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Aquatic Ecosystems Resource Assessment

Tongass National Forest Plan Revision

Cover Photo: Kalinin Creek, Kruzof Island on the Tongass National Forest.

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Aquatics Resource Assessment

Tongass National Forest Plan Revision

Forest Service, Alaska Region

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Introduction

The movement of water on the landscape, from its input as precipitation to where it enters the ocean defines the boundaries of aquatic and terrestrial ecosystems in Southeast Alaska. These waters act as a mechanism of transport by which nutrients, minerals, and chemicals move and contribute to the ecological condition of both aquatic and riparian areas. The naturally fragmented landscape of the region drives gradients in temperature, precipitation, on a backbone of geologic and glacial history. These conditions result in a diverse and complex mosaic of aquatic habitats across the landscape which are critical to lifecycles of fish and other aquatic species.

Over 53,000 miles of streams and rivers and 200,000 acres of lakes organized into over 900 sixth-level watersheds (USGS 2023) have been mapped on the Tongass National Forest. Based on the delineation of high-resolution remotely-sensed stream channels, many small tributary channels missed in the early photographic inventory remain unmapped. The density of the channel network and abundance of fresh water reaching the ocean from these streams is evidence of the maritime climate of the north Pacific and the importance of aquatic ecosystems to the overall health of the forest.

The Tongass is considered a salmon forest due to the ecological interconnectedness between the salmon, the trees, and the people. All five species of Pacific salmon spend a portion of their lifecycle in coastal freshwater streams of Southeast Alaska. This section focuses primarily on the physical nature of salmon habitat within the broader aquatic ecosystem, while the companion Salmon assessment details the ecological, economic and cultural aspects of the species themselves.

Hydrologic Regime

Climate patterns drive streamflow, controlling the amount and timing of peak and low flows throughout the year. In Southeast Alaska, hydrologic regimes show a gradient from rain to snow to glacial driven patterns across a generally southwest to northeast gradient. Watersheds with higher elevations are increasingly influenced by snow and ice melt (Curran and Biles 2021). Warming winters are projected to result in less precipitation falling as snow across southeast Alaska and declining contributions of snowmelt to spring and summer streamflow (Littell et al. 2018; Chapter 1). At the same time, fall and winter rainfall is projected to increase (Halofsky et al. DRAFT). Changes to the hydrologic regime and increases to temperature and precipitation can alter the form and function of aquatic ecosystems by increasing the frequency of channel forming flood events and the potential for summer drought. These physical changes drive changes to biological systems (Halofsky et al. DRAFT), with degree, magnitude and timing of change dependent on watershed location and topography as well as instream and riparian structure.

Major Aquatic Ecosystem Drivers and Stressors and Current Management Direction

Channel forming flood flows broadly control the size and shape of streams, recruit sediment and trees, and transport materials downstream. Floods range in size, frequency and seasonality tied to hydrologic regime. Large floods can significantly alter stream channels depending on channel size and power, landscape position, underlying geology, and riparian conditions. Land management activities can alter natural flood patterns by inhibiting natural channel movement, concentrating flows, and affecting the amount and timing of peak flows (Grant et al. 2008).

Landslides are a part of the natural disturbance regime in Southeast Alaska as detailed in the Geology and Geologic Hazards assessment. Landslides can alter streamflow, contribute sediment and large wood to streams, and impact people and infrastructure. Increased frequency and intensity of extreme weather events have resulted in increased frequency of landslides (Thoman and McFarland 2024) and increased the impacts to people in Southeast Alaska.

Windthrow, fully described in the Terrestrial Ecosystems section of the assessment, is a natural disturbance process that recruits large wood into stream channels. Historic patterns of windthrow are tied to landscape exposure to storm events, though small scale (single to several tree) blowdown can occur even in less wind prone areas.

Land management activities can exacerbate the frequency and magnitude of natural disturbance regimes or affect aquatic ecosystems through the direct manipulation of streams and riparian areas. Effects are often localized, but watershed scale effects, like changes to peak flow magnitude and timing, can also occur (Naman et al. 2024). There is insufficient data to determine magnitude or variability of watershed scale hydrologic effects in Southeast Alaska related to logging. Logging practices before 1992 largely ignored the value of natural channel and riparian function; harvested high value riparian forests, mined stream channels for gravel and removed large wood from the channels. Changes in land management standards following the implementation of the 1990 Tongass Timber Reform Act and the 1997 Forest Plan have alleviated many of the direct effects to streams. Forest Plan monitoring since the 2016 plan amendment show that current management is generally meeting desired watershed conditions. The existing road network, legacy riparian harvest effects and legacy instream wood removal continue to influence aquatic ecosystems.

Improperly located, installed, or maintained stream crossing structures can restrict migration of fish (red crossings) and have negative impacts to flood resiliency at the crossings. Obstacles include excessive vertical barriers, debris blockages, undersized structures that constrict the channel and are prone to plugging, and gradient barriers. Most of the problem stream crossings on the Tongass were installed prior to the implementation of the 1997 Forest Plan standards and guidelines for culvert installation.

The number of red crossings changes over time due to natural conditions (landslides or plugging) or maintenance activity (removals or replacements). There are approximately 1,170 red crossing currently inventoried along the Tongass road system, according to the Tongass National Forest Waterxing database (USDA 2016b). Prioritizing red crossings for replacement can be completed Forest wide or can be project specific depending on where work is occurring. Prioritization is based on the extent to which the crossing is affecting passage (barrierity of the crossing) and the quantity and quality of upstream habitat. Failing structures at the end of their service life are replaced and upgraded to current passage standards based on access needs regardless of quantity and quality of fish habitat. The median amount of habitat above existing red crossings is 266 meters for Class I (anadromous or adfluvial fish habitat) and 180 meters for Class II streams (resident fish or fish habitat). Since 1998, approximately 702 crossings have been removed, replaced, or retrofitted to restore access to approximately 217 miles of fish habitats. The median amount of habitat above replaced or removed crossings is 458 meters for Class I and 250 meters for Class II streams. This shows most of the crossings with high quality fish habitat have been replaced. Continued maintenance of road drainage, and improvements to road crossings will retain access to fish habitats and support properly functioning ecosystems

In addition to extensive land management activities, current and historic mines in Southeast Alaska have had localized impacts to water quality in freshwater estuarine and nearshore areas. Ongoing impacts include the State of Alaska Tributary Creek (Greens Creek) 303d listing for lead (ADEC 2022), and tailing pond issues at the Kensington mine described in detail in the Energy and Minerals and Watershed Condition and Water Resources assessments.

Southeast Alaska is relatively free of invasive freshwater species; however, warming conditions and increased access to freshwater ecosystems for recreation and tourism may pose a threat to the spread of invasives. Invasive species that could become established in river and stream ecosystems include Atlantic salmon, New Zealand mudsnail, zebra/quaaga mussels and European Green Crab in intertidal areas. The Tongass has several known infestations of non-native and potentially invasive aquatic animal species (USDA 2016a). These species include the red legged frog (*Rana aurora*) and pacific tree frog (*Pseudacris regilla*). Atlantic salmon (*Salmo salar*) have been observed in marine waters and rarely in streams in Southeast Alaska (USDA 2016a). Invasive plants, such as reed canarygrass used along roads, have become established in stream systems on exposed gravel bars. The limitations of invasives are a function of frost-free days, subbasin land surface runoff, and snow cover (Geist et al. 2023) all of which are projected to change in the coming decades.

Best Management Practices (USDA 2012) to limit the introduction of invasive species and protect aquatic ecosystems are requirements on Forest Service contracts that interact with water. Overall results of Best Management Practices monitoring are summarized in the Watershed Condition and Water Resources assessment.

Scope and Scale

This assessment describes the characteristics, ecosystem services, status and trends, and major drivers and stressors for the four major Tongass aquatic ecosystem types. There is a focus on freshwater surface flow, but the assessed types also include karst due to the complex interaction between surface and subsurface flow in karst systems, as well as nearshore marine systems not on National Forest Lands due to similar interactions. This section is further organized using a broad process-based classification following Paustian (1992), and others (see Figure 1 modified from Montgomery and Buffington 1997) to group ecosystem types with similar composition and function. Each of the ecosystem components are interconnected and as such, this assessment integrates the aquatic, wetland, and terrestrial components to evaluate ecosystem integrity while riparian and wetland types are addressed in detail in the Terrestrial Ecosystems assessment. The process-based lens exists independently from other hydrologic classifications such as flow-regime which drives differences in thermal and biochemical regimes among different watersheds and ultimately patterns of biological productivity (Halofsky et al. DRAFT).

Tongass stream categorizations are also based on the Alaska Region Channel Type Classification System (Paustian 1992 revised October 2010). In this system, streams are categorized into channel types, which are grouped into nine process groups, or a combination of similar channel types based on major differences in landform, gradient, and channel shapes (USDA 2016a, Appendix D). Tongass streams and rivers are additionally categorized by class, based on their fish production values. The four category classes include Class I for anadromous or adfluvial fish habitat, Class II for resident fish or fish habitat, Class III for perennial or intermittent stream without fish, and Class IV for smaller intermittent and ephemeral streams with insufficient follow or sediment transport capability to directly influence downstream water quality or fish habitat capability.

The aquatic ecosystem grouping used for this assessment are as follows, The remainder of this assessment is organized by these ecosystem types.

