



United States Department of Agriculture

Draft Drivers, Stressors and Climate Change Assessment

Tongass National Forest Plan Revision



Forest
Service

Alaska
Region

Tongass
National Forest

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Forest Service, Alaska Region

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Introduction

The almost 17 million-acre Tongass National Forest consists of a steep mountainous coastline with glaciers and icefields on the mainland, and an archipelago of over 1,000 islands. This complex coastal terrain, combined with the maritime influences of the Pacific Ocean and Gulf of Alaska, largely drives the cool, wet climate of the region, and the ecosystems and people who inhabit it. Warm marine air and ocean currents from Japan help to maintain a narrow range of daily and seasonal temperatures. Summers and winters are thus milder than usual for the latitude, with the former averaging in the mid-40s to mid-60s (°F) and the latter in the high 10s to low 40s. Temperatures are highest inland during warmer months and highest along the coasts during colder months.

Precipitation in Southeast Alaska occurs year-round and averages over 150 inches annually, with significant differences by subregion. At sea level, annual precipitation ranges from 30 inches at Skagway to 220 inches at Little Port Walter; these ranges increase with elevation. May through July is typically the drier season, while storms and heavy rains are more prevalent from September through November, with precipitation often reaching its peak around October.

This moderate maritime climate constrains the distribution and composition of the coastal temperate rainforest that covers much of the region. Forest dynamics are regulated by both smaller gap-phase processes — that is, phenomena that create canopy openings — as well as stand-replacing windthrow events, with these latter large-scale disturbances most frequently occurring closer to the coasts. Island ecosystems like the Alexander Archipelago on the Tongass are epicenters for endemism (Demboski et al. 1998), meaning ecologically distinct species that are found within a limited geographic area. Due to limited mobility across a fragmented landscape, these wildlife and plant species are especially vulnerable to climate change, introduction of invasive species, and other stressors (Cook et al. 2006).

Climate change in the region is expected to include substantial increases in both annual and seasonal temperatures, with autumn averages experiencing the most pronounced rise. The changes and effects from climate change were expressed as a significant concern during the 2024 Assessment Engagement. Annual precipitation is expected to increase, as is seasonal precipitation during spring, fall, and winter. Additionally, a greater proportion of precipitation will likely come as rain rather than snow, resulting in reduced snowpack and, subsequently, snowmelt. Despite increases in annual precipitation, climatic warming is expected to lead to decreased soil moisture levels due to increased evapotranspiration and growing season water deficit, which is an indicator of drought stress.

Insect and disease outbreaks are a significant concern as a leading cause of tree mortality, which is expected to worsen under a warming climate. Invasive species, while currently a relatively minor threat, are also expected to proliferate in the future. If glacial melt accelerates as predicted, some areas will experience sea level rise while others will experience relative sea level decline as a result of isostatic rebound. This sea level change combined with ocean acidification and warming will affect, among other things, the ability to harvest traditional foods and resources, which is central to the livelihoods and foodways of local communities, in particular Tlingit and Haida Natives who have stewarded the land of Southeast Alaska since time immemorial (Central Council of the Tlingit & Haida Indian Tribes of Alaska, 2018). The impacts of climate change on geologic hazards and other resource areas are not discussed in detail here but rather in their respective sections of this assessment.

Process, Methods, and Scale

This assessment primarily draws on and summarizes data and analysis presented in the climate change vulnerability assessment (CCVA) for the Tongass (Halofsky et al. DRAFT). Additional sources including

the 2016 Final Environmental Impact Statement (FEIS) and peer-reviewed publications are cited to differentiate them from information summarized from the CCVA. The working group who put together this assessment is comprised of USDA Forest Service specialists from the Tongass National Forest, Region 10, Pacific Northwest Research Station, Northwest Climate Hub, and Pacific Planning Services Group (PPSG), and convened as a group as needed to coordinate the data, analysis, and writing of this section. This assessment discusses drivers and stressors that affect broad areas of the Forest, though they may impact areas differently across the landscape. Drivers and stressors that impact localized areas or ecosystem types may be touched on in this section but will be covered in more detail in the resource specific assessment reports.

Following the structure of the CCVA, we refer here to four climate divisions as defined by Bieniek and co-authors at NOAA to summarize geographic sections of the Tongass based on shared climatic and environmental attributes. These climate divisions are the Northeast Gulf, North Panhandle, Central Panhandle, and South Panhandle, shown below (Figure 1). Nomenclature for these divisions may be better understood locally as the Outer North Tongass, Upper Lynn Canal/Skagway-Haines, Inner North Tongass, and South Tongass, respectively. That said, to maintain consistency with the CCVA, the divisions will continue to be referred to using the NOAA terminology rather than their common names.

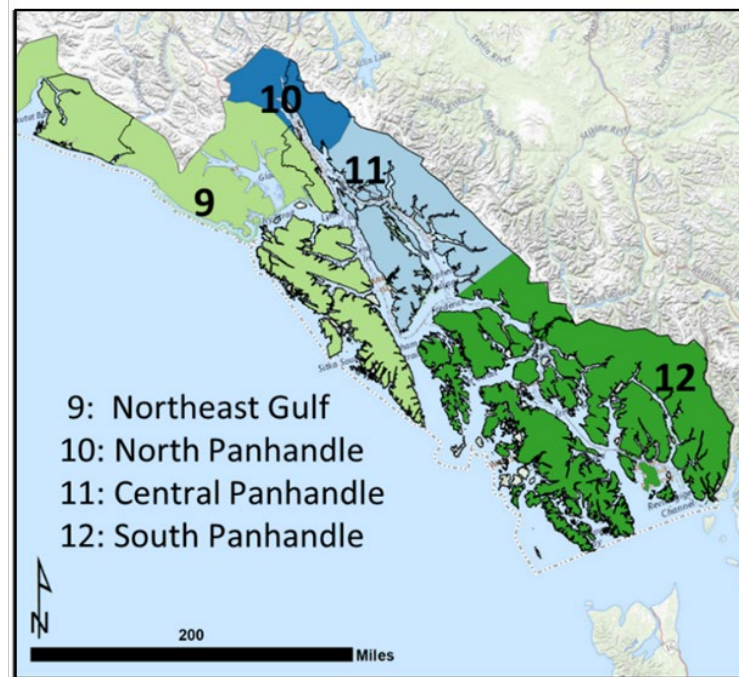


Figure 1: Southeast Alaska land delineated by NOAA Alaska Climate Divisions (CD) Northeast Gulf (CD 9), North Panhandle (CD 10), Central Panhandle (CD 11), and South Panhandle (CD 12). Adapted from Tongass CCVA Climate Chapter by Littell and Johnson [DRAFT].

In the CCVA, five regionally downscaled Coupled Model Intercomparison Project 5 (CMIP5; Walsh et al. 2018) global climate models obtained from the US Geological Survey Alaska Climate Adaptation Science Center summarize temperature, precipitation, and snowpack projections over the four climate divisions. CMIP5 is an archive of global climate and earth system model simulations from over 20 research centers around the world and was used in the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report. Two future greenhouse gas emissions scenarios, called Representative Concentration Pathways (RCPs), were incorporated into the projections, with RCP4.5 representing stabilization of

atmospheric greenhouse gas concentrations and RCP8.5 representing continued increases in emissions or “business-as-usual”. TerraClimate (Abatzoglou et al. 2018), another global source of climate projections and related water balance variables, was used for projected growing season and summer water balance changes, the outputs of which use two global average warming scenarios including a moderate warming scenario (+2°C, or ~3.6°F) and a higher warming scenario (+4°C, or ~7.2°F). In testing the consistency of these projected changes with those yielded by the global climate models, the results were found to be comparable.

Uncertainty and Data Limitations

Uncertainty in climate projections arise primarily from three sources: differences in how individual climate models are constructed, natural climate variability affecting both the magnitude and timing of projected changes, and varying future scenarios for greenhouse gas emissions. The sources of uncertainty are addressed, respectively, by utilizing multiple climate models, averaging climate data over 30 years, and presenting the two RCPs discussed above. It should be noted, however, that RCP4.5 and RCP8.5 are neither the best- nor worst-case scenarios, and in fact future emissions pathways may turn out to be lower, higher, or in between these estimates. It should also be noted that the reference period from 1970-1999, used as the climate baseline for comparing anticipated changes, may not be the most representative indicator for pre-anthropogenic climate change, but the observational record is sparser in earlier decades. Additionally, this reference period is only used for the CMIP5 projections, while TerraClimate employs an even more recent temporal range (1981-2010) in conjunction with future climate change. These differences and constraints associated with each baseline should be understood as a limiting factor in the data. Other areas of uncertainty include projections for sea level change, which are complicated by differential vertical land motion — that is, uplift or subsidence — along the southern Alaskan coastline, leading to inconsistent readings of relative sea level (Sweet et al. 2022). More on this topic is discussed in the Stressors section below.

Current Forest Plan Direction

The 2016 FEIS did not include an overall drivers and stressors section but rather considered relevant drivers and stressors in each resource section. The FEIS provides a comprehensive overview of Climate and Air, including climate change, as it relates to and impacts forest planning in subsection 3-11 of the Physical and Biological Environment effects analysis. In its discussion of stressors on particular resources, such as the effects of yellow-cedar decline on the Tongass (3-175), the FEIS lays out both current and anticipated future threats and subsequently follows up with general standards and guidelines for management. These guidelines typically focus on mitigating the effects of human activities, and encourage continued evaluation and varied approaches to management, including through chemical, mechanical, and biological methods.

Gaps in Current Plan Direction

No direction regarding climate adaptation is present in the 2016 Forest Plan, or previous plans. Land management plans, or Forest Plans, revised under the 2012 Planning Rule must consider system drivers and stressors as well as the ability of ecosystems to adapt to change (36 CFR 219.8, 36 CFR 219.10). System drivers, as defined by 36 CFR 219.8, include dominant ecological processes, disturbance regimes, and stressors, such as natural succession, wildland fire, invasive species, and climate change. As a subset of drivers, stressors are factors that may directly or indirectly degrade or impair ecosystem composition, structure or ecological process in a manner that may impair its ecological integrity, such as an invasive species, loss of connectivity, or the disruption of a natural disturbance regime (36 CFR 219.9).

Assessments are an integral step in the plan development or revision process. They rapidly evaluate existing information about relevant ecological, economic, and social conditions, trends, and sustainability and their relationship to the land management plan within the context of the broader landscape (36 CFR 219.5(a)(1)). Assessments should answer the following questions: what are system drivers and stressors that influence the plan area, and what is known about the opportunities to reduce risk and adapt to system drivers, stressors and the influence of climate change? Under the Sustainability (36 CFR 219.8) and Multiple Use (36 CFR 219.10) subparts, system drivers, stressors, and the ability of the plan area to adapt serves as a means of providing for social, economic, and ecological sustainability as well as for ecosystem services and multiple uses. This assessment is meant to represent the state of best-available scientific information regarding drivers, stressors, and climate change on the Tongass, and to clarify the need for considering climate change and adaptation in forest management.

Current Tribal Adaptation Plans

Climate change is a top issue for many Tribes. Concerns have been expressed about how climate change will impact the health of harvested resources (especially fish, deer, berries, mushrooms and cedar) and the habitat that they depend on. In light of this concern, many Tribes have created climate adaptation plans including the Sitka tribe, Central Council of Tlingit & Haida Indian Tribes of Alaska, Metlakatla and the Hoonah tribe. Hoonah Indian Association in particular is planning proactive climate adaptation strategies to create better anadromous stream habitat for fish, to create deeper pools with more oxygen flow.

Drivers

Current Climate as Driver of vegetation distribution

The drivers discussed in this assessment will focus on those explicitly related to climate and disturbance, as drivers of particular resources are covered in their corresponding sections. The climate on the Tongass is defined by cool temperatures, mild seasonality, and high precipitation. Temperature is the primary control of vegetation distribution regionally, such that species like cedar are constrained to the southern range of the Forest. Given that excessive year-round precipitation is present throughout the Forest, this is largely not a constraining variable on vegetation. Soil moisture and other soil conditions do play a role, however, with poorly drained soils hosting different community types than areas with better drainage. This mild, wet environment provides the conditions for temperate rainforest to thrive, with species such as Western hemlock (*Tsuga heterophylla*) and Sitka spruce (*Picea sitchensis*) dominating. Subregional variation is pronounced, with both temperature and precipitation differences driven largely by complex terrain.

