out plants in the caldera and decimating aquatic life in Surprise Lake

Figure 2. Aniakchak River flowing out of the caldera at "The Gates." When the ancient caldera ruptured, a massive flood ensued creating the present day Aniakchak River and a new migratory corridor for fish colonizing Surprise Lake.

Photograph © Troy Hamon

Figure 3. An iron spring flowing into the western end of Surprise Lake. The western and southern beaches of Surprise Lake have numerous springs but are unfit for sockeye salmon spawners because of anoxic conditions.

(Waythomas et al. 1996). Where the caldera wall ruptured, a drainage was formed connecting Surprise Lake with the Gulf of Alaska *(Waythomas et al. 1996)*. This drainage, now known as the Aniakchak River, provided new habitat for fish species and a colonization route to Surprise Lake.

In 1931, Aniakchak erupted again, covering the caldera with ash and debris, wiping out plants in the caldera and decimating aquatic life in Surprise Lake *(Jaggar 1932)*. This event occurred only nine years after the caldera was first described in 1922 *(Smith 1925, Hubbard 1931)*, providing rare photo-documentation of a completely natural ecosystem before and after a major eruption. Continuing volcanism and unique geologic landforms have contributed to Aniakchak's designations as a National Natural Landmark *(Bureau of Land Management 1970)*, National Monument and Preserve, and Wild River *(U.S. Public Law 96-487, 1980)*.

Colonization by Salmonids

The life history of sockeye salmon is highly variable among individual locations, but some general rules apply. After emerging from eggs buried in gravel, juvenile sockeye salmon typically rear in large freshwater lakes for one or two years before going to sea. Some populations do not use lakes but instead rely on river habitat for juvenile rearing. After rearing in freshwater, sockeye migrate to the sea as smolts. All sockeye spend one to three years at sea attaining most of their adult mass by feeding on rich marine food resources. As adults they return to their natal freshwater to spawn and restart the cycle.

Sockeye are anadromous, spawning in freshwater after migrating from the sea. This means that freshwater spawning habitat is essential for perpetuating their life history. The availability of new freshwater habitat following volcanism, glaciation, or other geological events provides opportunities for fish to colonize new areas and become locally adapted to their habitat. Colonizing a new habitat also provides a mechanism for creating new populations that are physically and genetically divergent from ancestral populations—key steps in the creation of species diversity and the process of evolution.

After the catastrophic Aniakchak flood, the connection between Surprise Lake and the ocean provided new freshwater habitat for anadromous species. Sockeye salmon and Dolly Varden *(Salvelinus malma)* subsequently colonized the lake and river, establishing spawning populations *(Mahoney and Sonnevil 1991)*. The natural history of the populations of sockeye salmon in Aniakchak Caldera is unique in two aspects: 1) they are some of the most recently established natural populations known in southwest Alaska, and perhaps the most recent, and 2) they either persisted through the 1931 eruption, or they recolonized quickly following the eruption.

Most other lake systems in southwest Alaska have had viable habitat for around 10,000 years while Surprise Lake has only been accessible for about 1,800 years. The eruption of 1931 likely wiped out most of the salmon run for a couple of years. Fish returning later may have found the environment suitable once again, or the present populations may be less than 70 years old. Because sockeye salmon generally have a five year life cycle, the current population in Surprise Lake has had between 14 and 400 generations to become adapted to local habitats.

Measuring Adaptation and Genetic Similarity

Management decisions that protect both the resource and resource users require a detailed understanding of focus species. Measurements of local adaptation (physical characteristics such as body size or shape) and genetic similarity/divergence are critical for establishing the presence or absence of multiple populations and, subsequently, defining the scale at which management actions are applied. If two groups of fish are clearly distinct both in physical and genetic characteristics, they may require independent management consideration.

In this context, the NPS and USGS began a multi-year study to determine how

National Park Service photograph

Figure 4. Representative sockeye salmon beach spawners from Surprise Lake. The fish on the left is a female (held by NPS employee Chistina Olson), and the right, a male (held by NPS employee Bill Hobbins).