- River and Streams – Glacial outwash channels
- Rivers and Streams – Hillslope channels

- Rivers and Streams – Toeslope channels
- Rivers and Streams – Valley bottom channels
- Rivers and Streams – Karst
- Lakes and Ponds
- Estuaries
- Nearshore Marine

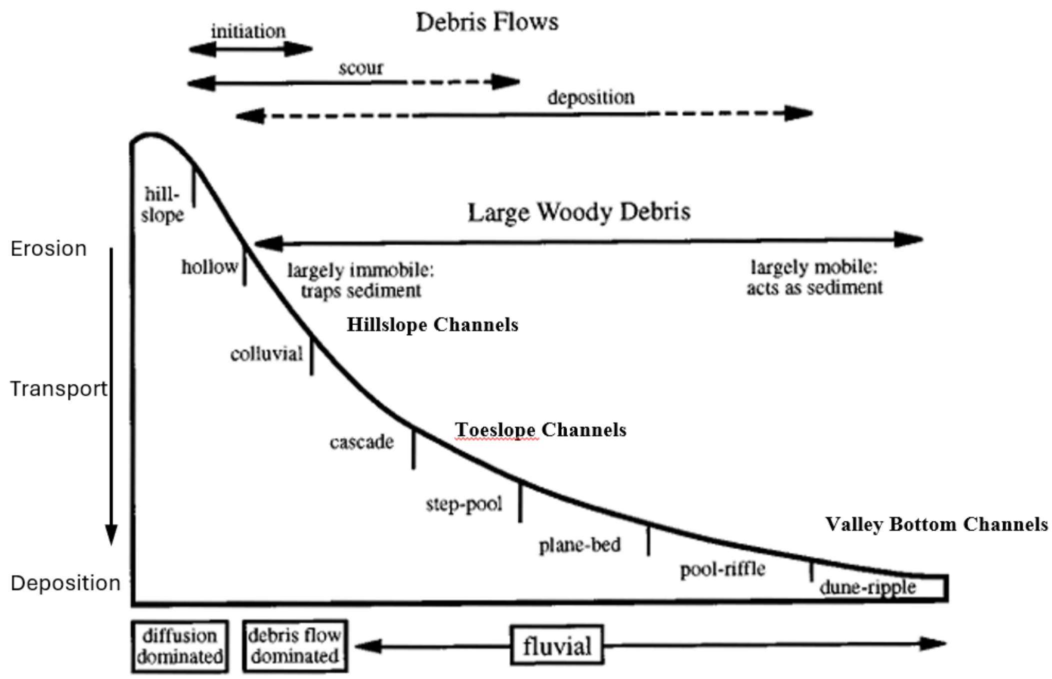

Figure 1. Conceptual diagram of channel form and process modified from Montgomery and Buffington 1997.

Ecosystem integrity is summarized as high, moderate, or low, which is spelled out in more detail in the Terrestrial Ecosystems assessment. In summary, high ecological integrity means that the ecosystem is expected to continue delivering major functions and services. Moderate ecological integrity means it is expected to continue delivering major functions and services, but at a reduced level. Low ecological integrity means it is expected to deliver only some of its major functions and services. However, no aquatic or terrestrial ecosystems on the Tongass National Forest were found to have low ecological integrity.

Types of Aquatic Ecosystems

Rivers and Streams

A streams' ability to carry water and nutrients from the mountaintops to the valley bottom and eventually out to the estuary and ocean can influence to the overall ecological integrity of the stream system. Each process group plays a role in the value of the overall aquatic ecosystem. The high gradient contained process group tends to source and transport sediments downstream while low elevation, low gradient floodplain streams tend to be more depositional in nature and act as salmon spawning and rearing habitats. Of the 46,000 miles of mapped stream, nearly 63% are high gradient contained process group (HC) and about 9% are high value salmon habitat floodplain (FP) streams (USDA 2016).

Key Takeaways

- Stream and river ecosystems on the Tongass are some of the world's most valuable freshwater ecosystems to salmon and other aquatic species.
- Stream ecosystems provide recreation, food resources, and both cultural and social values to people and communities that have access to them.
- The salmon lifecycle provides a pathway for marine derived nutrients to supplement freshwater aquatic and terrestrial ecosystems.
- Harvested riparian areas can result in fewer standing trees available for instream wood recruitment over time. As existing instream wood decays, there may be a gap in time before natural wood recruitment rates are attained.
- Shallow stream flows and warm stream temperatures can lead to low dissolved oxygen and fish die-offs. This can be exacerbated when the conditions exist in summer months when large numbers of adult fish return to spawn.
- Invasive plant species can be transported along streams and pose a threat to aquatic and terrestrial ecosystems. While there is currently very limited impact to aquatic and riparian systems from invasive species, there may be changes with changing climate.
- Land management activities including roadbuilding, mining, and vegetation management have the potential to alter the natural condition of aquatic ecosystems. While the current Forest Plan standards and guidelines have improved conditions, the legacy of land management on the Tongass still threatens aquatic ecosystems.

Glacial Outwash Channels

Ecosystem Description

Glacial processes and post-glacial sea level fluctuations reshaped the landscape of Southeast Alaska and continue to be the dominant process at work on the mainland (Nowacki et al. 2001, Halofsky et al. DRAFT). The meltwater from mainland and relic alpine glaciers feeds a variety of stream channel types that share common glacially driven temperature, sediment and flow regimes and play important physical and biological roles in the region.

Glacial outwash channels share many of the attributes of the flood plain process group. However, glacial streams tend to have larger seasonal variations in stream flow and large sediment loads that result in more dynamic or unstable channels and flood plains. These factors, along with colder water temperatures, tend to limit overall aquatic productivity. Adequate fish habitat and fish populations can vary in this process group, but it typically offers highly productive populations of resident and anadromous fishes within channel margins and side channels.

Ecosystem Services

- Glacier fed rivers and streams have more stable base flows and temperatures, which keeps water cooler during the summer.
- Cooler summer temperatures allow for higher dissolved oxygen in the water, which supports the conditions needed for healthy salmon runs

- Melt water from glaciers and snowfields provide downstream environments including the nearshore marine with a fresh supply of sediments, minerals and nutrients.

Status and Trends

Glaciers are projected to recede and, in some cases, disappear entirely in watersheds across the Tongass (Zieman et al. 2016; Rounce et al. 2023). In the next 50 years, the Juneau Ice Field is projected to decrease in volume and area by approximately 60% (Zieman et al. 2016). Over the last 10 years, maximum glacier ice melt occurred 2.5 days earlier in watersheds draining the western margin of the Juneau Icefield (Young et al. 2021). This has resulted in a shift in freshwater flow downstream in the early summers (Young et al. 2021). The reduction of glacial extent is resulting in new salmon habitat and increasing access to minerals for mining (Pitman et al. 2020). Currently, the western Juneau Icefield watersheds are still in an increasing glacier runoff period and have not reached peak water discharge. However, in watersheds with smaller glaciers where peak water discharge has already occurred, glacier meltwater contributions to lakes and rivers are declining. The timeline for glacier loss and impacts on stream hydrology in southeast Alaska is not well studied, though one study estimated that a period of peak water runoff to the Gulf of Alaska will occur between 2060-2070 (Hock and Huss, 2018). While most glaciers are receding, the Hubbard Glacier, near Yakutat, as well as a few others, is advancing. These differences will be important to understand when planning for infrastructure and other management in and adjacent to glacial outwash channels.

Drivers and Stressors

The main stressors for glaciers are changes in precipitation, increasing temperatures, the albedo effect, and other changes in climate. A shift in winter precipitation from snow to rain is an important hydrological potential trend that is projected for the Tongass National Forest (Zieman et al. 2016; Littel et al. 2018; Lader et al. 2020, Figure 1). These changes are expected to result in a loss in the diversity of hydrological regimes and will potentially result in temperature changes across aquatic ecosystems. The implications of these changes could negatively alter productivity and resilience of aquatic food webs (e.g. aquatic invertebrates, fish, wildlife) at watershed and regional scales.

Changing climate conditions are driving changes in glacial melt, stream temperatures, and runoff regimes. Glacier fed rivers have relatively high total summer streamflow and low summer streamflow variability as compared to non-glacier-fed rivers. Overall, the effects of receding glaciers on their associated aquatic ecosystem will initially result in a decrease in temperature and increase in flows, turbidity and nutrient cycling (Milner et al. 2017; Young et al. 2021).

As glaciers recede, some streams will initially have harsher conditions (e.g. scouring summer flows, cold and high turbidity). However, as glaciers shrink past a certain size relative to watershed area, glacier-fed streams will likely become more biologically productive and have a greater capacity to support fish. Although this may be associated with an increase in average biological productivity as streams warm, it could also reduce the unique foraging and growth opportunities that these systems likely provide, especially for cold-water species like salmon (Halofsky et al. DRAFT). Warmer streams may reduce the diversity of available foraging and growth opportunities for juvenile salmon and other freshwater fishes. Shifts in food availability for juvenile salmonids could decrease the capacity of watersheds to provide favorable year-round habitat.

Hillslope Channels

Ecosystem Description

High gradient headwaters channels are shallowly to deeply incised, high gradient mountain slope streams that compose the primary or first order drainage network in most Tongass watersheds and comprise the majority (60%) of mapped stream length. These channels are predominantly influenced by hillslope erosion processes. These steep, headwater streams are important source areas for runoff, organic and inorganic sediment transported to downstream riparian and fish habitats (Gomi et al. 2005). Hillslope channels are predominantly well-contained within narrow valley bottoms or ravines with riparian areas generally extending only to the upper stream side slope break. Riparian vegetation consists of narrow strips (often less than 50 feet wide) of alder, salmonberry, devil's club, or currant/shrub communities. Spruce and hemlock forests are also present on ravine side slopes. Soils in the adjacent upland area are shallow and subject to mass wasting. Although these are dominantly transport or erosive channels, significant amounts or forest litter and sediment can be trapped and stored temporarily behind woody debris jams. Most often, these segments are utilized by resident fish populations for various life stages. However, they also provide rearing habitat for anadromous fishes, typically in reaches less than 12% gradient.

Ecosystem Services

- Source areas for organic and inorganic sediment transport downstream

Drivers and Stressors

The drivers and stressors to hillslope channels include both natural and human induced influences. Natural influences include changes in climate conditions, frequency of landslides, and migration of species. Some human influences include land management activities such as road building, timber harvest, and mining.