Forest Insect, Disease, & Decline

Insects, diseases, and other damage agents play a critical role in disturbance and ecological process on the Tongass National Forest. Hemlock dwarf mistletoe (*Arceuthobium tsugense*) and conifer stem decays are naturally occurring on the Forest and ecologically important as a means of creating standing snags and cavities for wildlife habitat (Hennon and Mulvey 2014). Clearcut harvesting can reduce if not eliminate dwarf mistletoe and stem decay on the landscape for prolonged periods, while silvicultural treatments such as partial retention harvesting or thinning-induced top breakage can manage these agents within desirable conditions and enhance wildlife benefits (Muir and Hennon 2007; Hennon and Mulvey 2014). Invasive pests in the region are still relatively few and have a limited impact. Spruce aphids (*Elatobium*

abietinum) were introduced in the early 1900s and have spread north across coastal forest on the Tongass. Their populations are constrained by freezing temperatures during winter feeding periods. More substantial agents that are increasingly posing a threat to ecosystems in the region include yellow-cedar decline, western blackheaded budworm (*Acleris gloverana*), and hemlock sawfly (*Neodiprion tsugae*), while others such as spruce beetle (*Dendroctonus rufipennis*) and Mal del ciprés (a pathogen that infects and kills juniper, cypress and cedar trees) are not yet of significant concern but should be understood as potential threats in the future.

Tribes are concerned with the decline and death of cedar. Yellow-cedar decline is primarily caused by root freezing injury. In order for this to occur, the roots must be close to the soil surface, with no snow to insulate them from extreme cold events, as rooting depth can be limited by hydrology or bedrock (Hennon et al. 2012; Hennon et al. 2016). As cedar is both a culturally and economically critical species, yellow-cedar decline is perceived as one of the most pressing issues on the Forest currently. Future loss of snowpack as a result of warming and precipitation-as-rain will likely continue this trend. Yellow-cedar populations presently occupy less than 1% of their suitable range with little expansion and lagging episodic migration; as a result, in the absence of assisted migration strategies, the majority of existing stands are projected to be vulnerable to root freezing injury and mortality by 2070 (Kraepel et al. 2017).

Insects and diseases respond rapidly to climate conditions, and despite the wetter conditions anticipated in the mid- to late-century, rapid warming combined with hydroclimatic variability could still provide the necessary conditions for increased defoliator outbreaks (Howe et al. 2024). Dieback of Western red cedar in much of the Pacific Northwest indicates a need for close monitoring on the Tongass, particularly as a result of drought and warmer summers (Andrus et al. 2023). While Mal del ciprés has not been found in the region, the disease has affected cedars globally. Likewise, large-scale outbreaks of spruce beetle are not common on the Tongass, but drought conditions could make local outbreaks of already-present populations more probable.

Wind/windthrow

Wind is one of the most important natural disturbance agents on the Tongass and the leading cause of gap creation. Windthrow can occur as either windsnap (stem breakage) or windthrow (tree uprooting), collectively referred to as blowdown. Though small-scale gap disturbances affecting single or small groups of trees are the most frequent, stand-replacing catastrophic windthrow is an essential mechanism in facilitating forest regeneration, particularly in areas most prone to and least protected from wind damage (Kramer et al. 2001). Uprooting via windthrow occurs most frequently on saturated soils (Baer et al. 2024). During fall and winter, Southeast gales are the most damaging storms in the region, though wintertime Takus and other bora (downslope) winds also generate considerable force (Harris 1999). Despite the regularity of gale-force winds, their location and timing remain unpredictable; likewise, while soil and topography can inform managers where blowdown is most likely to occur, forest stands may still inhabit an area considered prone to windthrow without replacement for hundreds of years. Forested areas susceptible to maritime windstorms are shown to be more densely stocked with smaller trees, while wind-protected forests contain older, larger trees and are more frequently chosen as habitat for black bears (*Ursus americanus*) and other wildlife (DeGayner et al. 2005). Wind also interacts with other site factors and pathogens to cause tree failure, with stem breakage most commonly occurring in standing trees — live or dead — weakened by decay or decomposition (Baer et al 2024).

The impact of climate change on wind and storms remains insufficiently understood, but some trends are starting to emerge. Mean wind speeds are projected to either decrease or show little significant change in Southeast Alaska by end-of-century (Redilla et al 2019), though the number of extreme cyclones is expected to increase as storm activity in the Pacific shifts northeastward (Chang 2018). A weakening of

downdrafts is also predicted in Alaska more broadly, which — in tandem with warmer temperatures — will favor the organization of convective thunderstorms yielding flash floods and severe weather (Poujol et al 2021).

Fire

Fire occurrence on the Tongass has historically been low due to infrequent lightning and excessive precipitation, combined with timber and shrub vegetation types that are not conducive to significant fire spread. Most fire starts are human-caused. Fuel drying time and summers are historically not long enough to dry live and dead fuels to critical levels. Historical large fires, defined as fires exceeding 100 acres, have rarely been recorded and are constricted to open areas with fine fuel. As a result of the lack of extensive fire history in the region, there is limited research on fire locally. Studies in similar maritime forests of British Columbia show fire intervals over 1,000 years (Halofsky et al. 2024). While drought conditions may heighten the risk of fire, these changes would have to be significant to bring the Forest to fire-critical levels.

For most Tribes, fire management was not named as a top priority, given that the Tongass is located in a temperate rainforest climate. However, some Tribes are making preparations given the climatic changes facing the region. Tlingit & Haida has created a wildlands firefighting department that currently contracts out to fight fires across the State. There is possibility for growth in this department with erratic precipitation levels and events across the Tongass; the tribes anticipate more wildfires in the southern region, where drought conditions are more prevalent.

Stressors

Climate Change

Climate Change Executive Summary

Recent global climate modeling has been downscaled to the southeast Alaska region to provide a range of plausible future climates. At this scale, seven physical variables were specifically modeled for each of the four regional climate divisions and two time periods. Temperature is expected to increase both annually and seasonally for all climate divisions and time periods. Annual precipitation is likely to increase in some climate divisions and time periods. As temperatures increase, snow water equivalent is projected to decrease across all regions with more precipitation falling as rain during the October–March snow accumulation season. Streamflows will increase in winter but decrease in summer.

The growing season will lengthen, causing the potential evapotranspiration from vegetation to increase for many locations. Droughts, while sporadic, are expected to create seasonal water deficits which will stress plants as well as municipal water supplies and power generation. While not one of the seven variables projected in the downscaled climate models, wind is expected to slow down overall, but extreme wind events and storms will likely increase in frequency. In addition, accelerating glacial melt is leading to differential sea level change and land movement, with relative sea level decline over most of the Forest as a result of uplift via isostatic rebound. Alongside these shifts in shoreline access, impacts on salmon, shellfish, and other populations due to increasing stream and sea surface temperatures, as well as ocean acidification leading to higher corrosivity and decreased availability of calcium carbonate, has begun to, and will likely continue to affect the livelihoods and traditional practices of local communities.

Temperature Effects

Historical and Observed Conditions

Between 1970 and 1999, annual mean temperatures in Southeast Alaska ranged from 32.0°F in the North Panhandle to 39.8°F in the South Panhandle. These historical baseline temperatures have been steadily rising, however: since 1951, mean temperatures in the region increased by as much as 0.99°F per decade. Average yearly temperatures in Alaska more broadly have already increased twice as fast as the rest of the United States (Haufler et al. 2010; Chapin et al. 2014). Inter-annual and -decadal variability in temperature is largely driven by ocean-atmosphere dynamics, including El Niño Southern Oscillation (ENSO) in which sea surface temperatures in the equatorial Pacific periodically deviate from the average.

Though seasonality is mild in Southeast Alaska, mean temperatures historically range from 28.3°F in the winter to 52.4°F in the summer (USDA Forest Service 2013). The shoulder seasons are similar, with an average temperature of 38.5°F in spring and 40.4°F in autumn. Average seasonal temperatures also vary significantly across climate divisions on the Tongass, with temperatures typically lowest in the North Panhandle and highest in the South Panhandle. Mean spring temperatures range from 32.3°F to 38.9°F, summer temperatures from 47.5°F to 52.3°F, fall temperatures from 30.5°F to 39.3°F, and winter temperatures from 17.8°F to 28.7°F (Table 1). The Central Panhandle and Northeast Gulf predominantly maintain average temperatures within these ranges, with the latter being consistently the warmer of the two.

Table 1. Historical (1970 to 1999) annual and seasonal mean temperature and mean total precipitation by climate division (data: University of Alaska Fairbanks Scenario Planning for Alaska and Arctic, Walsh et al. 2018). Drawn from Halofsky et al. [DRAFT]. Seasonal month ranges: Winter December–February; Spring March–May; Summer June–August; Fall September–November.

	NE Gulf (CD 9)	North Pan- handle (CD 10)	Central Pan- handle (CD 11)	South Pan- handle (CD 12)	NE Gulf (CD 9)	North Pan- handle (CD 10)	Central Pan- handle (CD 11)	South Pan- handle (CD 12)
Temperature	(°F)	(°F)	(°F)	(°F)	(°C)	(°C)	(°C)	(°C)
Annual	37.7	32.0	35.2	39.8	3.1	0.0	1.8	4.3
Winter	25.6	17.8	22.6	28.7	-3.6	-7.9	-5.2	-1.8
Spring	37.2	32.3	35.0	38.9	2.9	0.2	1.7	3.8
Summer	51.0	47.5	48.8	52.3	10.6	8.6	9.3	11.3
Fall	36.8	30.5	34.2	39.3	2.7	-0.9	1.2	4.0
Precipitation	(in)	(in)	(in)	(in)	(mm)	(mm)	(mm)	(mm)
Annual	163.9	106.2	170.4	144.2	4163.0	2697.9	4329.2	3663.1
Winter	44.1	29.7	45.9	41.7	1120.3	753.9	1165.3	1060.1
Spring	31.0	17.5	30.1	28.5	786.2	444.6	763.6	724.1
Summer	25.3	16.7	29.0	21.4	643.7	425.2	736.0	543.0
Fall	63.2	42.2	65.4	52.5	1605.5	1071.4	1660.9	1334.4

Anticipated Trends

Alaska’s annual average temperatures have increased twice as fast as the rest of the U.S. over the past 50 years (Haufler et al. 2010). Mean annual temperature on the Tongass is expected to increase up to 4.7°F by the 2050s under RCP8.5, the “business-as-usual” future emissions scenario, nearly double the average decadal increase experienced during the historical baseline (Table 2). By the 2080s, that projected

increase under RCP8.5 is projected to reach 7.4°F. Under RCP4.5, the curbed emissions scenario, the mid- and end-of-century increases fall to 3.8°F and 4.6°F, respectively. By climate division (Table 3), the most substantial warming is predicted to occur in the Northeast Gulf, with a mean increase of 4.0°F by the 2050s and 5.1°F by the 2080s under RCP4.5, or an increase of 5.0°F by the 2050s and 8.4°F by the 2080s under RCP8.5. The South Panhandle is predicted to experience the lowest change in mean temperature (3.7°F by the 2050s and 4.5°F by the 2080s under RCP4.5, or 4.4°F and 7.2°F under RCP8.5). Ranges in projected means are variable across climate divisions, and are predictably higher in the 2080s than in the 2050s, with the latter typically spanning around 2-3°F and the former between 4 and 7°F.

Table 2. Projected annual temperature and precipitation changes for the Tongass and vicinity. Means are for five climate models downscaled for Alaska by SNAP. Ranges (in parentheses) indicate low-to-high model range from the five downscaled models. Note: mean values vary on the order of 0.2 °C from values presented in tables for maps presented in this chapter due to different resolutions of gridded products. This table is for 2-km resolution (instead of 771 m).

		2050s		2080s	
		RCP4.5	RCP8.5	RCP4.5	RCP8.5
Temperature (+ change °C)	Mean	2.1	2.6	2.5	4.1
	Range	(1.3–2.8)	(1.7–3.3)	(1.4–3.5)	(2.4–5.5)
Temperature (+change °F)	Mean	3.8	4.7	4.6	7.4
	Range	(2.3–5.1)	(3.0–6.0)	(2.4–6.3)	(4.3–10.0)
Precipitation (% change)	Mean	6.9	4.3	5.8	13.0
	Range	(0.2–13.7)	(-0.7–9.7)	(1.5–11.3)	(8.4–17.6)

Table 3. Annual temperature (Temp) and precipitation (Precip) changes for climate divisions 9–12, averaged over each climate division. Means are calculated from five climate models. Ranges reflect low and high value from the five downscaled models.