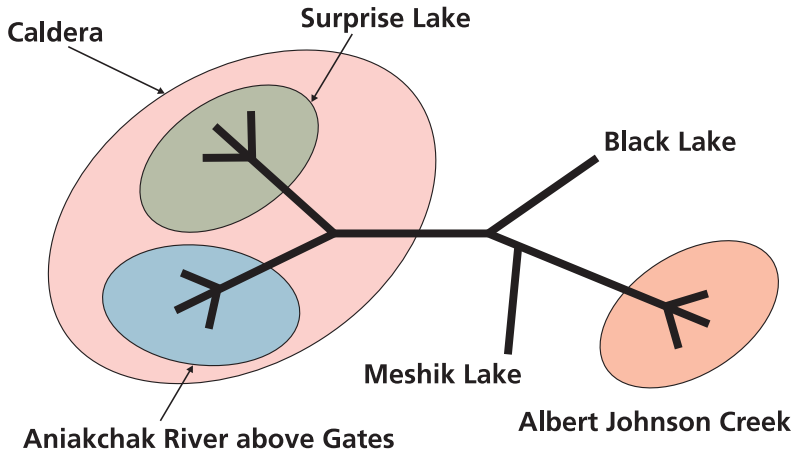

Figure 5. Diagrammatic representation of genetic similarity among Surprise Lake, Aniakchak River, and Albert Johnson Creek sockeye salmon. It appears that each group of salmon is genetically different from the others; however, fish from the caldera (Surprise Lake and Aniakchak River) are more similar to one another than either is to fish from Albert Johnson Creek. Black and Meshik Lakes represent two nearby sockeye populations outside of the Aniakchak River drainage.

USGS Alaska Science Center photograph

Biologists sampling sockeye spawners with a seine in the outlet of the Aniakchak River.

sockeye have adapted to the landscape of Aniakchak and to investigate genetic similarity among fish in certain habitat types. The study had four main objectives. First, the entire Aniakchak River drainage was to be searched to identify and catalogue spawning populations of sockeye salmon. Second, physical characteristics of habitat in use by sockeye were to be compared with characteristics of habitat not used by sockeye. Third, physical size and shape of sockeye were to be compared among populations. Finally, genetic analyses were to be used to examine the similarity and potential divergence among populations.

Extensive surveys both on the ground and by air confirmed the existence of populations in Albert Johnson Creek, in Aniakchak River within the caldera, and in Surprise Lake. There were no sockeye populations in the rest of the mainstem of Aniakchak River, nor in any of the other tributaries. In the caldera, there were populations of sockeye spawning along the lake beaches where water feeds into the lake from the caldera wall, but none along the opposite side of the lake where water drains in from the main interior of the caldera. Most of the groundwater entering from that side is high in heavy metals and has no dissolved oxygen *(Figure 3)*, consistent with the known vulnerabilities of incubating sockeye eggs; however, more than eight lake beach populations were identified. The aggregate number of spawners in any year is probably less than 50,000 or as low as 5,000, which is relatively small. The neighboring Chignik River system (Chignik and Black Lakes) usually has returns in excess of two million fish. As long as sockeye remain abundant in the Chignik lakes and commercial harvest effort remains focused on Chignik Bay, the small run of Surprise Lake and Aniakchak River sockeye salmon is unlikely to suffer adverse fishing impacts.

Comparisons of body depth revealed patterns of divergence among the different spawning populations. Overall, sockeye from Albert Johnson Creek and Surprise Lake *(Figure 4)* were deep bodied while those from the Aniakchak River were relatively shallow. The shapes of the caldera spawners fit patterns observed elsewhere in southwest Alaska, however the stream spawners from Albert Johnson Creek were surprisingly deep-bodied. In other sockeye populations, where different habitat

…Albert Johnson Creek fish, inhabiting a stream, are particularly deep-bodied, does not fit the pattern. It is not yet clear whether there is an alternative explanation due to the different life history or migration difficulty experienced by these fish, or if the present explanation for body depth variation needs closer scrutiny.

types are interconnected, body depth tends to be smallest in streams and greatest in lakes then rivers. It is not yet clear whether the differences in body shape are explained by adaptation to spawning habitat or responses to other factors such as migratory difficulty or life history variation. Nevertheless, we found that differences were consistent over several years, indicating a stable and real pattern of divergence in body shape.

Genetic sampling also confirms these differences. All three populations are genetically differentiated, suggesting reproductive isolation among the groups *(Figure 5)*. Even the nearby Surprise Lake and Aniakchak River spawning populations in the caldera appear to differ from each other. These results suggest that even with the relatively short time frame since colonization of the caldera, substantial differences in body depth and genetic markers have developed. The genetic analyses also suggest that caldera lake and river populations, as a group, are distinct from Albert Johnson Creek.

With additional data, these findings will help us understand the origins of colonizing sockeye salmon populations in the park. Additional work on both a small and a large scale will help us to determine how these results integrate with sockeye throughout their range, and may have implications for conservation and restoration of endangered populations. At present, the populations at Aniakchak, though relatively small, appear to be very healthy and represent adaptations to a unique region.

USGS Alaska Science Center photograph

Transporting field gear down the Aniakchak River from Surprise Lake. Field work in Aniakchak can be difficult because of weather, remoteness, and challenging river conditions.

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