Warming temperatures are projected to shift precipitation from snow to rain, with corresponding changes in hydrologic regime. Increases in peak flows could increase rates of erosion and sediment transport with consequences for channel scour downstream (Sloat et al. 2017).

Harvest within high-gradient channels has the potential to alter downstream transport of sediment and wood due to its generally steep and confined characteristics (USDA 2016, p. 3-64). With valley bottoms increasingly protected by riparian buffers, more logging takes place on hillslopes.

Roads crossing hillslopes fragment streams, interrupting natural sediment transport regimes and potentially introducing road sediments into stream channels. Roads also intercept groundwater flow, bringing it to the surface; consolidating and routing it laterally along road ditches.

Hillslope channels are more suspectable to windthrow then less incised lower slope channels, especially when both sides of the stream are harvested (USDA 2021).

Status and Trends

Hillslope channels are protected by buffers designed to maintain natural ranges of side slope stability and delivery of large wood to the channels with buffer widths varying by stream class and type. Additionally, reasonable assurance of windfirmness may be required that could include additional width to the buffer depending on site conditions. Reasonable Assurance of Windfirmness (RAW) buffers are managed areas designed to contain windthrow within the area where timber harvest is allowed. It is used to protect Riparian Management Areas and adjacent stands (USDA 2016a).

A 22-year study of monitored buffers on the Tongass found steep incised hillslope (class III) channels are more suspectable to blowdown than other channels. Higher average windthrow occurs adjacent to channels that have harvest and buffers on both sides of the channel as opposed to just one side having harvest (USDA 2021). Additional RAW buffer widths are important for maintaining the integrity of these buffers. Preliminary results indicate a median of 0.7% windthrow in all monitored stream buffers. Approximately 82% of buffers have had 10% or less windthrow. Buffers that had more than 50% windthrow were predominately on class III hillslope streams with timber harvest, and buffers, on both sides of the stream (USDA 2021). The average amount of trees blown down due to windthrow in hillslope buffers is 9.8%, The 22-year study of monitored buffers is currently being analyzed by Oregon State University researchers with results expected in late 2025. Hillslopes harvested without riparian buffers have not been the focus of instream restoration. Under the current Forest Plan (USDA 2016a), these channels will receive buffers and windthrow evaluation during the second harvest entry.

The existing road network continues to have long-term consequences on the function of hillslope channels. There are approximately 573 red crossings located on hillslope channels across the Forest. Gradient and perch of the crossing are the most common issues in these channels. Crossings are prioritized for replacement or removal based on road objectives, upstream habitat availability, potential consequences of failure and annual funding. Other aquatics issues related to channel interception and diversion by roads are addressed at the project scale through maintenance or removal of culverts (road storage), however lack of funding continues to limit proper implementation.

Toeslope Channels

Where steep mountain and hillslope channels transition to the valley floor, gradient and stream power decrease, the dominant process shifts from erosion to transport, and different types of channels occur. Whereas hillslope channels are dominantly controlled by bedrock, the toeslope types begin to include mixed bedrock and alluvial substrate as materials eroded from the hillside are incorporated into the channel bed. Areas of glacial till offer additional sources of erodible substrate. The most dramatic transitions form fan-shaped landforms of colluvial material through which channels alternately carve and deposit. Well-drained and productive forests are often adjacent to these channels.

While some valley-shapes support one to several large toeslope channels, the predominant condition is the existence of many small channels that gradually intersect and coalesce moving downstream. Various expressions of channel form can occur including step-pools formed by wood or rock, largely uniform plane-bed channels and sporadic pool and riffle sections. Toeslope channels encompass the upper bounds of anadromous fish habitat and the majority of habitat for resident cutthroat trout and Dolly Varden char. Mapped channel process groups within the toeslope category include: alluvial fans, moderate gradient mixed control, and moderate gradient contained. Each of these are briefly described here.

Alluvial Fans

These are generally tributary streams that are located on footslope landforms in a transitional area between valley flood plains and steep mountain slopes. They are low to moderate gradient (generally less than 5 percent gradient) stream channels that are strongly influenced by sediment deposition processes. Alluvial fans are formed by the rapid change in sediment transport capacity as the high energy mountain slope stream segments spill onto the valley bottoms. Stream channels change course frequently, resulting in a multi-branch stream network. Sediment deposition tends to create elongated islands of bare cobbles and gravel between these multi-branched channels. Alluvial fan stream channels are often unstable. Streamflow may be intermittent during the summer and winter months due to infiltration of water into coarse gravel substrate. Riparian areas commonly associated with these poorly contained streams are very narrow at the top of the fans and become wider as the fan spreads out. Due to the complex stream network, riparian areas for alluvial fan channels may be extensive.

Moderate Gradient Mixed Control

Mixed moderate channels are a mixture of stream channel containment. These channel types are moderate gradient (2-6 percent) streams where sediment deposition processes are limited. Some segments are constrained by bedrock outcrop or the valley walls, while other areas develop narrow flood plains. Streambanks are dominated by coarse alluvium (boulders, cobbles) or bedrock. These stream segments generally have a balance between sediment transport and deposition. Riparian vegetation is important in regulating stream energy losses through large woody debris input. Large wood forms such water energy dissipaters as log step pools and lateral scour pools. Wood can strongly influence channel form, sediment storage and pool and cover habitat in streams with minor bedrock control. These channels provide high quality rearing habitat, and spawning habitat in many cases, for resident and anadromous fish populations. Productivity can be variable in these segments, depending on flow regimes and seasonality variations. Riparian areas seldom extend beyond 100 feet from stream banks.

Moderate Gradient Contained

Moderate gradient contained channels are completely contained by adjacent landforms and channel side slopes. Streambank and streambed erosion are frequently controlled by bedrock outcrops. These channels have balanced or transport-oriented sediment regimes. Gravel bars are infrequent channel features (plain bed channels). Large wood within the wetted channel provides localized sediment storage sites and habitat diversity. Riparian areas are limited to the bank influence zone and are generally less than 100 feet. Resident and anadromous fish population are present in this process group. Spawning habitat is often limited due to variations of bedrock and alluvium streambed materials. These segments provide high quality rearing habitat and seasonal refugia for many fish species.

Drivers and Stressors

Toeslope channels are responsive to upslope conditions and disturbance. They often are the runout zone for avalanches and debris flows. Alluvial channels interact with large wood recruited from the adjacent riparian and provide roughness elements in the channel and floodplain which add complexity. Increases in streamflow are projected to affect toeslope channels by increasing scour and sediment transport (Sloat et al. 2017).

Riparian harvest predating the standards of the 1997 Tongass Forest Plan affected many small unmapped toeslope channels. Logging targeted the highly productive and well-drained alluvial fans as well as broadly harvesting across many toeslope areas. Lack of riparian structure on alluvial fans may result in increased channel movement.

The road network designed for logging extraction often traverses the toeslopes resulting in the fragmentation of many stream systems and fish habitat and the interruption of natural sediment transport regimes and natural channel movement. Small unmapped channels are often ignored and consolidated to single crossing points – effectively rerouting natural surface and subsurface flow paths.

Status and Trends

Timber: Improvement in stream mapping have identified many stream channels traversing the toeslopes. in already harvested areas. This allows improved understanding of hydrologic connections and maintenance of connectivity across roads and through second entry harvest units.

Thirty-eight windthrow monitoring sites occur in toe slope channels. Average amount of cumulative windthrow is 3.8%. Eleven sites had no windthrow and most of these sites were harvested and buffered on one side only.

There are 34 red crossings on alluvial fan channels, 355 red crossing on moderate gradient mixed control channels, and 60 red crossings on moderate gradient contained channels. Gradient, perch and constriction are the most common issues in toe slope channels. Crossings are prioritized at the District or Forest level and are upgraded to current design standards for fish passage when replaced.

Valley Bottom Channels

Ecosystem Description

Valley bottom channels include a suite of low-gradient stream channels common to valleys across the region. They range in form from dynamic alluvial channels with wide, well-drained riparian floodplains to entrenched bedrock-controlled reaches with limited off-channel areas and extensive poorly-drained wetland complex channels. The channels are predominantly depositional, with both single thread and multi-branched areas common.

At the watershed scale, valley bottoms are often composed of a mosaic of contained and alluvial types with riparian areas that range from well-drained and highly productive to forested or non-forested wetland systems as described below.

Flood plain channels are relatively efficient at trapping nutrients from riparian forest detritus and inorganic sediment delivered from headwater areas. These streams also buffer against flood disturbances by spreading runoff across densely vegetated flood plains and into numerous side channels and sloughs. Shallow alluvial aquifers associated with these streams store runoff from flood flows and hillslope tributaries and slowly release groundwater to surface channels during periods of low rainfall. The ability of flood plain channels to dampen the effects of runoff extremes and to store nutrients are primary factors contributing to productive aquatic communities found in these streams. These streams offer high quality spawning and rearing habitat for a variety of salmonid species.

In contrast, low-gradient contained channels are well contained by adjacent landforms. Bedrock outcrops that constrain or control channel migration and downcutting are common. The riparian influence zone often extends over 100 feet up channel side slopes on these entrenched streams. Channel side slope vegetation plays a major role in controlling the rate of downslope soil movement and large wood introduction into stream channels. Large wood accumulations also dissipate stream energy and store sediment within the stream channel. The larger valley and lowland streams often have narrow alluvial terraces within the river gorge. Riparian areas are discontinuous and are generally less than 150 feet wide. Streambed and banks are dominantly composed of coarse alluvium (cobble to boulder size) and occasional bedrock outcrops. These streams generally have a balance between sediment transport and deposition. Waterfalls and cascades that form at bedrock nick points can be barriers to upstream anadromous fish migration. Fish populations are moderately productive within this process group. Resident fish typically occupy channel margins and deep pools with slower moving water. Anadromous fish often utilize these reaches for migration to more appropriate spawning habitat. Predominant bedrock channel beds offer low quality spawning habitat.