DIV 9: N. Gulf		2050s		2080s	
		RCP4.5	RCP8.5	RCP4.5	RCP8.5
Temp (C)	Mean	2.2	2.8	2.8	4.7
	Range	1.2 - 3.1	1.9 - 3.6	1.3 - 3.8	2.5 - 6.3
Temp (F)	Mean	4.0	5.1	5.0	8.4
	Range	2.2 - 5.6	3.4 - 6.4	2.3 - 6.8	4.3 - 11.3
Precip (%)	Mean	5.1	2.2	3.9	11.6
	Range	-3.5 - 11.9	-2.7 - 7.3	-1.7 - 9.4	3.2 - 18.1

DIV 10: N. Panh.		2050s		2080s	
		RCP4.5	RCP8.5	RCP4.5	RCP8.5
Temp (C)	Mean	2.2	2.7	2.6	4.2
	Range	1.3 - 2.8	1.8 - 3.3	1.4 - 3.5	2.5 - 5.8
Temp (F)	Mean	3.9	4.8	4.7	7.6
	Range	2.4 - 5.1	3.2 - 6.0	2.5 - 6.3	4.4 - 10.4
Precip (%)	Mean	6.6	4.0	5.2	13.2
	Range	-1.9 - 14.1	-0.4 - 10.0	-0.9 - 10.7	5.5 - 19.1

DIV 11: C. Panh.		2050s		2080s	
		RCP4.5	RCP8.5	RCP4.5	RCP8.5
Temp (C)	Mean	2.2	2.7	2.6	4.3
	Range	1.2 - 3.0	1.8 - 3.4	1.3 - 3.5	2.4 - 5.8
Temp (F)	Mean	3.9	4.8	4.7	7.8
	Range	2.2 - 5.4	3.2 - 6.1	2.4 - 6.4	4.3 - 10.4
Precip (%)	Mean	4.2	1.3	2.8	10.5
	Range	-2.8 - 10.2	-4.3 - 6.2	-2.0 - 8.8	3.7 - 16.3

DIV 12: S. Panh.		2050s		2080s	
		RCP4.5	RCP8.5	RCP4.5	RCP8.5
Temp (C)	Mean	2.1	2.5	2.5	4.0
	Range	1.2 - 2.8	1.6 - 3.3	1.3 - 3.4	2.3 - 5.3
Temp (F)	Mean	3.7	4.5	4.4	7.2
	Range	2.2 - 5.1	2.8 - 5.9	2.4 - 6.2	4.2 - 9.5
Precip (%)	Mean	8.2	5.9	7.4	14.0
	Range	2.6 - 15.1	0.8 - 11.0	4.1 - 12.8	9.2 - 18.9

Seasonal temperatures in Southeast Alaska are projected to increase under all scenarios, most significantly in autumn (Table 4). Under RCP4.5, projected regionwide temperatures are expected to increase by 4.4°F in the fall by the 2050s, and by 5.3°F by the 2080s. Under RCP8.5, however, these increases in fall mean temperatures are projected to reach 5.4°F by the 2050s and 8.2°F by the 2080s. Changes in the North Panhandle are expected to be the highest of all climate divisions in autumn, and the lowest of all climate divisions in spring (Figure 2, Figure 3, Figure 4, Figure 5). Variability as well as uncertainty within these estimates remain to be sufficiently quantified.

Table 4. Projected winter (December–February), spring (March–May), summer (June–August), and autumn (September–November) temperature changes relative to 1970–1999.

	2050s				2080s			
	RCP 4.5		RCP 8.5		RCP 4.5		RCP 8.5	
	°F	°C	°F	°C	°F	°C	°F	°C
Winter	3.7	2.0	4.5	2.5	4.2	2.3	7.4	4.1
Spring	3.2	1.8	4.1	2.3	3.8	2.1	6.3	3.5
Summer	3.8	2.1	5.0	2.8	4.6	2.5	7.4	4.1
Autumn	4.4	2.4	5.4	3.0	5.3	3.0	8.2	4.6

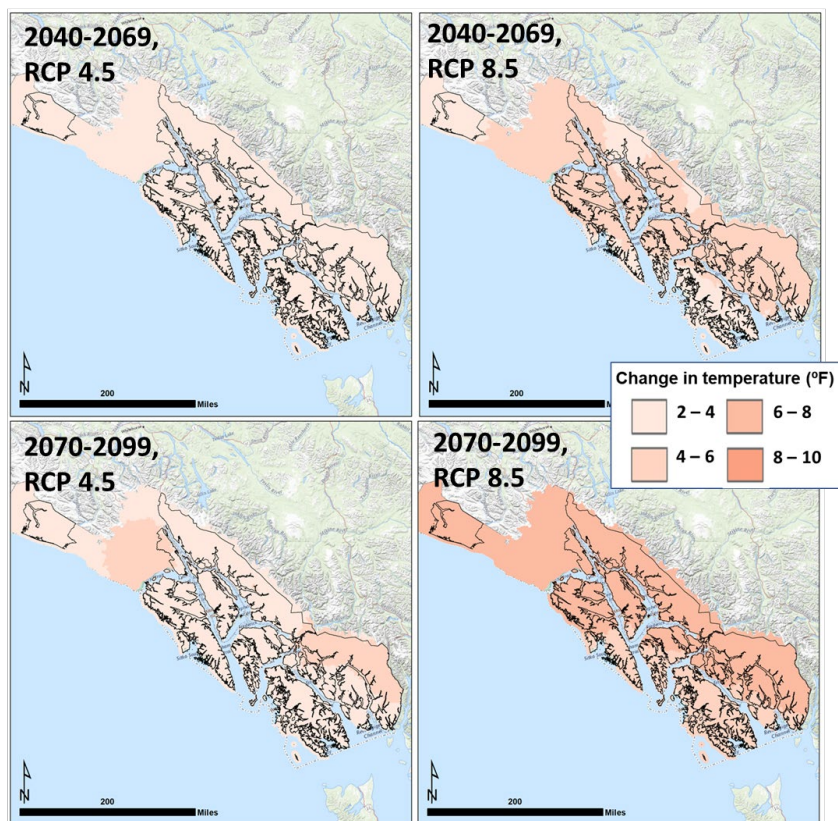


Figure 2: Projected spring (March-May) temperature changes relative to 1970-1999.

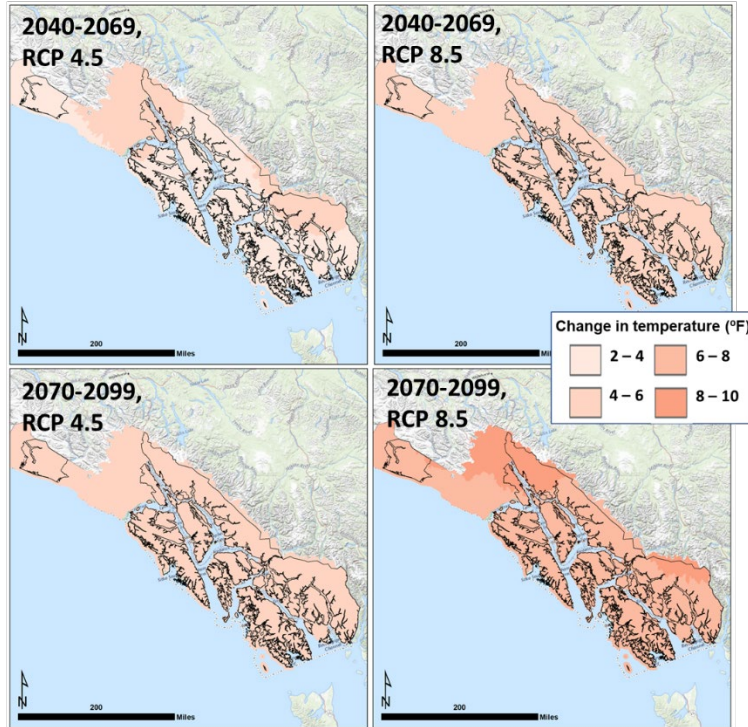


Figure 3: Projected summer (June-August) temperature changes relative to 1970-1999.

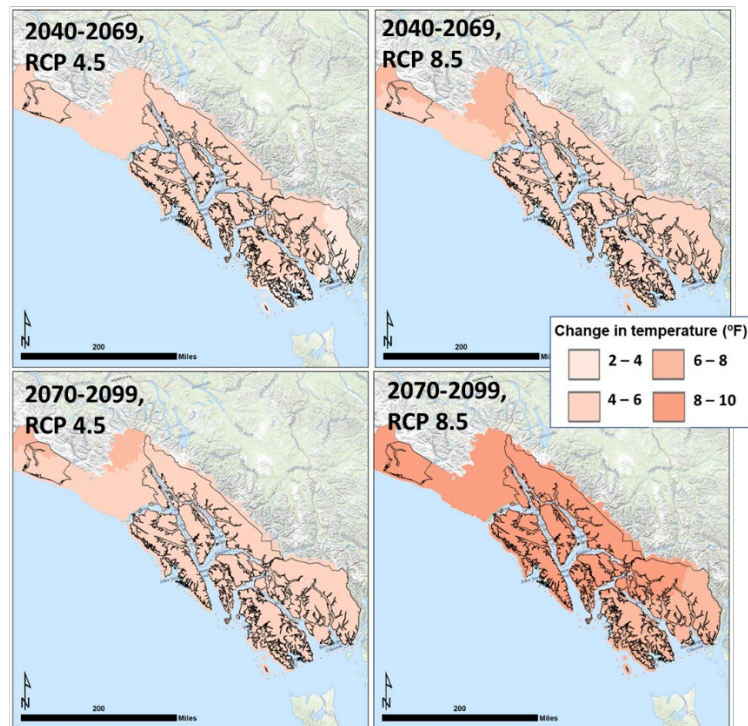


Figure 4: Projected autumn (September-November) temperature changes relative to 1970-1999.

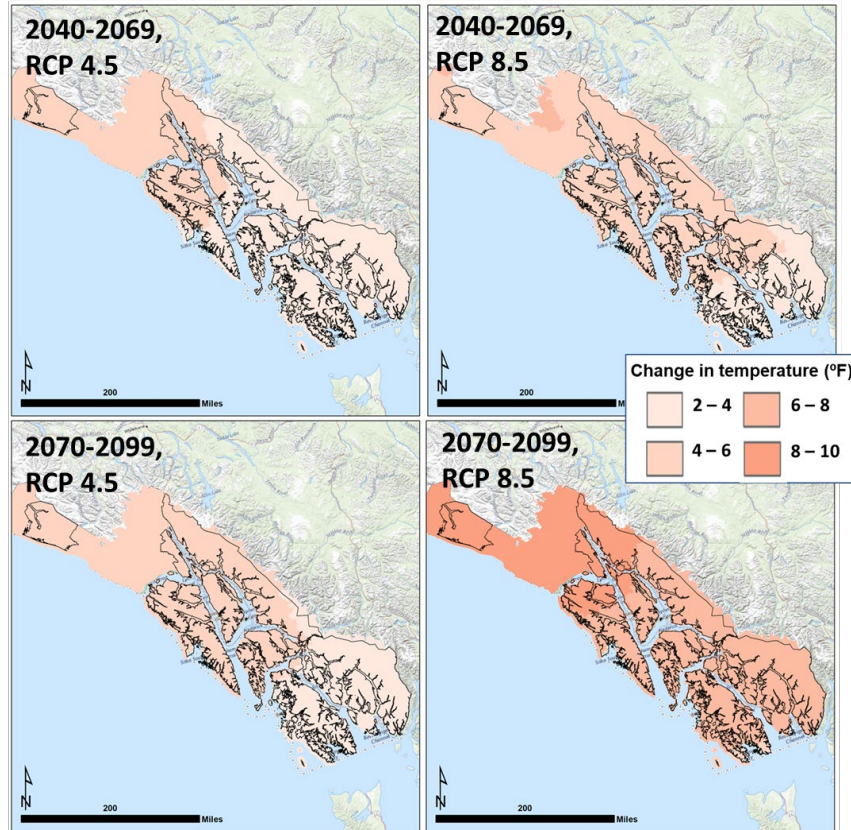


Figure 5: Projected winter (December-February) temperature changes relative to 1970-1999.

Decreases in soil moisture are projected for summer months, with the North Panhandle experiencing as much as a 17.3% decrease in July under +4°C warming. Under a curbed emissions scenario with +2°C warming, this decrease drops to 4.7%, with the highest change now in the South Panhandle with a 5.0% loss of soil moisture in the month of August. These shifts will correspond with projected increases in potential evapotranspiration and water balance deficit during the summer growing season.

Precipitation Effects

Historical and Observed Conditions

The Tongass receives substantial year-round precipitation, creating a permanently humid or “perhumid” local climate. Southeast Alaska averages roughly 153 inches annually, ranging from 30 inches at Skagway to 220 inches at Little Port Walter (Western Regional Climate Center, 2008). Generally, precipitation increases as one moves higher in elevation on the Forest. Broken down by climate division, annual averages range from 106.2 inches in the North Panhandle to 170.4 inches in the Central Panhandle (Table 1). Seasonal atmospheric rivers are regular occurrences in the fall and winter, with storms and heavier precipitation occurring especially frequently from September to November. Fall precipitation by climate division is greatest on average in the Central Panhandle, with a mean of 65.4 inches, and lowest in the North Panhandle, with a mean of 42.2 inches. Summer is generally the drier season, with average precipitation only reaching 29 inches in the Central Panhandle and 16.7 inches in the North Panhandle. The only season in which the Central Panhandle does not receive the most precipitation is the spring, in which the highest amount of mean precipitation falls in the Northeast Gulf at 31 inches.

Drought in the region is generally driven by high-pressure systems over the Aleutian Islands pushing storm tracks northward, thus creating drier conditions locally (Hoell et al. 2022). The recent drought from October 2016-September 2019 was exceptionally dry and warm, though temperatures were not as high as the summer 2004 drought and the duration were not as extensive as the 1994-1997 drought. According to data obtained from NOAA’s National Climatic Data Center, the areas of Sitka and Ketchikan saw record lows in precipitation in this most recent drought during the autumn of 2016 and 2017, respectively. In the case of the Northeast Gulf, the area received a mere 5.46 inches of precipitation in October 2016, a nearly 75% decrease from the average of 22.16 inches for the same month over the prior decade.

Historically, snow water equivalent (SWE), or the amount of water contained in snowpack, is highest in the Central Panhandle, with a mean total of 60 inches, and lowest in the Northeast Gulf, with a mean total of 46 inches (Table 5). Potential evapotranspiration (PET), or the maximum amount of water that would be evaporated or transpired (evapotranspired) given sufficient water availability, is typically highest in the South Panhandle during the growing season (April-September), averaging a total of 15.2 inches, and in the North Panhandle during the summer months specifically, at an average of 9.3 inches total. Lastly, water balance deficit – an indicator of drought stress – tends to be highest in the North Panhandle as well, with a mean total of 0.9 inches during both the summer and broader growing season.

Table 5. Historical hydrologic parameters for southeast Alaska, including snow water equivalent (SWE), potential evapotranspiration (PET), and water balance deficit (DEF) by climate division (CD). Note: SWE information is based on data from Littell et al. 2018; DEF is based on data from Abatzoglou et al. (2018). See Table 2 and Table 3 for further description of climate change variables. Both summer (June–August) and the complete plant growing season (April–September) are represented.

Hydrologic parameter	Mean total (inches)				Mean total (mm)			
	Northeast Gulf (CD 9)	North Gulf (CD 10)	Central Panhandle (CD 11)	South Panhandle (CD 12)	Northeast Gulf (CD 9)	North Gulf (CD 10)	Central Panhandle (CD 11)	South Panhandle (CD 12)
Snow season								
Oct.-Mar. SWE	46.0	46.7	60.0	34.8	1168.6	1187.3	1524.2	884.2
Apr.-Sep. PET	13.9	13.4	13.9	15.2	354.3	341.4	352.6	385.2
Jun.-Aug. PET	8.5	9.3	8.9	9.1	215.5	236.1	227.1	231.7
Apr.-Sep. DEF	0.3	0.9	0.1	0.2	6.4	23.1	3.7	4.9
Jun.-Aug. DEF	0.2	0.9	0.1	0.2	5.7	22.2	3.3	4.5

Anticipated Trends

Mean annual precipitation on the Forest is projected to increase 4.3% by the 2050s and 13% by the 2080s under the business-as-usual scenario (Table 2). Projected changes in precipitation by climate division are highest in the South Panhandle, with RCP8.5 estimates showing a mid-century increase of 5.9% and a late-century increase of 14% (Table 3). Precipitation increases are expected to be weakest in the Central Panhandle, with a 1.3% increase by mid-century and a 10.5% increase by late-century. Though precipitation increases are forecasted across all climate scenarios, RCP8.5 predicts more conservative increases for the 2050s than does RCP4.5; by the 2080s, however, higher emissions will likely yield substantially wetter conditions.

Seasonal precipitation is projected to increase across the region during spring, autumn, and winter, but changes during summer are more modest and within the range of historical variability. Under the business-as-usual scenario, autumn precipitation is projected to increase by over 12% by the 2050s, and by roughly 22% by the 2080s (Table 6). Increases expected in the spring and winter are 4.9% and 3.2%,

respectively, by mid-century, and 11.1% and 9.4% by end-of-century. While the same scenario forecasts a slight decrease in 2050s summer precipitation, by the 2080s this projected increase reaches over 10%. Overall, data suggests that the perhumid environment on the Tongass will only get wetter as the century progresses, albeit still with uncertainty and variability over the next 30 years and depending on whether greenhouse gas emissions are curbed or continue to rise.

Table 6. Projected winter (December–February), spring (March–May), summer (June–August), and autumn (September–November) precipitation changes relative to 1970–1999 (percent change)

	2050s		2080s	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Winter	6.4	3.2	1.9	9.4
Spring	4.7	4.9	8.8	11.1
Summer	5.4	-1.1	5.4	10.4
Autumn	9.8	12.1	11.5	21.7

Snow water equivalent (SWE) and snow index are both projected to decrease regionwide during the cool season in each future emissions scenario. Overall changes in October–March snow water equivalent in Southeast Alaska include mid-century decreases from 29.5% (RCP4.5) to 36.2% (RCP8.5), and late-century decreases of 36.7% (RCP4.5) to 56.8% (RCP8.5). By climate division, anticipated snow water equivalent reductions under the business-as-usual scenario range from 20.7% in the Northeast Gulf to 38.5% in the North Panhandle by the 2050s, and from 42% to 59.3% in the same divisions by the 2080s (Table 7; Figure 6). These reductions are expected to be greatest at lower elevations (<820 ft), with an overall decrease of 44% by the 2050s under a higher-emissions scenario; higher elevation estimates are more variable but are still expected to see reductions, especially by the end of the century. Snow index, a measure of the proportion of precipitation that falls as snow, is projected to drop to 27.8% (RCP4.5) or 25.5% (RCP8.5) by the 2050s, and to 25.7% (RCP4.5) or 18.3% (RCP8.5) by the 2080s, with the South Panhandle becoming dominated by rain and most other areas of the region experiencing increasingly mixed precipitation towards the end-of-century (Table 7; Figure 7).

Table 7 (a) Change in snow water equivalent by climate division and (b) snow index by climate division

(a) Change in snow water equivalent by climate division, displayed as percent change.

	2050s		2080s	
Division	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Northeast Gulf (CD 9)	-15.3	-20.7	-22.6	-42.0
North Panhandle (CD 10)	-31.4	-38.5	-39.5	-59.3
Central Panhandle (CD 11)	-22.6	-28.9	-30.3	-50.5
South Panhandle (CD 12)	-31.0	-37.6	-37.6	-57.9

(b) Change in snow index in percent of October through March precipitation that falls as snow.

	2050s		2080s	
Division	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Northeast Gulf (CD 9)	53.7	50.6	50.6	38.8
North Panhandle (CD 10)	28.5	25.7	26.0	18.0
Central Panhandle (CD 11)	39.7	36.8	37.0	27.2
South Panhandle (CD 12)	23.4	21.3	21.6	15.1

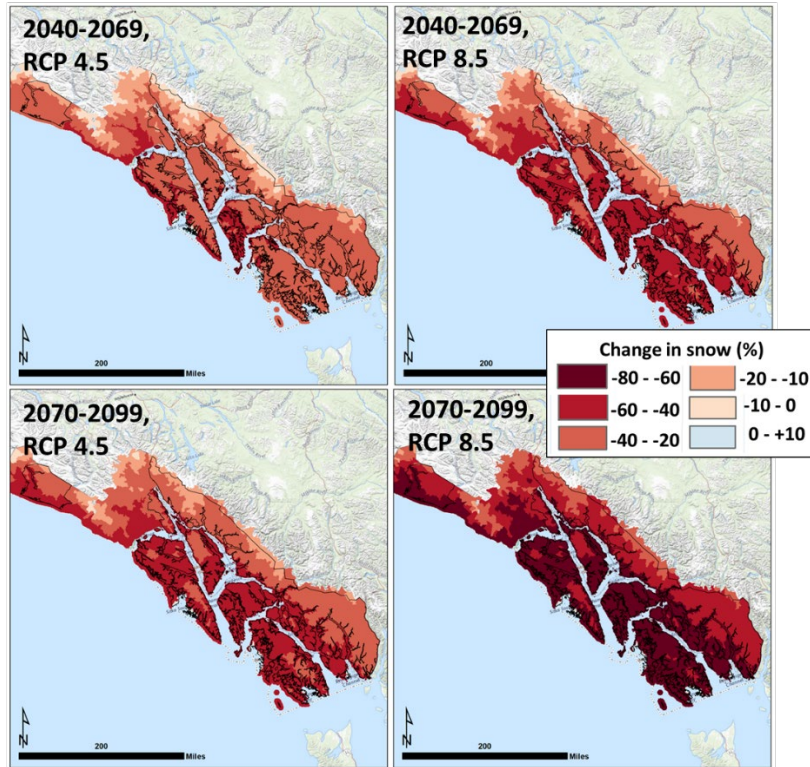


Figure 6: Projected change (percent) in October–March snow water equivalent relative to 1970–1999.

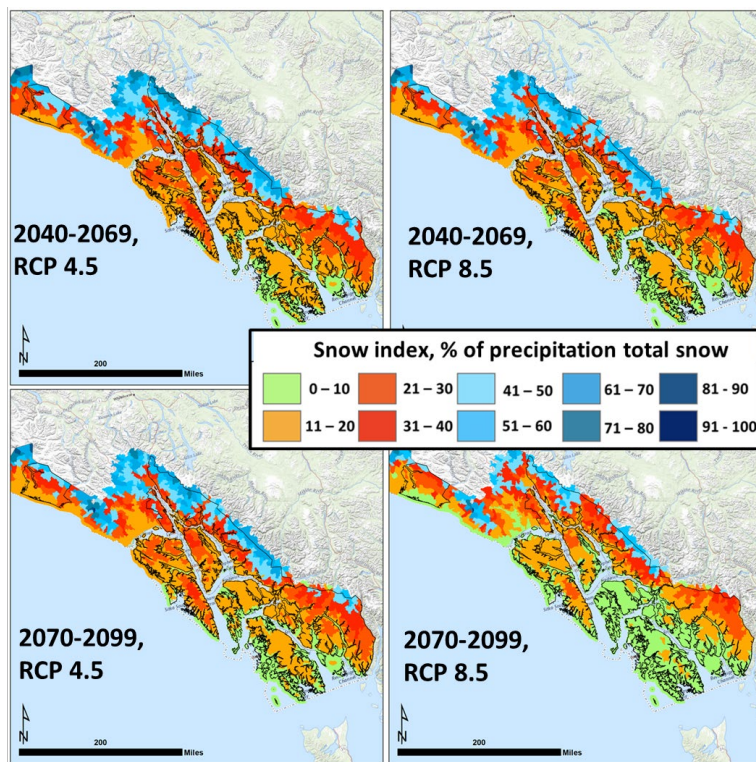


Figure 7. Projected snow index (the percentage of precipitation as snow) from October to March. Blues indicate areas dominated by snow, reds and oranges are mixed snow and rain, and greens represent areas dominated by rain.