Palustrine channels are low gradient (less than 1 percent slope) and associated with low relief landforms dominated by wetlands. Water movement and sediment transport rates are low. These channel types typically act as storage areas for fine sediments. Streambanks are composed of dense organic root mats that are resistant to bank erosion. Streambeds consist of fine alluvial gravel and sand, and organics.

Flood waters spread out across adjacent wetlands to buffer against downstream flooding. Another important function of these channels is to sustain streamflows during dry periods. Slow flowing palustrine streams can have elevated water temperatures that can be detrimental to some aquatic species during summer months. Riparian areas are usually wider than 100 feet and can be very wide in peatland landscapes. Streambed material is typically too fine to provide spawning habitat for fish. These segments provide high quality rearing habitat for juveniles, and in some cases, adult fish may overwinter within palustrine areas.

Ecosystem services

- Large wood instream and on floodplains act to mitigate flood flows and provide critical components to aquatic ecosystems by diversifying sediments, forming pools and riffles, and capturing food and for aquatic species.
- Shallow aquifers store and slowly release groundwater during periods of low flow
- Provision of high-quality spawning and rearing habiatt for salmonids

Drivers and Stressors

In undisturbed watersheds in-channel process and function is closely linked to adjacent floodplains – delivering sediment and wood during floods and through lateral erosion recruiting trees to the stream channel adding structural complexity. Large wood in turn encourages the development of distinct slow water channel units (pools), sediment sorting and hyporheic flow. These depositional systems are sensitive to changes in the adjacent riparian areas as well as from upslope in the watershed.

Pulses of sediment delivered to the stream channel from upland sources such as landslides can affect valley bottom channels for years to decades as the channel transports, sorts and stores the sediment. Natural patterns of erosion and scour in hillslope and toeslope channels are predicted to increase (Sloat 2017), increasing the potential for sediment loading in the valley bottoms. At the reach scale the effects of large sediment inputs can be dramatic; dispersed flow, channel evulsion, and diminished habitat capability would be expected. At the watershed scale, these events add complexity and may offset change elsewhere in the watershed.

Seasonal pulses of marine derived nutrients delivered by spawning salmon bring substantial benefit to instream and valley bottom riparian areas (Rinella et al. 2013), where the majority of adult anadromous fish return. When adult salmon return to the freshwater ecosystem to spawn and die they contribute directly and indirectly to aquatic and terrestrial productivity. Fish carcasses may be moved by floodwaters onto the floodplain, or carried by wildlife intro the riparian areas where they decay and contribute nutrients. Indirectly, nutrient availability enhances primary production and ultimately overall system productivity. Changes in fish populations over time could have subsequent changes in nutrient cycling and associated food webs. While this is true in all channel types supporting adult salmon returns, valley bottoms have the vast majority of adult anadromous fish return.

Natural incidence of windthrow affecting valley-bottom riparian forest tends to be lower than that of exposed hillslopes, however, it is still present and a natural mechanism for wood recruitment to channels and riparian areas.

Riparian harvest practices have been shown to interrupt the natural rate of large wood delivery to stream channels (Woodsmith et al. 2005), however the post-harvest projections of in channel wood decline and subsequent channel simplification are not equal among channels with direct riparian harvest. Initial wood loading, stream size and power, and riparian productivity factor into channel response. Recent analyses of in-channel data suggest that instream large wood in harvested channels is increasing naturally (Flitcroft et al. 2022, Moore et al. 2024).

Timber harvest adjacent to streams can influence stream temperature, large wood contributions, and extent of refugia fish can find from summer low flows. In a study of fish populations and stream habitats on the Tongass, researchers found that fish may have greater opportunities for refuge from late summer, low flow conditions in watershed with greater than 42% old growth (Flitcroft et al. 2022).

Roads crossing the valley-bottom or running parallel to the channels alter the access to floodplains, side channels and tributaries. Legacy road construction practices included mining gravel from streams and adjacent floodplains for road construction resulting in alterations to natural channel form as well as connectivity with the adjacent floodplain.

Mining impacts are a concern brought up during many public engagements. Valley-bottoms are specifically a concern for trans-boundary mines on larger rivers. Possible impacts from tailings pile breaches in Canada, bringing contaminated materials into larger rivers on the Tongass, could affect fish habitat and aquatic ecosystems. While the Tongass National Forest Plan cannot affect mining activities in Canada, the understanding of potential impacts and emphasis on cooperation is important.

Status and Trends

Mandatory no-harvest buffers along fish bearing streams have been in place on the Tongass since the implementation of Tongass Timber Reform Act (TTRA) in 1992 and the additional riparian protection in the 1997 Forest Plan; however, effects of direct riparian harvest prior to TTRA continue to affect natural rates of large wood recruited to the channel and instream wood loading. Proper Functioning Condition (PFC) surveys (Dickard et al. 2015) of channels affected by riparian harvest have shown a mixed response possibly due to multiple factors including initial wood loading at the time of harvest, channel size, stream power and degree of in channel management (e.g. active wood removal, gravel mining). Some channels show lower wood and pool counts and have been targeted for instream wood placement restoration projects. Other channels with similar riparian history have maintained in-channel structure, though are still considered at risk. Smaller sized (large) wood, such as alder and smaller conifer trees, which are recruited from harvested riparian area; play a role in moderating streamflow and capturing sediments and may be bridging the gap in riparian recruitment but have shorter residence times. (Flitcroft et al. 2022).

In-channel restoration projects have been implemented primarily on low-gradient salmon-bearing habitat across the Forest, focusing on areas where management has degraded natural channel function. Described in more detail in the Watershed Condition and Water Resources assessment, instream restoration adds wood to the channel to accomplish specific objectives including channel stabilization, habitat creation and maintenance, floodplain connectivity and improved resilience to flood flows. Channel evaluation and restoration projects are ongoing across the Forest and an evaluation of restoration effectiveness is in progress.

Monitoring of twenty-nine valley bottom stream-buffers to detect harvest-related windthrow affecting valley bottom stream channels took place from 2000 to 2022. The results show an average of 6% windthrow in valley bottom buffers compared to almost 10% in hillslope channel buffers. All sites are buffered and harvested on one side.

Roads originally built in or across floodplains continue to affect natural channel movement. Where roads are no longer needed, they have been identified for storage or decommissioning following the current Access and Travel Management guidelines. These activities improve the connectivity of water across the road prism and minimize road-derived sediment transport. Improvements to operational roads including fish passage and drainage improvements are ongoing with the goal to minimize impacts to physical and biological connectivity and function while maintaining infrastructure. There are currently 27 red crossings on floodplain channels, 117 on palustrine channels and one red crossing on a low-gradient contained channel. The common issues are constriction, gradient and perched culverts on floodplain channels where palustrine channels are more often blockage and gradient issues. In almost all cases (USDA 2016b) culvert replacements increase the size of the structure to better match channel widths and accommodate flood flows.

Karst

Key Takeaways

- Karst systems moderate the effects of storms on streams, critical in an era of increased precipitation events and extreme weather patterns. Resident time for groundwater in karst systems results in cool, even water temperature and consistent flow rates.
- Karst systems support a large diversity of aquatic invertebrate populations in caves and streams.
- Karst and cave systems provide critical habitat, food, and shelter for fish populations. Smolts and resident trout use the cave systems for protection from predation, for shade, and for a feeding area, since many invertebrates utilize the photic zone of the cave system for breeding and shelter. Adult salmon have been seen spawning through some cave systems, and evidence of salmon spawning in the caves has been found.
- Karst forests are productive since they are well drained and support mature, old-growth Sitka spruce, western hemlock, and cedar trees.
- Current management direction specific to karst consideration and protection has been effective in minimizing known effects to these ecosystems.

Ecosystem description

Karst ecosystems, formed by the dissolution of soluble limestone and other carbonate bedrock, are distinctive environments characterized by a unique interplay between surface and subsurface processes. Karst areas are characterized by distinctive landforms such as caves, sinkholes, and springs. The high degree of connectivity, driven by water readily moving between the surface and subsurface, creates distinct sediment, energy, and nutrient cycles not found in other ecosystems.

The Tongass National Forest contains over 400,000 acres of globally-rare, temperate rainforest karst. The region's high precipitation, acidic groundwater drainage from muskeg peat, and pure limestone each contribute to rapid limestone dissolution rates that form dramatic karst features and a unique ecological environment. Some characteristics of this ecological unit include mature, well-developed spruce and hemlock forests along valley floors and lower slopes, increased productivity for plant and animal communities, productive aquatic communities, well-developed subsurface drainage, and the underlying unique cave resources (Baichtal and Swanston, 1996, Wissmar et al. 1997, Bryant et al. 1998). The alpine meadows found on karst support 2-3 times the species diversity of forbs, flowering plants, grasses and sedges compared to no karst substrate.

Cave ecosystems provide stable environments in total darkness with buffered pH, high humidity, and constant temperatures between 37 and 42° Fahrenheit. Due to the darkness and resulting lack of photosynthesis in caves, there are very few energy inputs in the ecosystem. Most energy enters the caves in the form of particulate organic matter or dissolved organic carbon (Simon and Benfield 2001). This dark, stable, low-energy ecosystem is hostile to most life, except for species that are well adapted to it. Of the species that can thrive in the cave environment, many can only survive underground. As such, caves are often home to endemic and rare species not found anywhere else.

Ecosystem Services

Karst landscapes on the Tongass National Forest host highly productive aquatic habitats and fisheries that directly benefit human subsistence, commercial, and recreational uses. Karst ecosystems can be eight to ten times more productive than adjacent non-karst dominated aquatic habitats. They support a higher abundance, distribution, density, and variety of invertebrate species than the non-carbonate-based systems, have higher growth rates for smolts and resident fish, reflects less variable water temperatures and flow regimes, and contain unique habitat affecting species distribution, abundance, and adaptations (Baichtal and Swanston 1996). The increased productivity of both resident and anadromous fisheries in karst ecosystems directly benefits recreational, subsistence, and commercial fishing in Southeast Alaska.