Little to no changes in spring runoff are predicted on the Forest, though winter runoff is expected to increase in all climate divisions as more precipitation comes in the form of rain rather than snow. The most substantial impacts are projected to occur in the North Panhandle, receiving as much as a 110.9% (+19.1 mm, or 0.75 in) increase in runoff during February under +2°C warming, and a 313.8% increase (+54.1 mm, or 2.13 in) under +4°C warming during the same month. Potential evapotranspiration is projected to increase throughout the summer and broader growing season in the future across all climate divisions, with an overall growing season increase of 18.0 mm (0.71 in) under +2°C warming and a 58.7 mm (2.31 in) increase under +4°C warming. These changes will be most pronounced in the North Panhandle, with growing season potential evapotranspiration rates increasing to 27.5 mm (1.08 in) under the warm scenario and 82.7 mm (3.26 in) under the hot scenario (Table 8). Likewise, growing season water balance deficit is expected to increase regionwide, ranging from a 6.4 mm (0.25 in; +2°C) or 20.6 mm (0.81 in; +4°C) change in the Northeast Gulf to a 13.0 mm (0.51 in; +2°C) or 34.7 mm (1.37 in; +4°C) change in the South Panhandle.

Table 8. Projected changes in potential evapotranspiration (PET) and growing season water balance deficit (DEF).

	Northeast Gulf (CD 9)		North Panhandle (CD 10)		Central Panhandle (CD 11)		South Panhandle (CD 12)	
Change (inches)	+2 °C	+4 °C	+2 °C	+4 °C	+2 °C	+4 °C	+2 °C	+4 °C
PET (April–September)	0.43	1.83	1.08	3.26	0.90	2.76	0.78	2.38
PET (June–August)	0.25	0.92	0.49	1.40	0.43	1.30	0.48	1.35
DEF (April–September)	0.25	0.81	0.41	1.37	0.38	1.01	0.51	1.37
DEF (June–August)	0.14	0.48	0.29	0.95	0.27	0.68	0.38	0.83
Change (mm)	+2 °C	+4 °C	+2 °C	+4 °C	+2 °C	+4 °C	+2 °C	+4 °C
PET (April–September)	10.9	46.5	27.5	82.7	23.0	70.2	19.9	60.4
PET (June–August)	6.3	23.4	12.4	35.7	11.0	32.9	12.1	34.3
DEF (April–September)	6.4	20.6	10.4	34.7	9.8	25.8	13.0	34.7
DEF (June–August)	3.5	12.1	7.2	24.2	6.8	17.2	9.7	21.2

As previously mentioned, despite its perhumid environment, drought remains a potential threat on the Tongass, especially within the context of current and future climate change. Uncertainty surrounding future precipitation lessens as projections approach the end of the century, but warmer temperatures leading to increased evapotranspiration and drier soils indicate that drought may remain a possible risk as the century progresses. More data and multivariate modelling efforts would be needed to better assess the threat that this particular phenomenon may pose to the Forest.

Glaciological Effects and Sea Level Change

Historical and Observed Conditions

Glaciers and ice fields in Alaska are decreasing in size and extent. The average thinning rate for Alaskan glaciers from 1995–2001 was 1.8 meters per year (Arendt et al. 2002). From the 1950s to the mid-1990s, this thinning rate was -0.52 meters per year. A study of the Juneau icefield found that the rates of glacier area shrinkage were five times as high from 2015–2019, relative to 1979–2010 (Davies et al. 2024). The LeConte and Triumph glaciers in Southeast Alaska decreased in thickness by approximately 2.37 meters

and 1.71 meters respectively per year from 1995-2001, up from 0.52 meters and 0.4 meters annually during the earlier period. Overall average loss of volume in the Coast Range, which covers much of Southeast Alaska, was 5.4 cubic kilometers per year from 1950 to 1995. Tidewater glaciers — including the LeConte Glacier — have typically shown to retreat exceptionally rapidly, leading to an outsized influence on quantification of glacial melt rates.

In part as a result of ice melt, Southeast Alaska has experienced significant uplift in the form of isostatic rebound, a centennial-scale unloading of previously glaciated land in the wake of glacial retreat. This phenomenon constitutes a major driver on the Forest and facilitates greater spatial heterogeneity of sea level change, given that uplift leads to a relative lowering in sea level, as opposed to the sea level rise associated with glacial melt. Since the Little Ice Age roughly 250 years ago, the region has experienced rapid thinning of icefields and glaciers, with peak rates of uplift around 30-32 mm per year contributing to an overall sea level change of 5.7 meters (Larsen et al. 2005). The effects of isostatic rebound are determined by where glaciers are most drastically retreating or losing mass, and as such these effects are greatest in the northern half of the Tongass.

Anticipated Trends

On top of already-drastic rates of retreat, glaciers in Southeast Alaska are projected to lose upwards of approximately 35% volume by the end of the century (O’Neel et al. 2015). The effects of glacial melt yield impacts ranging from loss of habitat and cooling of streams to sea level rise, landslides, and flooding. Extreme cases such as tsunamis caused by landslides or calving may also become more common, (see the Geology and Geologic Hazards assessment section for further discussion). Ketchikan and nearby communities are projected to experience a 0.30-meter rise in relative sea level by 2100, with higher rises anticipated further south (Gregovich et al. 2019). In the northern half of the region, however, isostatic rebound is projected to be more pronounced than sea level rise. Areas like Skagway may experience as much as a 1.70-meter relative decline in sea level over the next 100 years as a result of uplift. This anticipated rebound reaches its zenith around the Wachusett and upper Muir Inlets of Glacier Bay, with around 2.80-2.90 meters in relative sea level decline.

High rates of uplift driven by glacial isostatic adjustment co-occurring with subsidence create more variable relative sea level projections. In general, there appears to be a spatial gradient from north to south of projected sea level change within Southeast Alaska, with isostatic rebound dominating in the Northeast Gulf and North Panhandle, glacial melt dominating in the South Panhandle, and future changes in the Central Panhandle presenting as moderate or somewhat unpredictable. The substantial differences in vertical land motion — in other words, subsidence or uplift — along the coast make a regionally representative tide-gauge time series more difficult to create and thus lead to higher uncertainty (Sweet et al. 2022). Given these geographic differences, combined with other climatic factors, effects on the Forest will vary based on latitude and elevation. Land surface exposed by uplift yields new habitats, thereby facilitating primary succession of vegetation while also becoming susceptible to potential colonization by invasive species. Sea level change will additionally affect access to shorelines for traditional and cultural gathering. Areas with abundant butter clams and eelgrass populations, for example, are predicted to be most vulnerable to change, especially along coastlines with shallow slopes and low fetch, meaning little to no wave energy generated by wind (Johnson et al. 2019). By contrast, steep, rocky sites dominated by blue mussels, red algae, or canopy kelps are predicted to be the most resilient.

Ocean Chemistry and Sea Surface Temperatures

Sea surface temperatures (SST) in the Gulf of Alaska have experienced continual warming over the past 100 years, with an average rise of 0.17°C per decade during the 20th century (Alexander et al. 2018).

Over the 21st century, however, this trend is expected to more than double, reaching rates of 0.41°C warming per decade. Monthly SST anomalies per decade are also projected to exceed monthly maxima during the historical period over 80% of the time by the 2050s in the Gulf. Likewise, annual SST anomalies are expected to exceed the historical maximum approximately 75% of the time by mid-century and nearly 100% of the time by late-century. Future SST warming will likely occur most quickly during the late summer or early fall, with an anticipated total warming of 3.5°C overall, according to ensemble mean estimates.

Oceans serve as one of the most important carbon sinks globally, calculated to have absorbed at least a quarter of anthropogenic CO₂ emissions since 1960 (Gruber et al. 2023). This proportion has remained relatively constant, meaning that as atmospheric greenhouse gas concentrations increase, oceans absorb higher amounts of CO₂, which lowers the average pH of the water in a process known as ocean acidification. This process is especially threatening in Alaska, as colder waters store more CO₂ and are thus more vulnerable to the impacts of ocean acidification on shorter timescales (Fabry et al. 2009; Alaska Ocean Acidification Network 2019). Ocean acidification also negatively affects shellfish, as lower availability of carbonate ions reduces calcium carbonate saturation states – or the potential of these minerals to form or dissolve (Mathis et al. 2015; Gattuso and Hansson 2011) – to levels that are corrosive to shell-forming marine organisms (Evans et al. 2014).

Other natural and forced processes can influence this process as well, including high productivity, glacial melt, and upwelling. Glacial meltwater can have diluting effects on the nutrient content of downstream marine waters, increasing corrosivity of surface waters and thereby contributing to intensified ocean acidification (Cantoni et al. 2020). As a result of high meltwater inputs, the Lynn Canal in the North Tongass has shown to be especially susceptible to corrosivity of aragonate, which is the most soluble carbonate biomineral (Evans et al. 2022). Annual surface blooms of phytoplankton uptake CO₂ and subsequently release it after they sink to the ocean floor and decompose, thus lowering deep-ocean pH. This CO₂-rich water can be brought back to the surface in a wind-driven process called upwelling, which then results in acidification near the coasts (Alaska Ocean Acidification Network 2019). Climate change is accelerating these phenomena, with surface ocean acidification as indicated by hydrogen ion concentration projected to increase upwards of 150% globally by the end-of-century under RCP8.5 (Orr et al. 2005; Bindoff et al. 2019). While climate change impacts specific to ocean acidification in the Gulf of Alaska are understudied, given the high sensitivity of the region and the importance of marine conditions for traditional subsistence and harvesting, this is a threat that should be considered in management on the Tongass.

Invasive Species (Terrestrial and Aquatic)

Tribes have expressed concern around the spread of invasive species and their ability to crowd out native plants. Preventing the spread of invasives is important to many Tribes. Due to these concerns, Skagway, Tlingit & Haida, STA and Kake all have mitigation plans to address the spread of invasive species.

Significant invasive plant species in Southeast Alaska include knotweed (*Fallopia japonica* and *Fallopia x bohemica*, or Japanese and Bohemian knotweed, respectively), reed canarygrass (*Phalaris arundinaceae*), and orange hawkweed (*Hieracium aurantiacum*). Non-plant species include chytrid fungus (*Batrachochytrium dendrobatidis*) and European green crab (*Carcinus maenas*). The presence of invasive plants on the Tongass predominantly occurs alongside human development—in communities, along trails and roads, and at cabin sites and marine access points (Figure 13). The road system and associated stream crossings on many islands create a conduit for the movement of invasive plants from communities into more remote locations and the natural setting (Figure 14). Reed canarygrass, for example, is widespread along road corridors, and further establishment in upper beach meadows and stream corridors is a

growing concern, as the highly aggressive species has shown to have negative impacts on water quality, riparian processes and community composition, and subsistence resources (Alaska Center for Conservation Science [ACCS] 2011; Greenstein and Schake 2021; Spellman and Swenson 2012). Orange hawkweed (Figure 11), originally introduced as a garden ornamental, is now widespread in lawns and along corridors and trails, outcompeting native vegetation and eliminating native pollinators and other forage species through the creation of dense mats (ACCS 2011; French 2021). The spread of non-plant invasive species, on the other hand, is tied to temperature gradients and animal migration (e.g. chytrid fungus) and ocean currents (e.g. European green crab).

The temperate rainforest is largely resilient to invasion with large areas of somewhat poorly- to very poorly drained organic soils or closed tree canopy, inhospitable to the currently known or suspected invaders. The habitats most vulnerable to invasion include estuaries, upper beach meadows, riparian corridors, and the small gaps created at recreation sites. Emerging habitats vulnerable to invasion include recently deglaciated landscapes and uplifted upper beach meadows as a result of isostatic rebound, a phenomenon that is discussed in greater detail in the section below. Silvicultural treatments involving heavy equipment that remove woody material (organics), disturb soil, and reduce shade-cover may also make forested habitat that is typically resilient to invasion more susceptible. Preventing the introduction and establishment of invasive species remains the best management strategy available to Tongass land managers working to protect terrestrial and aquatic ecosystems. The Forest Service has the lead role in managing terrestrial invasive species and a supporting role in managing aquatic invasive species.

Established invasive species may lead to a loss of biodiversity, competition with native species, altered habitat, disrupted food webs, and a shift in physical and chemical processes (Barney et al. 2013, David et al. 2017, Schwoerer et al. 2019). Terrestrial community changes indirectly alter nutrient cycling, forage availability for mammals and insects, and associated impacts to other trophic levels both aquatic and terrestrial. The combination of both natural and human stressors with invasive species will produce effects we can only infer from species biology and modeled climatic changes. Warmer air and water temperatures, more growing degree days, and hydroclimatic variability will support the establishment of some invasive species and likely increase the area impacted. The pathogenic amphibian chytrid fungus (*Batrachochytrium dendrobatidis*), for example, is a leading cause of global amphibian declines, especially in the tropics (Fisher and Garner 2020). Though there are hundreds of native chytrid fungi that are essential decomposers of pollen and algae on the landscape, the amphibian chytrid fungus causes a skin disease in amphibians, chytridiomycosis, that can be fatal. There is evidence that the amphibian chytrid fungus is widespread in Alaska (Chestnut 2015, Chestnut et al. 2008) and it is likely that amphibians co-evolved with native strains, making them more resilient to some infections (Carvalho et al. 2024). The fungus can survive in the aquatic environment without an amphibian host (Fisher and Garner 2020). It does not appear to survive freezing water temperatures or desiccation, for example when a waterbody freezes completely in winter or a wetland dries completely in summer (Fisher and Garner 2020, Chestnut 2015). In species like wood frogs (*Lithobates sylvatica*) that can survive freezing temperatures, infections are reduced when they are exposed to temperatures just below freezing (Chestnut 2015). Higher winter minimum temperatures alongside reduced freezing regimes in waterbodies could create suitable conditions for chytrid to persist in waterbodies over longer time periods, which could increase amphibian exposure to the fungus. The introduction of non-native virulent chytrid strains, by accidental or intentional release of amphibians, for example the red-legged frog (*Rana aurora*) to Chichagof Island, or introduction of an alternate host such as crayfish, could have deleterious effects on the ecosystem by reducing amphibian populations.

Data obtained from the Alaska Exotic Plants Information Clearinghouse (AKEPIC) and the Threatened, Endangered, and Sensitive Plants and Invasive Species (TESP-IS) database reveal spatial trends of non-native taxa through October 2023. By far the most abundant non-native plant species on the Forest

summed across watersheds (Hydrologic Unit Code 10) is reed canarygrass (Figure 8; 3,523 acres), followed by orange hawkweed (290 acres), bull thistle (104 acres), and white sweetclover (Figure 12; 38 acres). Though Japanese and Bohemian knotweed (Figure 10) only cover a combined area of roughly 14 acres on National Forest System (NFS) land, when one factors in an ecologically significant buffer distance around Forest Service lands to include nearby towns, knotweed-infested acreage increases dramatically, from 14 to 47 acres. Both species of knotweed are known to have negative impacts on native flora populations, invertebrate biodiversity, soil bacteria, and ecosystem quality for arthropod consumers, including amphibians, reptiles, birds, and some mammals (Lavoie 2017). During engagement on tribal uses, Japanese knotweed was brought forward as one of the more damaging invasives. Most other invasive species do not occur in significant proportions outside of the federal administrative boundaries, though garlic mustard infestation covers roughly 6 acres outside FS land as opposed to only 1.5 acres within. Figures 8–13 display total infested acreage of top invasive plant species by watershed, with Figure 14 showing road density by watershed as a means of visualizing conduits of species spread. In order to best capture the extent of infestation, as previously alluded to, the area of interest (AOI) for each map includes a 2-mile buffer around surface ownership boundaries of NFS lands.

Table 9. Total acreage of invasive plant species infestation in the AOI.

Species	Total Acres Infested
Bohemian knotweed	17.7
Bull thistle	97.4
Creeping thistle	16.4
Garlic mustard	7.5
Japanese knotweed	51.8
Meadow hawkweed	11.5
Orange hawkweed	278.4
Ornamental jewelweed	0.4
Reed canarygrass	3126.8
Spotted knapweed	8.8
White sweetclover	65.6
All Species Combined	3682.2

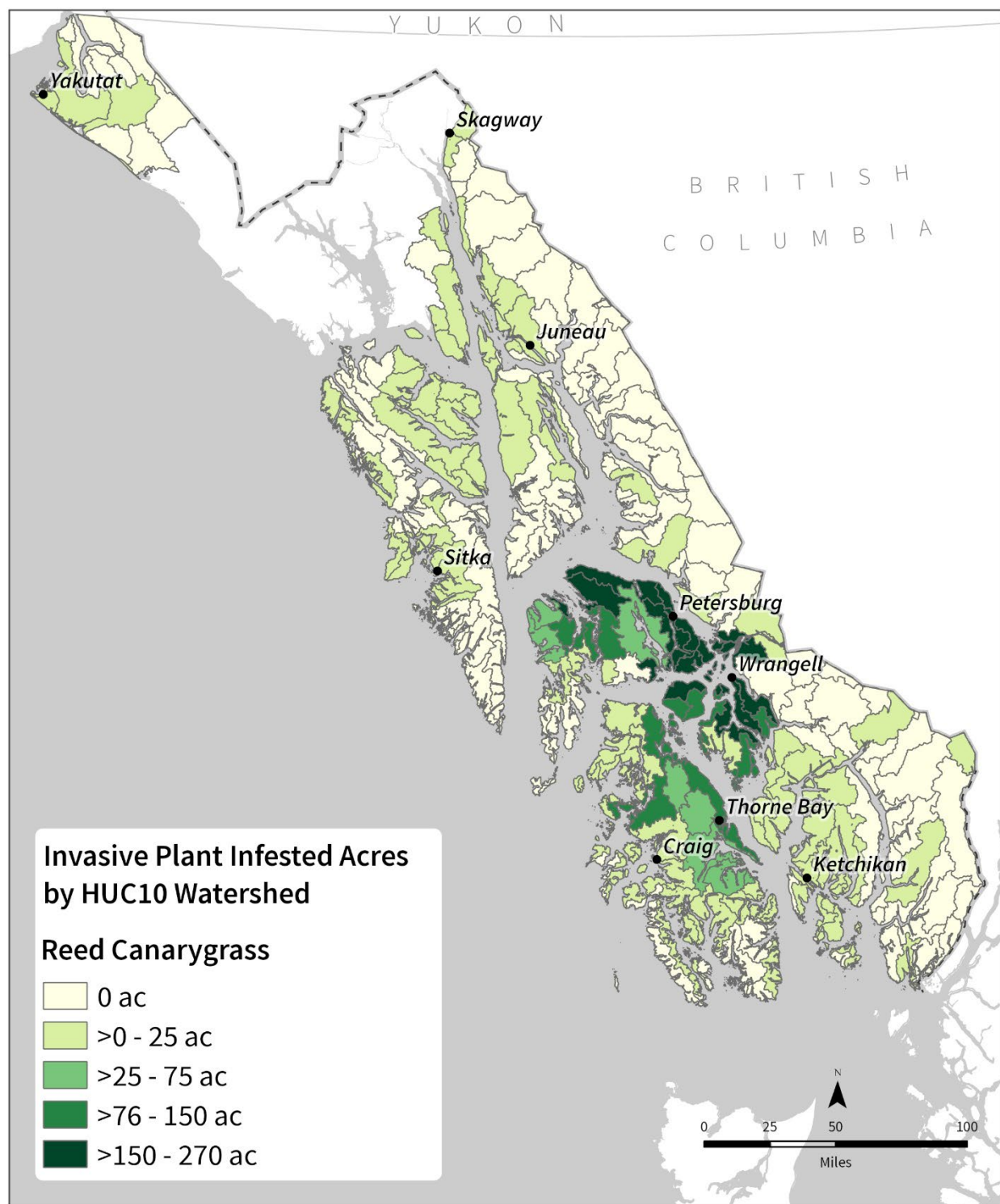


Figure 8. Total acreage of reed canarygrass infestation in the AOI by watershed.

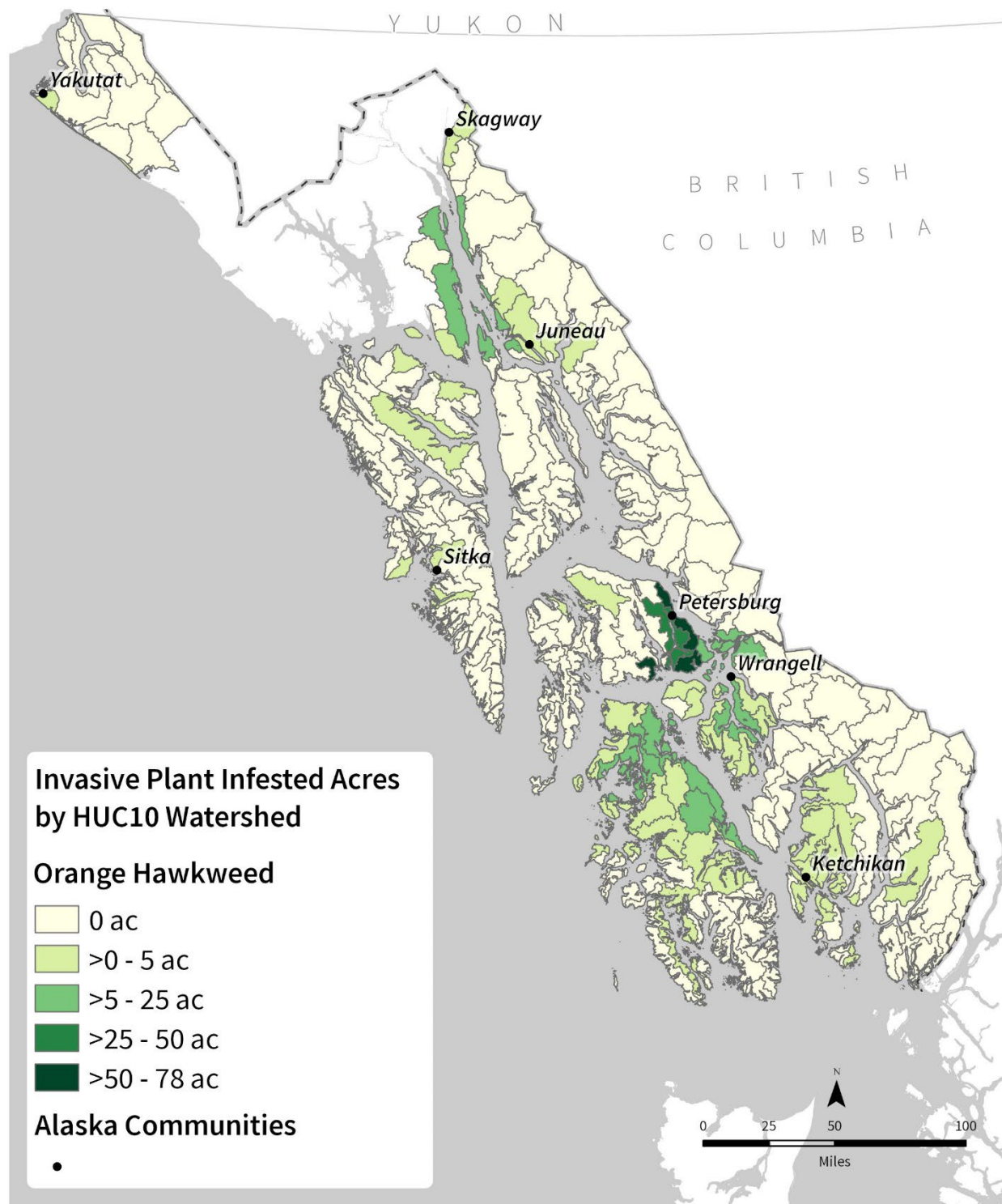


Figure 9. Total acreage of orange hawkweed infestation in the AOI by watershed.