Karst aquifers can store and transmit large amounts of water and are often used a source of clean drinking water. While few municipal water supplies are sourced directly from a spring in a karst landscape, some are fed either partially or entirely through karst systems, such as Port Protection.

Drivers and Stressors

Karst ecosystems on the Tongass are vulnerable to both natural and human-induced drivers and stressors. Because of the connectivity between surface and subsurface in karst areas, aquatic and terrestrial habitats on the surface and subsurface can be affected by surface activities. Human development, timber extraction and windthrow on karst landscapes may mobilize soil and may lead to desertification, plugging of subsurface conduits, and cause changes in hydrology. These, in turn, affect vegetation growth, water quality, water quantity, and the productivity of terrestrial and aquatic habitats. While uncommon in karst areas, landslide that occasionally occur in steep karst areas have similar effects. While windthrow and landslides are natural occurrences, they can be affected my management activities.

Past timber management on karst predating the protective measures in the 1997 Forest Plan affected the caves of the Tongass. Slash, large cut logs, and thick beds of sediment are common in the sinkholes and cave entrances of young growth forests which were harvested decades ago, but not those harvested since 1997. Many cave entrances and passages have been so filled with debris that they limit access by humans and animals and alter hydrologic regimes.

Status and Trends

The broad-scale effects of past timber harvest on the karst landscapes on the Tongass are not well studied, but studies in similar forests in British Columbia have shown that timber harvest on karst led to increased soil loss and bare-rock exposure (Harding and Ford 1992, Baichtal 1993). Field observations and aerial photo interpretations on the Tongass show evidence of greatly increased surface runoff on karst areas after older harvest, increasing the sediment, nutrient, and debris transport capability of these systems. Soil loss, increased bare-rock exposure, plugging of open features with slash, and increase variability and termination of flow in karst springs were all been observed on the karst landscapes of the Tongass from past harvest activities. Most low-elevation karst landscapes on the Tongass National Forest have been harvested for timber. Timber harvest is now moving onto steeper, higher elevation karst areas which are characterized by shallower, better-drained soils, and often observed as a thin, organic mat.

Standards and guidelines for karst protection were introduced in the 1997 Forest Plan and revised during plan amendments (USDA 2016a). Plan direction includes the categorization of karst vulnerability into low, medium and high risk and protections tailored to each category. Timber harvest and road building is generally not permitted in high risk areas. Focused karst mapping from field-surveys, dye traces and remote sensing has improved the understanding of the extent of karst systems and allowed for more precise management of timber adjacent to karst. Observations have shown that the current standards and guidelines have minimized the type of effects seen in pre-1997 timber harvest, with recent observations supporting their efficacy. Refer to the Geology and Geologic Hazards assessment for detail.

Timber management on young growth karst forests is expected to increase in the coming decades, in those areas that are found to be suitable for timber harvest. Impacts of repeated harvest on karst in the Tongass has not been studied. Even without active restoration, karst features impacted by slash, log fill, and sedimentation may experience some level of natural remediation over the next few hundred years as the slash and logs within them decay and flush out. Recent timber harvest on karst is far less impactful on karst ecosystems than historic harvests due to the implementation of karst management strategies in the Forest Plan, and avoidance of high vulnerability karst. Continued focus on, and protection of, karst ecosystems in planning timber harvest and other management activities can continue to support the upward trend of karst ecosystems on the Tongass National Forest.

Lakes and Ponds

Key Takeaways

- Lakes on the Tongass National Forest are overall in pristine condition. The majority of data suggest that no considerable sources of pollution are affecting the health and integrity of this ecosystem.
- Lakes provide important physical and biological roles within the watershed by physically influencing streamflow and temperature, and by providing habitat to aquatic and terrestrial organisms.
- Low elevation lakes are often high-quality fish rearing habitat providing for many species of wildlife (e.g. beaver, mustelids, loons, eagles, swans, and other water birds).
- Lakes are important to the communities in Southeast Alaska as hydropower sites, hatchery and remote release locations, and for their subsistence and recreational values.
- As with many other resources, lake conditions are likely to change with projected changes in temperature and hydrologic regime.

Ecosystem description

Approximately 213,000 acres of lakes and ponds are present on Tongass National Forest lands. Of these, approximately 3,300 lakes and ponds are mapped as having anadromous or high-value resident fish habitat. Another 1,000 lakes and ponds are mapped as resident fish habitat (USDA 2016, p. 3-104).

“Lakes in southeast Alaska have been similarly categorized as turbid, clear, and stained/brown water based on their physicochemistry, which diverges based, to some extent, on their runoff source, similar to fluvial systems” (Koenings and Edmundson 1991). Darkly colored or “brownwater” lakes have high dissolved organic carbon concentrations, including colored tannins and humic acids resulting from runoff through organic-rich soils. In contrast, clear-water lakes, which are often found at higher altitudes and in drainages with shallower soils, have low turbidity, nutrients, and organic carbon concentrations (McCoy et al. 1976). Lakes fed by glacial meltwater (proglacial lakes) are turbid and cold, and can have high total phosphorus depending on watershed lithology (Burpee et al. 2018, St. Pierre et al. 2019, Halofsky et al. DRAFT).

Lakes accessible to salmon are classified as essential fish habitat. Large anadromous lake systems accessible to communities in Southeast Alaska are important for subsistence (Klawock, Redoubt, Sitkoh, and others). Lakes offer high quality spawning, rearing and refugia for a variety of salmonid species and other aquatic organisms. Small ponds, particularly beaver ponds, can be highly productive overwintering habitat for salmon. Both fish bearing and non-fish bearing lakes have been used for fisheries enhancement. The 2016 Forest Plan (USDA 2016a) listed 5 lake/stream fertilization projects, and 7 lake stocking projects completed between 1996-2014.

Most of the hydro-electric projects in Southeast Alaska (on and off NFS lands) are sourced from lakes. The target lakes are predominantly in steep drainages with little anadromous habitat overlap. However, as most stream systems have some near-saltwater anadromous habitat, any flow modification from dams, or penstock/powerhouse development has the potential to alter flow regimes or habitat quality (temperature, dissolved oxygen, nutrient and sediment flux), affecting small populations of salmon and other fish species.

Ecosystem Services

Lakes play important physical and biological roles within the watershed. Lakes act to buffer both high and low streamflow and insulate downstream reaches from upstream disturbance effects. Lakes play important roles in spawning, overwintering and rearing of salmonid species, are important habitat for resident and migratory waterfowl. Lakes are important for surface-groundwater exchange and moderating water temperatures.

Drivers and Stressors

Historically, large lakes accessible by floatplane from surrounding communities were stocked with native and non-native lake species including brown trout, rainbow trout and grayling. Many of these stocking efforts have not persisted to the present day due to lake conditions or competition with native species, though the State of Alaska still stocks sportfish species in lakes across the region. In Yakutat, illegally stocked northern pike were eradicated from ponds due to concerns over their potential to invade the Situk river. No other invasive lake species are of current concern. Lake temperature can have both positive and negative implications at multiples scales. At the watershed scale lake coverage is an important physical driver for stream temperature (Winfree. et al. 2018). Lake coverage is associated with warming downstream reaches in both summer and winter. Increases in lake temperature are associated with increases in biological production (Kovach et al. 2013) but may also influence the prevalence of hypoxia and fish kills in low gradient reaches downstream (Sergeant et al 2023).

Status and Trends

Under the 2016 Forest Plan, lakes are protected by a 100’ no-cut commercial harvest buffer. The function of the lakeside riparian buffer, like streams, is to minimizes excess sedimentation input and allow for allochthonous inputs to lakes including large wood (LW) as cover, and leaf litter/insects to support biological production (USDA 2016a, Appendix D). Approximately 890 acres of lake riparian harvest has occurred on national forest lands. The majority (57%) of this harvest is clustered in three areas, Yakutat, South Prince of Wales Island and Admiralty Island. While no habitat (large wood placement) enhancement projects have focused on lakes, thinning treatments to improve lakeside riparian habitat have been proposed and are underway in the Cube Cove priority watershed on Admiralty Island. Lakes affected by upstream sediment load have been considered for dredging, and shallow lakes in Yakutat have undergone vegetation removal projects.

The most recent comprehensive sample of lake condition was undertaken by the Alaska Department of Environmental Conservation (ADEC) in 2017 as part of the Alaska Monitoring and Assessment Program. A statistical sample of 37 lakes were surveyed using a suite of physical and biological parameters and a field report produced (ADEC 2017). The report showed that lakes sampled on NFS lands did not exceed state water quality standards in any parameter. Even so, signatures of industrialization are evident in lake sediments, where atmospherically deposited mercury levels are higher than background levels (Lepak et al, 2020), and site-specific problems related to roads and mining do occur.

Estuarine

Key Takeaways

- Estuarine channels are important rearing locations for anadromous fish and exist within larger highly productive estuarine areas that are important for many species.
- Estuarine channels are sensitive to changes in both upland and marine processes.
- Forest Plan standards for estuarine and beach fringe management are sufficient to protect the natural condition and function of estuarine channels.

Ecosystem Description

Estuarine channels occur at the mouths of watersheds with estuarine landforms located along inlets and deltas at the head of bays. Water level fluctuations, channel morphology, sediment transport, and water chemistry are influenced to some degree by saltwater inundation in these channels. Riparian areas consist of saltwater marches, meadows, mudflats, and gravel deltas that are depositional environments (described in the tidal wetland section of the Terrestrial Ecosystems assessment). Estuarine channels include single to multiple thread channels, often shallowly entrenched, and poorly constrained. Stream substrate is fine textured alluvium that is easily eroded by currents and wave action. Much of the sediment produced from any given watershed is ultimately deposited in or along the estuarine channel types, consequently, these channels are highly sensitive to upstream disturbances. Sedge and grass communities dominate the riparian vegetation. The amount of stream migration and channel braiding varies, depending on bank and bed materials and upstream erosion and sediment transport regimes. Riparian areas are normally more than 100 feet wide and are often several hundreds of feet wide on large river deltas. Estuarine areas provide habitat for highly productive spawning areas. Foraging activities are substantial for marine and freshwater fish within these areas. Wetted vegetation in estuaries provides refugia for rearing fish, including salmon species. Large estuarine channels are prime recreation access points for fishing and boating. A discussion of tidal wetlands from a terrestrial perspective can be found in the Terrestrial Ecosystems assessment.

Drivers and Stressors

The intertidal, including estuarine stream channels, is a dynamic ecosystem subject to both terrestrial and marine drivers and stressors. Estuarine channels receive and deposit sediment from the upland watershed and are sensitive to changes in flow and sediment load. Deposition, combined with isostatic rebound is extending estuarine systems seaward, especially where the adjacent nearshore environment is shallow.

Changes to the marine environment affects estuarine channels. Changes to sea surface temperatures, sea level and changes to water chemistry can affect the biological capability of estuaries.

Coastal roads and marine access points that intersect or are adjacent to estuarine channels can alter natural channel movement and inhibit fish passage. Elevated road prisms act as dikes that restrict natural channel location and deposition patterns and have the potential to introduce pollutants to estuarine waters.

Status and Trends

Considered on a Forest-wide scale, estuarine channels have high scenic integrity. Approximately 400 acres of estuarine riparian area was harvested on the Tongass National Forest, mostly between 1958 and 1972. Estuarine and beach fringe standards and guides exclude these areas from development in the current Forest Plan (USDA 2016) with the harvested areas left to naturally regenerate.

The current Forest Plan (USDA 2016) recognizes the ecological value of estuaries and has guidelines to minimize changes to the natural ecological processes and functions present in the channel and associated intertidal areas. Where management will affect estuarine channels best management practices will be put in place to minimize impacts.

Road infrastructure currently affects several estuarine channels. There are 3 red crossing in estuarine type channels with gradient as the common issue. These impaired crossings are listed for remediation as funding allows.

Estuarine channels and their adjacent intertidal areas are vulnerable to climate driven changes in freshwater and marine temperatures and upland conditions that influence the magnitude and timing of streamflow and sediment transport. Estuarine channels are highly dynamic, so changes may not risk integrity.

Nearshore Marine

Key Takeaways

- The nearshore ecosystem is a unique and important triple interface between air, land and sea that provides linkages for transfer of water, nutrients, and species between watersheds and offshore habitats.
- The inside coastal waters, where this runoff is concentrated, have estuarine characteristics, whereas the outer coast has greater stability of salinity and temperature, directly influenced by the Gulf of Alaska
- The nearshore is the base of the food chain. It is a source of primary production for export to adjacent habitats (primarily by kelps, other seaweeds, and eelgrass), as well as a recipient for primary (phytoplankton) and secondary production (zooplankton) transported from offshore systems.
- The nearshore includes a variety of unique habitats for resident organisms (e.g. sea otters, seals, sea lions, shorebirds, seabirds, nearshore fishes, kelps, seagrasses, clams, mussels, and sea stars).
- It provides nursery grounds for migratory marine animals (e.g., crabs, salmon, herring, seabirds, and whales) and feeding grounds for important consumers (e.g., killer whales, harbor seals, sea otters, sea lions, sea ducks, shorebirds and many species of fish.
- Nearshore ecosystems are a source of animals important to commercial and subsistence harvests (e.g. marine mammals, fishes, crabs, mussels, clams, chitons, and octopus).
- Recreational activities including fishing, boating, camping, and nature viewing are important to residents and tourists.

Ecosystem description

Seaward, beyond the tidal wetlands and estuaries (addressed in the Terrestrial Ecosystems assessment section) lies the nearshore marine environment. While this ecosystem component is not within the bounds of the Tongass National Forest, there are strong physical and biological linkages between land and ocean. defined by species interactions across ecological boundaries. High densities of specialist predators (sea otters, sea ducks, black oystercatchers, sea stars) exist within a diverse and productive system full of kelps and invertebrates that don't occur in any other habitats. Kelps and eelgrasses are "living habitats" that serve as nutrient filters and provide understory and ground cover for planktivorous fish, clams, and urchins, and a physical substrate for other invertebrates and algae. Kelps and eelgrasses also provide spawning and nursery habitats for forage fish and juvenile crustaceans. Nearshore marine ecosystems face significant challenges at global and regional scales, with threats arising from both the adjacent lands and oceans.

Southeast Alaska is a subarctic region where glacial ice and erosion have created an intricate landscape with many islands, deep inlets, fjords, and interconnected channels. The complex coastal topography of Southeast Alaska leads to environmental variability, most notably between inner coast and outer coast regions (Weingartner et al. 2009). We refer to the interior islands and waters adjacent to the Coast Mountain range as the inner coast region. The outer coast region includes the outermost islands and waters directly connected to the Gulf of Alaska, including Sitka Sound.

Glaciers and ice fields contribute significantly to freshwater discharge to the Gulf of Alaska and are responsible for 47% of the total freshwater discharge to the Gulf of Alaska (Neal et al. 2010). In Southeast Alaska, the gradient of freshwater discharge is from the interior Coast Mountain range to the outer coast (Weingartner et al. 2009). Freshwater runoff is seasonally most pronounced during the spring and autumn, causing water column stratification that is strongest near freshwater discharge sites (Pickard 1967; Royer 1982; Weingartner et al. 2009). The inside coastal waters, where this runoff is concentrated, have estuarine characteristics, whereas the outer coast has greater stability of salinity and temperature, directly influenced by the Gulf of Alaska (Pickard 1967; Murphy and Orsi 1999). This significant freshwater influx fuels coastal circulation in the Gulf of Alaska (Royer 1981). As a result of significant glacial fluctuations in the last 10,000+ years, marine communities in inner coast regions of Southeast Alaska are glacially influenced, while those on the outer coast are not. Recent studies indicate that levels of glacial coverage can alter the timing and magnitude of freshwater, dissolved organic matter, and nutrient yields to coastal marine communities (Hood and Scott 2008; Hood et al. 2009).

Southeast Alaska has a more diverse macroalgal community than any other Alaska region (Lindstrom 2006, 2009). Large within region diversity differences, in particular greater diversity at the outer coast sites, may be strongly influenced by variation in freshwater discharge to the nearshore marine environment due to glaciation at the inner coast. There exists biogeographic distinction between the outer and inner coast sites of northern Southeast Alaska for shallow subtidal macroalgal, invertebrate, and fish communities. Shallow subtidal invertebrates are understudied in Southeast Alaska, and consequently the ecology of many species is poorly understood.

Ecosystem Services

The nearshore is considered an important ecosystem because it provides:

- A variety of unique habitats for resident organisms (e.g. sea otters, seals, sea lions, shorebirds, seabirds, nearshore fishes, kelps, seagrasses, clams, mussels, and sea stars).
- Nursery grounds for marine animals from other habitats (e.g. crabs, salmon, herring, and seabirds).
- Feeding grounds for important consumers, including killer whales, harbor seals, sea otters, sea lions, sea ducks, shore birds and many fish and shellfish.
- A source of animals important to commercial and subsistence harvests (e.g. marine mammals, fishes, crabs, mussels, clams, chitons, and octopus).

- An important site of recreational activities including fishing, boating, camping, and nature viewing.
- A source of primary production for export to adjacent habitats (primarily by kelps, other seaweeds, and eelgrass), as well as a recipient for primary (phytoplankton) and secondary production (zooplankton) transported from offshore systems.
- An important triple interface between air, land and sea that provides linkages for transfer of water, nutrients, and species between watersheds and offshore habitats.

Drivers and Stressors

Kelps are the major primary producers in the nearshore marine and because they grow in shallow water, they are prone to be more impacted by oil spills and other human-related activities. Other potential stresses include activities that disturb the beds directly, such as dredging and anchor scars, and events that reduce the ability for light to penetrate into the water column, such as runoff (increased turbidity) or nutrient addition (eutrophication).

Southeast Alaska is an understudied region with respect to nearshore marine ecological processes. Marine ecosystem shifts are expected for coastal regions of the Gulf of Alaska as a consequence of ocean warming and increased freshwater input to the North Pacific marine environment (Royer 1989; Royer et al. 2001; Weingartner et al. 2005; Royer and Grosch 2006). Given that glaciers and ice fields are responsible for 47% of the total freshwater discharge to the Gulf of Alaska (Neal et al. 2010) and that Alaskan glaciers are losing mass more rapidly since the 1990s than they were several decades earlier (Arendt et al. 2002), studies are needed along the fjord coast of Southeast Alaska to understand marine community shifts over time with these environmental changes.

Status and Trends

- The major gradient of freshwater discharge from the coast to the open ocean is persistent and has been stable since the 1960s, which is important for sediment and nutrient transport.
- Species diversity, especially invertebrates, increases toward the outer coast and in deeper water.
- Based on long-term monitoring in Icy Bay, juvenile salmon are entering the Gulf of Alaska (GOA) with average to below-average size.
- Smaller fish are less efficient at foraging and more vulnerable to predation. Further growth and survival will be dependent on favorable over-winter conditions in the GOA.
- Plankton community response to temperature indicates base of food web climate effects that can have broad ecosystem ramifications.
- Declines in kelp (macroalgae) were observed, which is a critical food source for filter feeders (e.g., mussels), benthic feeders (e.g., kelp greenling) and pelagic feeders (e.g., black rockfish) in the nearshore ecosystem.
- Seabirds, marine mammals, and groundfish experienced shifts in distribution, mass mortalities, and reproductive failures during the Pacific Marine Heatwave in 2014-2016, from which they are still recovering.
    - Given anticipated increases in marine heatwaves under current climate projections, it remains uncertain when or if the Gulf of Alaska ecosystem will return to a pre-Pacific Marine Heatwave (PMH) state.