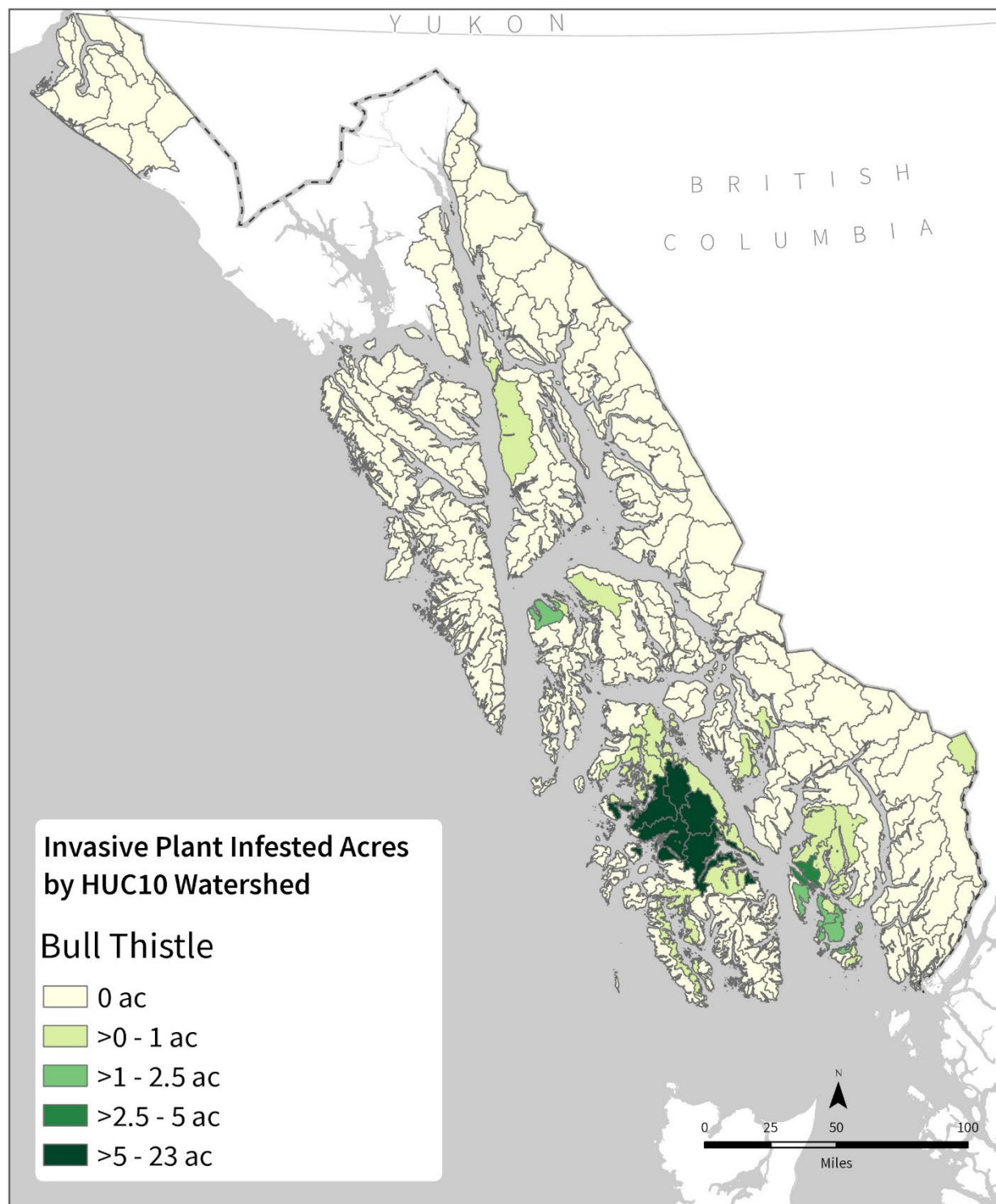


Figure 10. Total acreage of bull thistle infestation in the AOI by watershed.

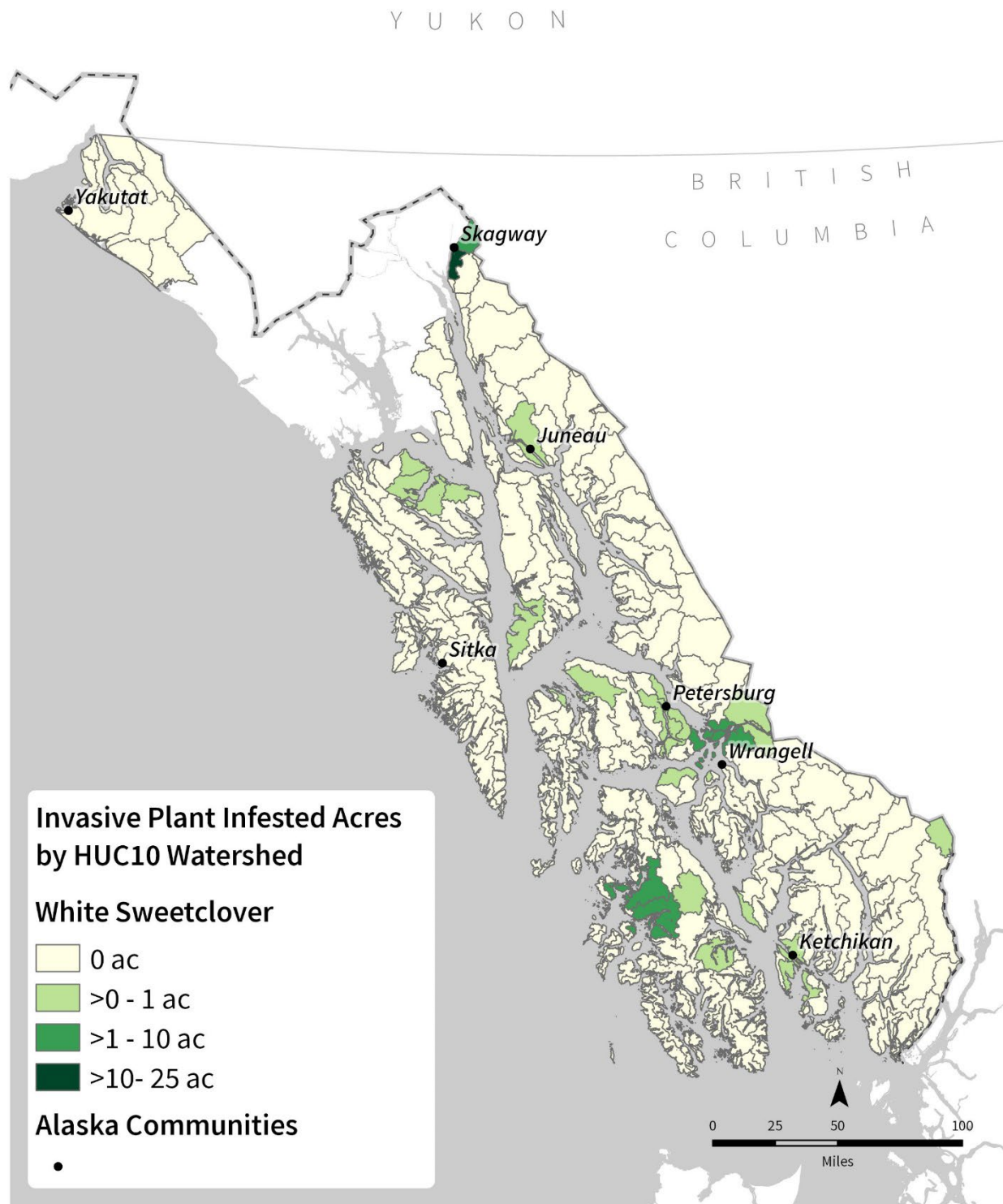


Figure 11. Total acreage of white sweetclover infestation in the AOI by watershed.

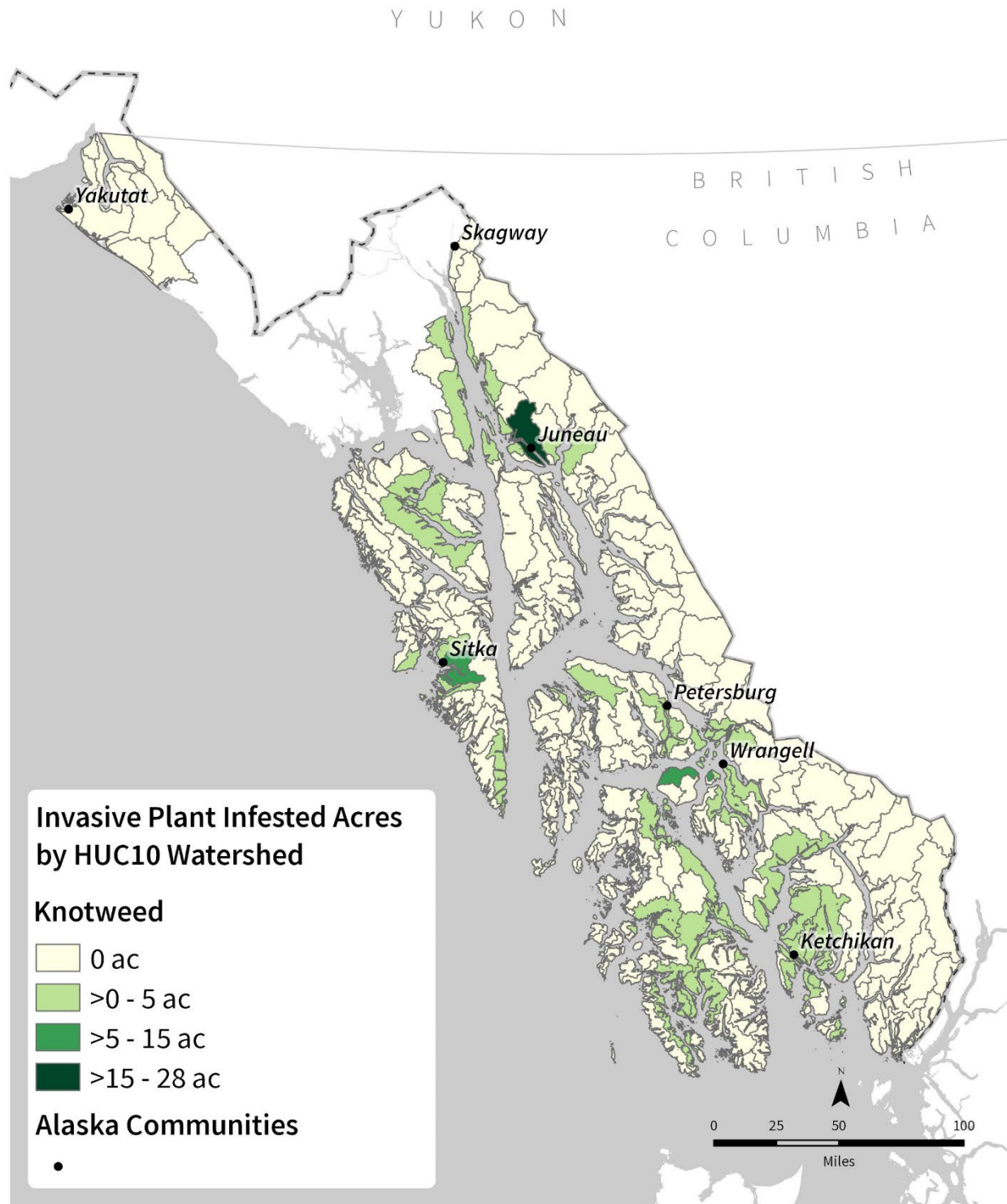


Figure 12. Total acreage of knotweed infestation in the AOI by watershed.

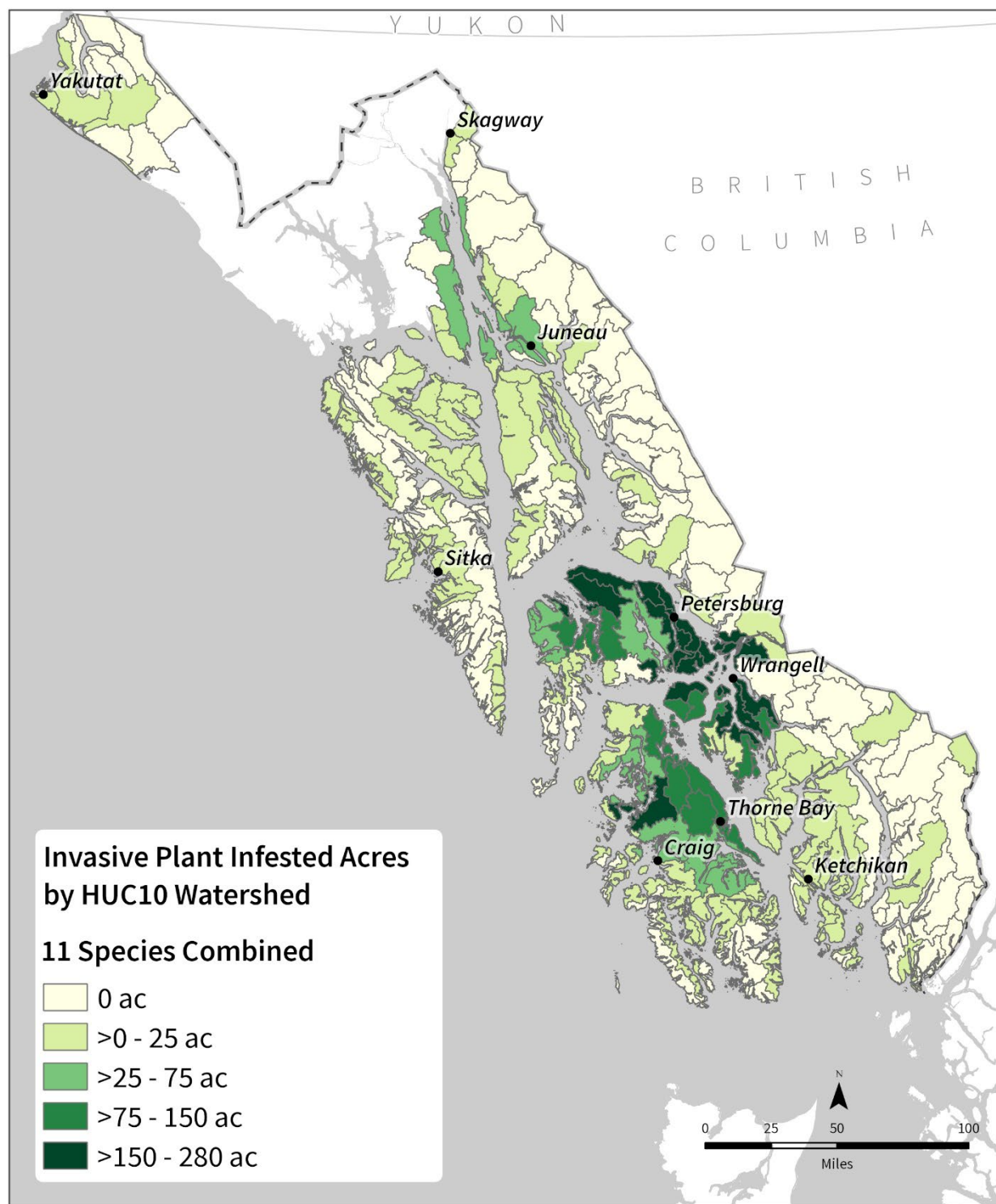


Figure 13. Total acreage of all invasive plant species in the AOI by watershed.

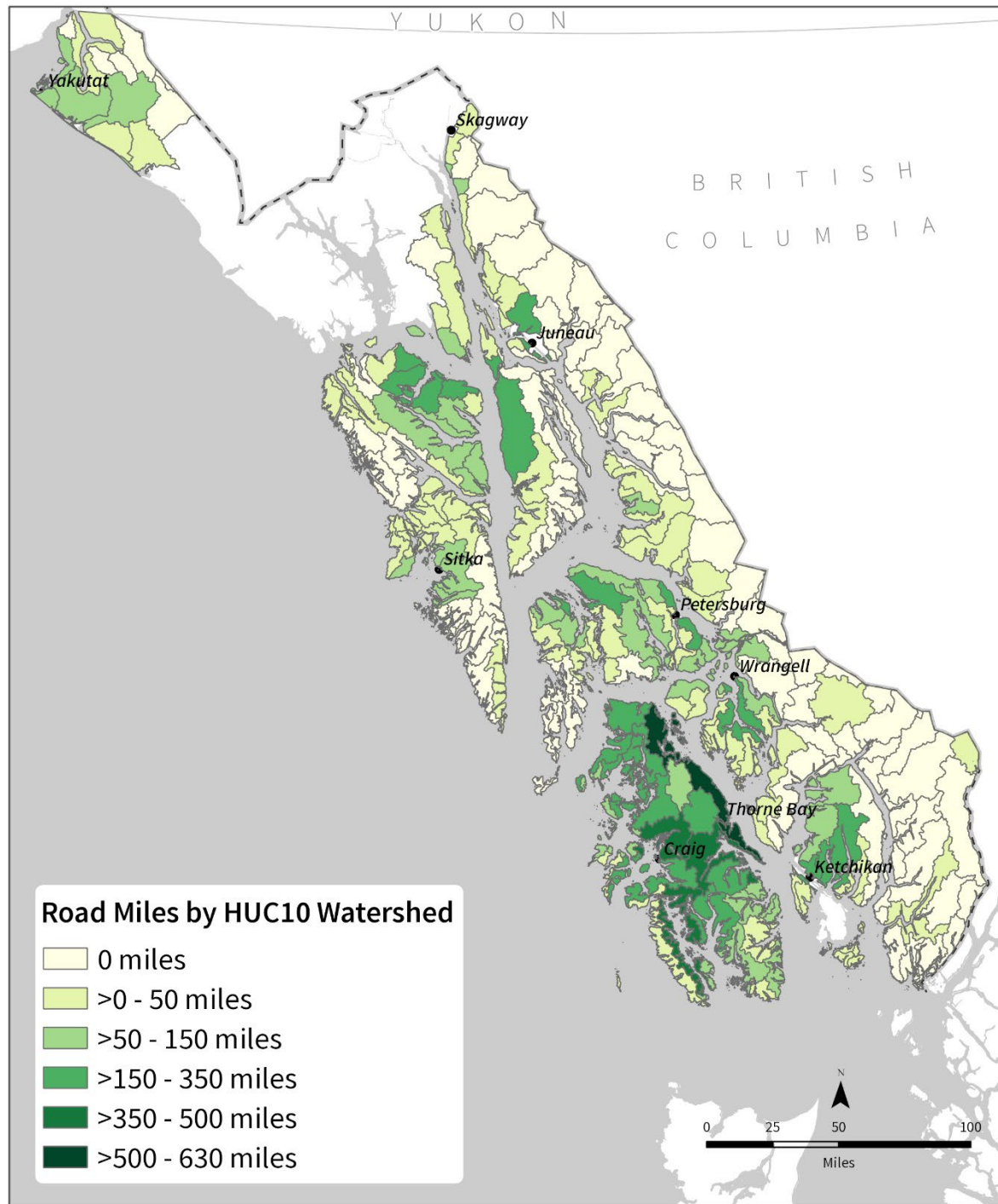


Figure 14. Road length (in miles) on the AOI by watershed.

Ability of Plan Area to Adapt

The majority of the Tongass is comprised of intact ecosystems with high ecological integrity and ecosystem components that have evolved and interacted for millennia. These systems are globally important and unique in that they are broad in extent (covering millions of acres), are minimally impacted by human development, contain vast intact communities of flora and fauna, and continue to be shaped by

relatively unchanged disturbances and natural processes. These characteristics make the Tongass uniquely suited to adapt to and address stresses from climate change and thus have a high level of ecological resilience during the planning horizon.

Key Findings

Summary of Drivers and anticipated impacts of climate changes

- Temperatures on the Forest have historically remained cool and mild but are expected to rise significantly as the century progresses, with as much as a 4.6°F increase in mean annual temperature by the 2080s. Projected changes are most pronounced in the Northeast Gulf, where end-of-century estimates reach 8.4°F warming under high-emissions scenarios, and seasonal increases will be highest during autumn.
- Precipitation, which typically falls year-round with geographic variability and seasonal storms in the fall and winter, is forecasted to increase by up to 13.0% in average yearly amount, with the lowest changes in the Central Panhandle and the greatest in the South Panhandle. Spring, fall, and winter precipitation show projected increases under all scenarios, with a higher proportion of precipitation falling as rain, especially in the South.
- Wind is a major disturbance agent in the region and plays a key role in renewing the forests, with small-scale gap phase disturbances predominating in areas protected from windthrow and catastrophic disturbances more likely in windthrow-prone areas. The impacts of climate change on wind dynamics remain unclear, but will likely include a decrease in average wind speeds while heavy storms and wind/rain events increase in frequency.
- Glacial melt is already occurring rapidly on the Tongass, and is expected to accelerate with climate change, with uneven effects on the landscape.
- Isostatic rebound as a result of glacial melt, thinning, and retreat is a driving landscape process in the region, creating new surface land from uplift and thus leading to lowering sea level locally. Sea level decline will likely form the predominant mechanism of sea level change, with uplift occurring most prevalently in the northern half of the Tongass.
- Insects and diseases are key ecosystem regulators and a leading cause of tree mortality in the area, with outbreaks expected to increase with warming and hydroclimatic variability. As a result of reduced snowpack, yellow cedar will be more susceptible to root freezing injury, which is the primary driver of its decline. Invasive species are a growing concern, and introductions would have deleterious impacts on forest vegetation and wildlife.
- Ocean acidification is projected to be pronounced in the Gulf of Alaska and North Pacific, which will likely lead to declines in shellfish populations as a result of increased corrosivity and reduced availability of calcium carbonate.

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Glossary and Acronyms

Adaptation - Adjustment in natural or human systems to a new or changing environment that exploits beneficial opportunities or moderates negative effects. Adaptation includes, but is not limited to, maintaining primary productivity and basic ecological functions such as energy flow; nutrient cycling and retention; soil development and retention; predation and herbivory; and natural disturbances. Adaptation occurs primarily by organisms altering their interactions with the physical environment and other organisms (WO Handbook 1909.12 Zero Code).

Disturbance - Any relatively discrete event in time that disrupts ecosystem, watershed, community, or species population structure and / or function and changes resources, substrate availability, or the physical environment (36 CFR 219.19).

Driver: System drivers, including dominant ecological processes, disturbance regimes, and stressors, such as natural succession, wildland fire, invasive species, and climate change; and the ability of terrestrial and aquatic ecosystems on the plan area to adapt to change; (adapt language (WO Handbook 1909.12_10)

Global Climate Model or General Circulation Model (GCM) - models used to predict future climate projections based on various greenhouse gas emissions scenarios. There are over 20 GCMs available with different parameters, assumptions, physical processes represented, interactions amongst those processes, and other aspects.

Greenhouse gas (GHG) - Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere and clouds. This property causes the greenhouse effect. Water vapor (H₂O), carbon dioxide (CO₂), nitrous oxide (N₂O), methane (CH₄), and ozone (O₃) are the primary greenhouse gases in the Earth's atmosphere (IPCC, 2021).

Invasive Species - An alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health. A species that causes, or is likely to cause, harm and that is exotic to the ecosystem it has infested. Invasive species infest both aquatic and terrestrial areas and can be identified within any of the following four taxonomic categories: Plants, Vertebrates, Invertebrates, and Pathogens (Executive Order 13112).

Multiple Use - The management of all the various renewable surface resources of the National Forest Service lands so that they are utilized in the combination that will best meet the needs of the American people; making the most judicious use of the land for some or all of these resources or related services over areas large enough to provide sufficient latitude for periodic adjustments in use to conform to changing needs and conditions; that some land will be used for less than all of the resources; and harmonious and coordinated management of the various resources, each with the other, without impairment of the productivity of the land, with consideration being given to the relative values of the various resources, and not necessarily the combination of uses that will give the greatest dollar return or the greatest unit output, consistent with the Multiple-Use Sustained-Yield Act of 1960 (16 U.S.C. 528–531) (36 CFR 219.19).

Representative Concentration Pathway (RCP) - a future greenhouse gas emissions (atmospheric concentration) scenario used as an input for global climate change models (GCM)s. representing a scenario (4.5) in which greenhouse gases are significantly reduced by year 2100 and one (8.5) in which

global greenhouse gas emissions continue at similar rates to earlier in the 21st century through the end of 2100.

Resilience - The ability of an ecosystem and its component parts to absorb, or recover from the effects of disturbances through preservation, restoration, or improvement of its essential structures and functions and redundancy of ecological patterns across the landscape (WO Handbook 1909.12 Zero Code).

Stressors - For the purposes of the land management planning regulation at 36 CFR part 219 and this Handbook, factors that may directly or indirectly degrade or impair ecosystem composition, structure, or ecological process in a manner that may impair its ecological integrity, such as an invasive species, loss of connectivity, or the disruption of a natural disturbance regime (36 CFR 219.19).

Sustainability - The capability to meet the needs of the present generation without compromising the ability of future generations to meet their needs. For the purposes of the land management planning regulation at 36 CFR part 219 and this Handbook “ecological sustainability” refers to the capability of ecosystems to maintain ecological integrity; “economic sustainability” refers to the capability of society to produce and consume or otherwise benefit from goods and services including contributions to jobs and market and nonmarket benefits; and “social sustainability” refers to the capability of society to support the network of relationships, traditions, culture, and activities that connect people to the land and to one another, and support vibrant communities (36 CFR 219.19).

Vulnerability – The degree to which physical, biological, and socioeconomic systems are susceptible to and unable to cope with the adverse impacts of climate change.