Aquatic Ecosystems Key Findings

- The integrity of freshwater ecosystems is generally high. Across the Tongass, rivers, streams, lakes and ponds are expected to continue delivering highly functioning conditions and services including biodiversity and productivity without human interference.
- The integrity of glaciers and nearshore marine ecosystems is moderate. Glaciers are expected to deliver functioning conditions and services including biodiversity and productivity at a reduced level relative in the future. Changes to climate are the primary stressor affecting these ecosystems.
- Extreme weather events and changes in climate have affected water temperature, timing of runoff, flooding, and water chemistry throughout all aquatic ecosystems, and these changes are expected to continue. A shift in precipitation from snow to rain is predicted to result in loss of heterogeneity across aquatic ecosystems. However, all potential effects are not understood.
- Fish (anadromous and non-anadromous), amphibians and aquatic invertebrates occupy various aquatic habitats throughout their lifecycles.
- Salmon are essential part of the health of freshwater and marine ecosystems. When salmon return to freshwater to spawn, they provide marine-derived nutrients that are key for forest health.
- Management, including timber harvest, mining, and roads has altered aquatic ecosystem integrity at a localized scale.
- At a local scale, the legacy effects of timber harvest are observed, particularly where large, productive old-growth was harvested from valley bottoms, so that large wood is no longer recruited into aquatic ecosystems.
- Restoration efforts include instream large wood placement and installing culverts designed for aquatic organism passage (fish passage) to increase habitat complexity and resilience to flooding, maintain connectivity to upstream habitats, and restore habitat quality near roads.
- Threats to freshwater ecosystems include point and non-point source pollution from physical conditions and chemical pollutants including urbanization, mining, timber harvest, and aquaculture practices including hatcheries and shellfish farming.
- Aquatic ecosystems can be degraded as a result of mass wasting and other erosion, culvert blockages, water diversions, channelization, and hydroelectric dams.
- Invasive species may occur in freshwater, estuarine, and marine waters, displacing native species and altering habitats. Ongoing efforts to minimize introduction of invasive species, monitor their proliferation and implement eradications are expensive and typically stopgap measures. Climate controls on invasives may lessen as freshwater and marine temperatures increase.
- Threats to the estuarine ecosystem include changes in upland flow and sediment processes, development and changes in climate.

References

Alaska Department of Environmental Conservation (ADEC). 2017. 2017 Southeast Alaska Lake Survey Sites. Retrieved December 16, 2024 https://dec.alaska.gov/media/9085/2017-southeast-lakes-survey.pdf.

Alaska Department of Environmental Conservation (ADEC). 2022. Alaska Department of Environmental Conservation, Waterbody Determination Paper, Tributary Creek, Admiralty Island, Alaska Lead Determination.

Aley, T., Aley, C., Elliott, W. R., Huntoon, P. W. 1993. Karst and cave resource significance assessment, Ketchikan area, Tongass National Forest, Alaska. Report of the Karst Resources Panel, 79.

Arendt, A. A., Echelmeyer, K. A., Harrison, W. D., Lingle, C. S., & Valentine, V. B. 2002. Rapid wastage of Alaska glaciers and their contribution to rising sea level. Science, 297(5580), 382-386.

Baichtal, J.F. 1993. Evolution of karst management on the Ketchikan area of the Tongass National Forest: development of an ecologically sound approach. Proceedings of the 1993 National Cave Management Symposium, Carlsbad, New Mexico. p. 190-202.

Baichtal, J. F. and Swanston, D. N. 1996. Karst landscapes and associated resources: a resource assessment. Gen. Tech. Rep. PNW-GTR-383. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 13 p.

Burpee, B. T., Anderson, D., & Saros, J. E. 2018. Assessing ecological effects of glacial meltwater on lakes fed by the Greenland Ice Sheet: The role of nutrient subsidies and turbidity. Arctic, Antarctic, and Alpine Research, 50(1). https://doi.org/10.1080/15230430.2017.1420953

Bryant, M.D., Swanston, D.N., Wissmar, R.C., and Wright, B.E. 1998. Coho salmon populations in the karst landscape of north Prince of Wales Island, southeast Alaska. Transactions of the American Fisheries Society 127(3): 425-433.

Curran, J.H.; 1933 Biles, F.E. 2021. Identification of seasonal streamflow regimes and streamflow drivers for daily and peak flows in Alaska. Water Resources Research 57(2): e2020WR028425. https://doi.org/10.1029/2020WR028425

Dickard, M., Gonzalez, M., Elmore, W., Leonard, S., Smith, D., Smith, S., Staats, J., Summers, P., Weixelman, D., & Wyman, S. 2015. Riparian area management: Proper functioning condition assessment for lotic areas. Technical Reference 1737-15**.** U.S. Department of the Interior, Bureau of Land Management, National Operations Center, Denver, CO

Ferriss, B.E. 2023. Ecosystem Assessment. In: Ferriss, B.E. 2023. Ecosystem Status Report 2023: Gulf of Alaska, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 1007 West Third, Suite 400, Anchorage, Alaska 99501.

Flitcroft, R., Munyon, J., Claeson, S., Johnson, A., Moore, M., Tucker, E., Prussian, K., Jacobson, S., and Lombard, H. 2022. Forest legacies and climate realities: Spatial and temporal variation in fish populations and habitat characteristics on the Tongass National Forest, Alaska. Gen. Tech. Rep. PNW-GTR-1009. Portland, OR: USDA Forest Service, Pacific Northwest Research Station. 77 p.

Grant, G.E., Lewis, S.L., Swanson, F.J., Cissel, J.H., and McDonnell, J.J. 2008. Effects of forest practices on peak flows and consequent channel response: A state-of-science report for western Oregon and Washington. Gen. Tech. Rep. PNW-GTR-760. Portland, OR: USDA Forest Service, Pacific Northwest Research Station. 76 p.

Geist, M., Jarnevich, C., Steer, A., Osnas, J., Carey, M.P., Martin, A.E., Davis, T., and Kelty, R. 2023. Modeling, mapping, and measuring the risk of freshwater invasive species across Alaska. Alaska Center for Conservation Science, University of Alaska Anchorage, AK. 236 pp.

Gomi, T., Dan Moore, R. and Hassan, M.A. 2005. Suspended sediment dynamics in small forest streams of the pacific northwest[1]. JAWRA Journal of the American Water Resources Association, 41: 877-898. https://doi.org/10.1111/j.1752-1688.2005.tb03775.x

Halofsky, Jessica E.; Prendeville, Holly R.; Peterson, David L.; Parrish, Robert. eds. DRAFT. Climate change vulnerability and adaptation in the Tongass National Forest. Gen. Tech. Rep. PNW-GTR-XXX. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station

Harding, K. A., & Ford, D. C. 1993. Impacts of primary deforestation upon limestone slopes in northern Vancouver Island, British Columbia. Environmental Geology, 21, 137-143.

Hock, R., and Huss, M. 2021. Glaciers and climate change. In Climate change (pp. 157-176). Elsevier.

Hood, E. & Scott, D. 2008. Riverine organic matter and nutrients in southeast Alaska affected by glacial coverage. Nature Geoscience 1, 583-587. https://doi.org/10.1038/ngeo280

Hood, E., Fellman, J., Spencer, G.M., Hernes, P.J., Edwards, R., D'Amore, D.D., & Scott, D. 2009. Glaciers as a source of ancient and labile organic matter to the marine environment. Nature, Vol 462, 1044-1047. https://doi.org/10.1038/nature08580

Huntoon, P. W. 1992a. Hydrogeologic characteristics and deforestation of the stone forest karst aquifers of south China. Groundwater, 30(2), 167-176. https://doi.org/10.1111/j.1745-6584.1992.tb01788.x

Huntoon, P. W. 1992b. Exploration and development of ground water from the stone forest karst aquifers of South China. Groundwater, 30(3), 324-330. http://dx.doi.org/10.1111/j.1745-6584.1992.tb01999.x

Kiernan, K. 1993. Management under ice. Cave Management in Australasia, 10, 24-31.

Koenings, J.P. and Edmundson, A. 1991. Seechi disk and photometer estimates of light regimes in Alaskan lakes: Effects of yellow color and turbidity. Retrieved December 17, 2024 https://aslopubs.onlinelibrary.wiley.com/doi/10.4319/lo.1991.36.1.0091

Kovach, R.P., Joyce, J.E., Echave, J.D., Linberg, M.S., Tallmon, D.A. 2013. Earlier migration timing, decreasing phenotypic variation, and biocomplexity in multiple salmonid species. PLoS ONE. 8(1): e53807. https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0053807

Lader, R., Bidlack, A., Walsh, J. E., Bhatt, U. S., & Bieniek, P. A. 2020. Dynamical downscaling for Southeast Alaska: historical climate and future projections. Journal of Applied Meteorology and Climatology, 59(10), 1607-1623.

Lepak, R.F., Janssen, S.E., Engstrom, D.R., Krabbenhoft, D.P., Tate, M.T., Yin, R., Fitzgerald, W.F., Nagorski, S.A., and Hurley, J.P. 2020. Resolving atmospheric mercury loading and source trends from isotopic records of remote North American lake sediments. Environmental science & technology 54(15): 9325-9333. https://pubs.acs.org/doi/10.1021/acs.est.0c00579

Lindstrom, S. C. 2006. Biogeography of Alaskan seaweeds. Journal of applied phycology, 18, 637-641.

Lindstrom, S. C. 2009. The biogeography of seaweeds in Southeast Alaska. Journal of Biogeography, 36(3), 401-409.

Littell, J. S., McAfee, S. A., & Hayward, G. D. 2018. Alaska snowpack response to climate change: Statewide snowfall equivalent and snowpack water scenarios. Water, 10(5), 668.

McCoy, G. A., Wiggins, W. W., & Schmidt, A. E. 1976 Limnological investigations of six lakes in southeast Alaska. U. S. Geological Survey Water Resources Investigations Report 76-122. https://pubs.usgs.gov/publication/wri76122

McDaniel, Josh; Johnson, Adelaide (Di); Bellmore, J. Ryan; Haught, Stormy; Medel, Ron. 2020. Alaska's forest fish: Calculating the value of wild salmon from the Chugach and Tongass National Forests. Science Findings 234. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 5 p.

Milner, A. M., Khamis, K., Battin, T. J., Brittain, J. E., Barrand, N. E., Füreder, L., and Brown, L. E. 2017. Glacier shrinkage driving global changes in downstream systems. Proceedings of the National Academy of Sciences, 114(37), 9770-9778.

Montgomery, D.R. and Buffington, J.M. 1997. Channel-reach morphology in mountain drainage basins. Geological Society of America Bulletin 109, 596–611.

Moore J, M. J., Flitcroft, R. L., Tucker, E., Prussian, K. M., & Claeson, S. M. 2024. Same streams in a different forest? Investigations of forest harvest legacies and future trajectories across 30 years of stream habitat monitoring on the Tongass National Forest, Alaska. Plos one, 19(7), e0301723.

Murphy, J. M., and J. A. Orsi.1999. Physical oceanographic observations collected aboard the NOAA ship *John N. Cobb* in the northern region of southeastern Alaska, 1997 and 1998. AFSC Processed Report 99-02, 239 p. Alaska Fish. Sci. Cent., Natl. Mar. Fish. Serv., NOAA, Auke Bay Laboratory, 11305 Glacier Highway, Juneau, AK 99801-8626.

Naman, S.M., Pitman, K.J., Cunningham, D.S., Potapova, A., Chartrand, S.M., Sloat, M.R., and Moore, J.W. 2024. Forestry impacts on stream flows and temperatures: A quantitative synthesis of paired catchment studies across the Pacific salmon range. Ecological Solutions and Evidence. Vol. 5, e12328. https://doi.org/10.1002/2688-8319.12328

Neal, E.G., Hood, E. & Smikrud, K. 2010. Contribution of glacier runoff to freshwater discharge into the Gulf of Alaska. Geophysical Research Letters, Vol 37, L06404. https://doi.org/10.1029/2010GL042385

Nowacki, G., Shepard, M., Krosse, P., Pawuk, W., Fisher, G.B., Baichtal, J.F., Brew, D.A., Kissinger, E., and Brock, T. 2001. Ecological Subsections of Southeast Alaska and Neighboring Areas of Canada. Dated: October, 2001. R10-TP-75. Anchorage, AK: USDA Forest Service, Alaska Region (R10). 306 p.

Paustian, S.J. 1992.. A channel type user's guide for the Tongass National Forest, southeast Alaska. Technical Paper 26. Juneau, AK: USDA, Forest Service, Alaska Region. Revised 2010.

Pickard, G.L. 1967. Some Oceanographic characteristics of the larger inlets of Southeast Alaska. Journal of the Fisheries Board of Canada, Volume 24, Number 7. https://doi.org/10.1139/f67-123

Pitman, K.J, Moore, J.W., Sloat, M.R., Beaudreau, A.H., Bidlack, A.L., Brenner, R.E., Wood, E.W., Pess, G.R., Mantua, N.J., Milner, A.M., Radić, V., Reeves, G.H., Schindler, D.E., Whited, D.C. 2020. Glacier Retreat and Pacific Salmon. BioScience Volume 70, Issue 3

Rinella, D. J., M. S. Wipfli, C. M. Walker, C. A. Stricker, and R. A. Heintz. 2013. Seasonal persistence of marine-derived nutrients in south-central Alaskan salmon streams. Ecosphere 4(10):122. http://doi.org/10.1890/ES13-00112.1

Rounce, D. R., Hock, R., Maussion, F., Hugonnet, R., Kochtitzky, W., Huss, M., and McNabb, R. W., 2023. Global glacier change in the 21st century: Every increase in temperature matters. Science, 379(6627), 78-83.

Royer, T. C. 1989. Upper ocean temperature variability in the northeast Pacific Ocean: Is it an indicator of global warming? Journal of Geophysical Research: Oceans, 94(C12), 18175-18183.

Royer, T.C. 1982. Coastal fresh water discharge in the northeast Pacific. Journal of Geophysical Research: Oceans, 87(C3), 2017-2021. https://doi.org/10.1029/JC087iC03p02017

Royer, T. C. 1981. Baroclinic transport in the Gulf of Alaska. Part II. Fresh water driven coastal current. Journal of Marine Research, 39, 251-266.

Royer, T. C., & Grosch, C. E. 2006. Ocean warming and freshening in the northern Gulf of Alaska. Geophysical Research Letters, 33(16).

Royer, T. C., Grosch, C. E., & Mysak, L. A. 2001. Interdecadal variability of Northeast Pacific coastal freshwater and its implications on biological productivity. Progress in Oceanography, 49(1-4), 95-111.

Sergeant, C.J., Bellmore, J.R., Bellmore, R.A., Falke, J.A., Mueter, F.J., and Westley, P.A.H. 2023. Hypoxia vulnerability in the salmon watersheds of southeast Alaska. Science of the total environment 896: 12.

Simon, K.S., and Benfield, E.F., 2001, Leaf and wood breakdown in cave streams: Journal of the North American Benthological Society, v. 482, p. 31–39. https://doi.org/10.2307/1468087

Sloat, M. R., Reeves, G. H., & Christiansen, K. R. 2017. Stream network geomorphology mediates predicted vulnerability of anadromous fish habitat to hydrologic change in southeast Alaska. Global Change Biology, 23(2), 604–620.

St. Pierre, K. A., St. Louis, V. L., Schiff, S. L., Lehnherr, I., Dainard, P. G., Gardner, A. S., ... & Sharp, M. J. 2019. Proglacial freshwaters are significant and previously unrecognized sinks of atmospheric CO2. Proceedings of the National Academy of Sciences, 116(36), 17690-17695.

Thoman, R. and H. R. McFarland, editors. 2024. Alaska's Changing Environment 2.0. Alaska Center for Climate Assessment and Policy, International Arctic Research Center, University of Alaska Fairbanks. uaf-iarc.org/communicating-change.

United States Department of Agriculture (USDA), Forest Service. 2012. National Best Management Practices for Water Quality Management on National Forest System Lands. FS-990a. Washington, DC: U.S. Department of Agriculture, Forest Service

United States Forest Service (USDA), Tongass National Forest. 2016. Final Environmental Impact Statement: Tongass Land and Resource Management Plan (No. R10-MB-769e,f).

United States Forest Service (USDA), Tongass National Forest. 2016a. Land and Resource Management Plan. Forest Service Alaska Region, Tongass National Forest R10-MD-769j.

United States Forest Service, Tongass National Forest (USDA). 2021. Tongass National Forest Monitoring and Evaluation Report – Streams and Fish Habitat, Riparian. https://www.fs.usda.gov/sites/nfs/files/r10/tongass/publication/Biennial%20MonitoringReport20202021.pdf

United States Forest Service (USDA). 2021. Tongass National Forest Salmon Factsheet.

United States Forest Service (USDA). 2021b. Tongass National Forest Water Crossing Public View. Alaska Geoportal https://gis.data.alaska.gov/datasets/98429a09729a4620a8cf29cf939a9054_0/explore?location=56.023827%2C-131.548433%2C9.70

U.S. Geological Survey (USGS), 2023. *Watershed Boundary Dataset (WBD)*. Available at USGS National Hydrography. https://www.usgs.gov/national-hydrography/watershed-boundary-dataset

Weingartner, T. J., Danielson, S. L., & Royer, T. C. 2005. Freshwater variability and predictability in the Alaska Coastal Current. Deep Sea Research Part II: Topical Studies in Oceanography, 52(1-2), 169-191.

Weingartner, T., Eisner, L., Eckert, G.L., and Danielson, S. 2009. Southeast Alaska: Oceanographic Habitats and Linkages. Journal of Biogeography 36(3): 387-400.

Winfree, M. M., Hood, E., Stuefer, S. L., Schindler, D. E., Cline, T. J., Arp, C. D., & Pyare, S. 2018. Landcover and geomorphology influence streamwater temperature sensitivity in salmon bearing watersheds in Southeast Alaska. Environmental Research Letters, 13(6), 064034.

Wissmar, R., Swanston, D., Bryant, M., and McGee, K. 1997. Factors influencing stream chemistry in catchments on Prince of Wales Island, Alaska. Freshwater biology 38(2): 301-314.

Woodsmith, R. D., Noel, J. R., & Dilger, M. L. 2005. An approach to effectiveness monitoring of floodplain channel aquatic habitat: Channel condition assessment. Landscape and Urban Planning, 72, 177-204

Young, J. C., Pettit, E., Arendt, A., Hood, E., Liston, G. E., & Beamer, J. 2021. A changing hydrological regime: Trends in magnitude and timing of glacier ice melt and glacier runoff in a high latitude coastal watershed. Water Resources Research, 57(7), e2020WR027404. Accessed at: https://doi.org/10.1029/2020WR027404

Ziemen, F. A., Hock, R., Aschwanden, A., Khroulev, C., Kienholz, C., Melkonian, A., & Zhang, J. 2016. Modeling the evolution of the Juneau Icefield between 1971 and 2100 using the Parallel Ice Sheet Model (PISM). Journal of Glaciology, 62(231), 199-214.